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Report

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Producing low sulphur marine fuels in Europe - 2020-2025 vision

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Producing low sulphur marine fuels in Europe - 2020-2025 vision

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With the support of: RTSG Members (Refinery Technology Support Group)

For: RMG (Refinery Management Group)

ABSTRACT

The global Sulphur cap entered into force from the 1st of January 2020, and it is seen by the refinery sector as an unprecedented step evolution for a key specification of one of their products. The sulphur going down from 3.50% max to 0.50wt%S is not just operating the refinery in a different way to remove the Sulphur from the current High Sulphur Bunker fuel. For the vast majority of refineries, it means producing the bunker using different internal streams, with new blending recipes, new constraints and resulting in a new optimum operation, which is affecting the refinery sector.

Being ready for the transition is a top priority for the refiners. They have done many simulations and lab testing to ensure their product will meet the required quality, and especially the stability[1]. Internal procedure and blending rules will make sure that incompatibility of internal streams will be avoided.

This Concawe Supply study (Linear Programming modelling) is highlighting several constraints and potential difficulties. It appears feasible to supply the demand of Marine Fuel (MF) 0.50%S, but with a significant market incentive and debottlenecking when required for the Sulphur Recovery (SRU) and Hydrogen Production (HMU). The crude slate is not expected to evolve in a significant way, even though marginal, the current evolution (lower density, lower S content) goes in the right direction to ease the production of MF 0.50%S.

A key uncertainty remains on the export of High Sulphur (HS) fuel oil. Historically, European refiners have exported to Asia, with the current volume being around 10Mt per year. However demand for HS fuel oil in Asia is also declining, according to public sources, creating potential supply issue. The degree of installation of on-board installed scrubbers may also impact the situation.

For middle distillate, the issue is the opposite with a strong need for import in Europe (more than 30 Mt/year). With an expected evolution towards middle distillate for the marine fuels, the global demand will increase, creating tension in regions already seeing a deficit of middle distillate.

The typical current heavy fuel oil quality is widely available over the globe (high sulphur, high density, and high viscosity) and evolves towards a multiple range of different qualities just like hybrid fuels. The trend being a clear evolution towards middle distillate type of fuel (low density, low viscosity) for more than 50% of the market demand. Every new fuel will raise the concern of stability and compatibility[2]; every stakeholder will have to consider it as a top priority and develop its own learning curve accordingly.

[1] The stability of a fuel is defined as the ability of the solution to keep the asphaltenes (heavy molecules made of several aromatic rings) in suspension

[2] A definition of Compatibility can be found in the report from the Joint Industry Guidance: https://www.ipieca.org/resources/good-practice/joint-industry-guidance-on-the-supply-and-use-of-050-sulphur-marine-fuel/

The term 'compatibility' is often confused with stability, but although the chemical and physical processes at work are the same, these terms have different meanings. Compatibility cannot be described as a characteristic of a single fuel, rather it is an indication of the suitability of commingling one fuel with another. If two fuels are commingled together and the resulting blend remains stable (i.e. does not precipitate asphaltenic sludge), the fuels would be termed compatible. On the other hand, if the resulting blend is unstable, then the component fuels are said to be incompatible, even though each component is individually stable. Incompatibility generally arises as a consequence of lack of stability reserve and changes to the solvency of the continuous phase for the asphaltenes.

The data and vision have been updated in 2019. Therefore, the economic and Trade crisis, linked to the Covid-19 pandemic, have not been taken into account in this study. The impact on our sector being an unexpected and dramatic decrease in fuels Demand, the year “2020” is only relevant as representative of a year where the Demand goes back to 2019 level. The year “2025” as referred in this study remains, so far, fully relevant.

The data used in this study are historic and/or based on publicly available reports from independent consultancies. This study does not rely on data from Concawe members.

KEYWORDS

Marine fuels, IMO 2020, global Sulphur cap, availability, refining, HFO, VLSFO

INTERNET

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SUMMARY

The European refineries, reacting to changes in market demand, have always proven to be resilient and adaptive. Refinery operation is complex by its very nature and each refinery is unique. However, the magnitude of the step change provoked by the IMO Global Sulphur Cap, a key specification for the refinery bottom of the barrel, leads to some uncertainties on the availability and quality evolution of the Marine fuels.

Linear Program (LP) modelling is well designed to give a good indication of the effect of this change on the refinery behaviour on aggregate in Europe.

For the ship operator, who is the obligated party, the compliance can be met using one of two options. The first one being the use of Marine Fuel (MF) 0.50wt%S and the second alternative solution is installation and use of an Exhaust Gas Cleaning System (for SOx emission compliance). In this study, the most updated scrubber uptake hypothesis[3] has been considered (14% of total MF demand). The European LP model finds a solution to match supply and demand for the 0.50%S MF, but with strong constraints leading to high incentives to compensate production cost which are close to Marine Gasoil.

In the 2025 environment, the scrubber up-take reaching 20% of the Demand (EU) and the total demand going down, the constraints for the refinery sector are alleviated. The supply/demand balance requires a lower market incentive (slightly lower than Marine Gasoil).

This situation, in which 2 different industry sectors have a different option to invest to satisfy a market demand evolution, leads to a strong uncertainty and may be a source of a wait and see attitude. The purpose of this study is to explore some of these uncertainties by bringing technical knowledge and information on refinery flexibility, creating simulations using historic and/or publicly available data from independent consultants.

Through many different simulation cases, the model shows a clear evolution of the MF 0.50wt%S towards lighter fuels, i.e. an increasing content of middle distillates to meet demand requirement. The model converge to find an equilibrium where the supply meets the predicted demand. Adaptation is required, as well as sustained demand, the refinery system in Europe should be able to evolve as demand is increasing. However, key uncertainties remain for the international trade flows, especially middle distillate imports in Europe and export of heavy fuel oil (high sulphur) to Asian markets. The European average crude slates may evolve but it is not expected to be significant; the adaptation will come from internal operations and not from a drastic change in crude slate.

[3] Hypothesis from pour Demand data supplier, WoodMackenzie, 2019

1. CONTEXT AND BACKGROUND

Concawe routinely monitors and evaluates the major factors affecting the EU refining industry. The Concawe Refinery Technology Support Group (RTSG) has conducted several studies evaluating the potential impacts on the EU refining industry of the legislative and market challenges affecting refined fuel qualities and quantities. A study, published in 2013 (Concawe Report 1/13R [1]), updated previous work in the context of the latest demand scenario, announced changes in refining capacities and foreseen changes in product quality requirements over the 2020-2030 period.

One crucial element in this respect is the impeding reduction of the marine fuel maximum sulphur content to 0.5% m/m due to MARPOL, which has been legislated and came into force the 1st of January 2020. This is the biggest single specification change to ever hit the refined product market and could cause major disruption in Supply, Demand and market strains. The shipping, Bunkering and Refining industries are all interlinked with respect to this change and the response by one sector will affect the decision of others.

This study focusses on the implications of this significant new constraint on the EU refining industry and its ability to supply the required quantities at the new specification.

The data and vision have been updated in 2019. Therefore, the economic and Trade crisis, linked to the Covid-19 pandemic, have not been taken into account in this study. The impact on our sector being an unexpected and dramatic decrease in fuels Demand, the year “2020” is theoretical and only relevant as representative of a year where the Demand reaches 2019 levels, with quality being 0.50wt%. The year “2025” projection as referred in this study remains, so far, fully relevant.

2. MARINE FUEL OIL QUALITY LEGISLATION

The sulphur content of marine fuels is regulated on a worldwide basis through the International Maritime Organisation (IMO). The Marine Environment Protection Committee (MEPC) was established in November 1973 with the responsibility of coordinating the IMO's activities in the prevention of marine pollution from ships. To better address marine pollution, the International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted in 1973.

2.1. MARPOL ANNEX VI

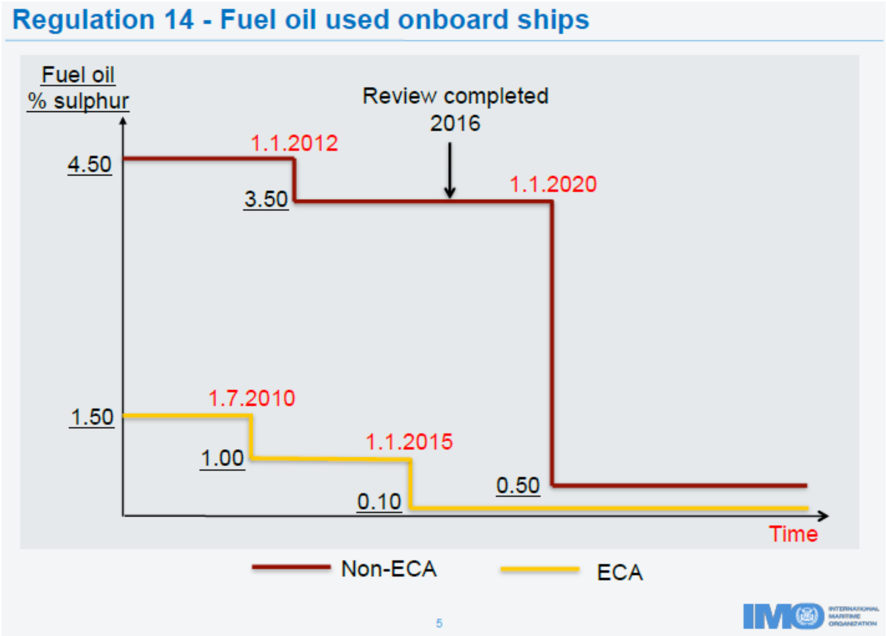
An agreement under the International Convention for the Prevention of Pollution from Ships (MARPOL), known as MARPOL Annex VI, was adopted in 1997 and came into force in May 2005. It introduced a global sulphur content cap of 4.5% m/m. Annex VI applies to all ships trading internationally involving countries that have endorsed the conventions. It expanded MARPOL's scope to include air pollutant contained in ship exhaust gas (88 states out of 197 have ratified MARPOL Protocol 97 Annex VI). Recognizing the harmful effects of sulphur oxide (SOx) emissions, Regulation 14 of Annex VI sought to reduce emissions by limiting the sulphur (S) content of bunker fuels. It also mandated its monitoring for Residual Marine Fuel Oils. Initially, it sets the global limit on the S content of marine fuels at 4.5% m/m.

It also introduced the concept of Emission Control Areas[1] (ECAs) which are designated sea areas where ship sulphur emissions are consistent with a fuel having a maximum sulphur content of 1.5% m/m. The Baltic and North Sea have been designated as ECAs. Following its ratification in 2005, MARPOL Annex VI came into force as of May 2006 for the Baltic Sea and November 2007 for the North Sea. A revision process of that legislation was initiated by IMO's Marine Environment Protection Committee (MEPC) in July 2005 (other ECA regions: 3.North American area (2012) and 4.United States Caribbean Sea area (2014)).

In addition, the EU adopted Directive 2005/33/EC regarding the sulphur content of marine fuels which extends the IMO 1.5% m/m sulphur limit to "passenger ships on a regular service to or from an EU port" (further referred to as "ferries") and came into effect in August 2006.

In October 2008 the IMO's MEPC adopted a proposal to decrease the maximum sulphur content in ECAs to 1.0% by July 2010 and 0.1% by 2015 and to decrease the global marine fuels sulphur cap elsewhere to 3.5% by 2012 and down to 0.5% by 2020 or 2025 at the latest (subject to a review in 2018 at the latest). In July 2011 the EC proposed a draft amendment to Directive 2005/33/EC which would align the Directive with the stricter IMO rules and extend the ECA sulphur reduction schedule to non-ECA "ferries" with a 5 year delay. The compromise amendment adopted by the European Parliament in September 2012 confirmed the sulphur reduction to 0.5% by 2020 in EU waters but did not include the extension of the ECA sulphur limits to non-ECA ferries. Fuel used by non-ECA ferries is therefore subject to the same sulphur content limits as all other non-ECA vessels when operating in EU waters, i.e. 3.5% in 2012 and 0.5% from 2020.

[1] Detailed information on IMO web site:
http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Sulphur-oxides-(SOx)---Regulation-14.aspx



2.2. LATEST DEVELOPMENTS

In October 2016, at the 70th session of the IMO's MEPC, in a landmark decision for both the environment and human health, 1 January 2020 was confirmed as the implementation date for a global sulphur cap of 0.50% m/m (mass/mass). This decision was supported by a study prepared by the IMO's hired consortium of consultants, led by CE Delft, which concluded that sufficient quantities of compliant marine fuels would be available by 2020. A complementary study performed by EnSys Energy and Navigistics Consulting was more cautious, highlighting the uncertainties, difficulties and risks of limited availability.[2]

The above limits on sulphur content apply equally to residual marine fuels (RMF) and distillate marine fuels (DMF). However, the EU "SLFD" Directive 1999/32/EC imposes an additional requirement on the latter category, limiting the maximum sulphur content to 0.1% m/m for marine gas oils (MGO) used in EU territory from 1 January 2008. Directive 2005/33/EC extended this 0.1% limit to MGO placed on the market in EU Member States' territory from 1 January 2010. Marine gas oils correspond to the lighter DMX and DMA grades (density 890 kg/m3 @15°C) in the ISO 8217:2010 distillate marine fuels specifications, as opposed to marine diesel oils (MDO) which correspond to the heavier DMB grade (density 900 kg/m3 @15°C). Statistics are not available on the relative shares of MGO and MDO in the EU DMF market but Concawe member company estimates suggest that MGO constitutes more than 90% of the DMF market. For this reason all DMF production in this study was assumed to be MGO (DMA grade) subject to a sulphur limit of 0.1% from 2008 onwards.

It should be noted that, outside the ECAs, the IMO cap reduction and the Directive do not directly mandate the fuel sulphur contents but rather emissions consistent with these sulphur contents. Therefore, Ships may meet SOx emission requirement by using approved equivalent methods, such as exhaust gas cleaning systems (EGCS) or 'scrubbers', which aim to remove sulphur oxides from the ship's exhaust gases

[2] EnSys Energy-Navigistics Consulting Supplemental Marine Fuel Availability Study submitted to the IMO, July 2016. Available from:
https://www.ensysenergy.com/downloads/supplemental-marine-fuels-availability-study-2

before they are released into the atmosphere. Where such an equivalent arrangement is adopted, it must be approved by the ship's Administration (i.e. flag State).

2.3. IMPLEMENTATION AND ENFORCEMENT

The IMO has no regulatory or enforcement power, i.e. it develops and adopts regulations that must then be ratified by its member countries. Implementation is the remit and responsibility of the Administrations (referred to as flag State Control—the country where a ship is registered) and Port/coastal State Control (PSC—the country in whose waters the vessel is sailing, anchored or docked). Ensuring the consistent and effective implementation of the 2020 0.50% sulphur limit should be considered a high priority.

The daunting task of providing uniform, international enforcement across the high seas lies with the IMO's MEPC and Pollution Prevention and Response (PPR) Sub-Committee. The PPR has the responsibility to develop enforcement of the 0.50% global sulphur cap to achieve the environmental benefits sought through Regulation 14.

2.4. AVAILABILITY

MARPOL Annex VI Regulation 18.2 on fuel oil availability requires each Party to 'take all reasonable steps to promote the availability of fuel oils which comply with [Annex VI] and inform the [IMO] of the availability of compliant fuel oils in its ports and terminals'. Parties are also required to notify IMO when a ship has presented evidence of the non-availability of compliant fuel.

Notifications of non-availability of compliant fuel oil are reported on the IMO Global Integrated Shipping Information System (GISIS) database. This shows that, since the introduction of a 0.10% sulphur limit in the Baltic and North Sea ECAS on 1 January 2015 (Revised Annex VI, Regulation 14.4), there have been 9 notifications of non-availability in EU ECAs out of a total of 84 notifications from all ECAs globally. Even though compliant fuels are assumed to be available at all times due to the limited demand, it can be seen that instances of non-availability are numerous; hence the necessity to anticipate the necessary actions prior to the introduction of a global cap of 0.50% m/m sulphur in 2020.

The FONAR (Fuel Oil Non Availability Report) has been further developed to anticipate potential issues post 2020 and minimize disruption and avoid delays. The IMO guidelines have been updated accordingly.[3]. However, a FONAR is not an exemption, as stated in the 2019 IMO guidelines, Appendix 1:

- "3.1 it is the responsibility of the Party of the destination port, through its competent authority, to scrutinize the information provided and take action, as appropriate."
- "3.2 In the case of insufficiently supported and/or repeated claims of non-availability, the Party may require additional documentation and substantiation of fuel oil non-availability claims. The ship/operator may also be subject to more extensive inspections or examinations while in port."

[3] 2019 Guide and ensure lines on consistent implementation of 0.50% sulphur limit under MARPOL Annex VI adopted by resolution MEPC.320(74)

3. THE BASICS OF REFINING IN SIMPLE AND COMPLEX REFINERIES

The function of the oil refinery is to convert crude oil into the finished products required by the market in the most efficient and hence, the most profitable manner. The four basic operations are:

1) fractionation or distillation;

2) converting or chemically transforming certain cuts into components of higher value;

3) treating, i.e. removing/transforming all unwanted components; and

4) blending of finished components into commercially saleable products.

The methods employed vary widely from one refinery to another, depending on the crude processed, the nature and location of the market, the type of equipment available, etc. The choice of methods will depend on individual strategic decisions taken by the refiners over time.

Refineries in the EU range from simple (hydroskimming) to highly complex; the complexity often reflected in the use of deep conversion units such as delayed coker, solvent deasphalting or hydrocracking units. A detailed design engineering study performed by Amec Foster Wheeler[4] lists performance levels for these typical units. **Table 1** here below shows the average yields from the EU refining industry (LP simulation).

Table 1 Refinery main product categories yields

	Typical Refineries		Concawe LP optimisation	
	Hydro Skimming.	Highly. Complex	2020 No spec change	2020 Global S cap
Gasoline	18%	25%	19%	20%
Middle Distillates	45%	51%	55%	58%
Heavy Fuel Oil Bottom of Barrel	29%	9%	14%	10%

Table 1 demonstrates that the challenges faced by refineries due to decreasing demand for heavy fuel oil (i.e. fuel used inland as well as bunker fuel used at sea) following the global cap will be very different from one refinery to another. Therefore, while an overall impact assessment may be possible, the local impact of the global sulphur cap could be very different; refiners may face difficulties because they will be unable to reduce their heavy fuel oil yields whereas demand will strongly reduce in 2020 (Blends for marine Fuels 0.50%s will contain more middle distillates). However, EnSys Energy[5] believe that the expected short-term nature of this phenomenon is likely to deter many refiners from making major investments. They also expect refinery investment to be restricted because of the perception commonplace today that the wide price differentials between light (middle distillates) and heavy fuel oils will induce a rapid take-up of scrubbers. The likely

[4] "Recap project, Understanding the cost of retrofitting CO_2 capture to an integrated oil refinery", Description of reference Plants, Sintef 2017
https://www.sintef.no/en/projects/recap/

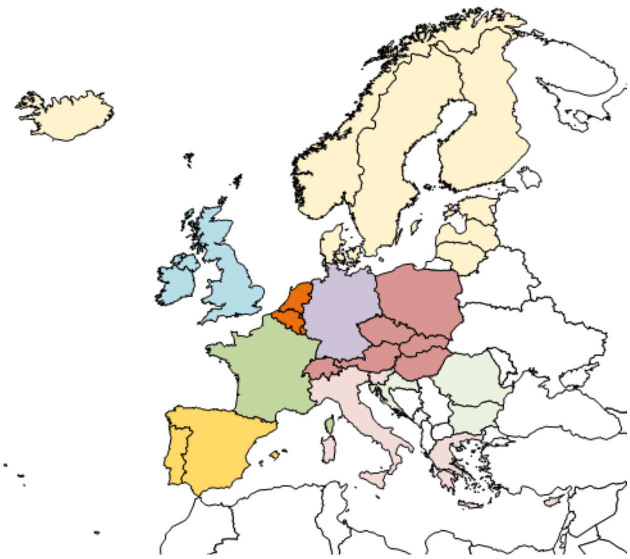
[5] "EnSys and Navigistics Still See Major Impacts and Big Risks from the IMO 2020 Sulphur Rule in Full Update to 2016 Study", on www.ensysenergy.com/posts/

effect of this could be a reversion, for part of the demand, away from 0.50% sulphur fuel oil and back toward 3.50%.

Refiners acting in strict compliance with competition law, do not share their strategic decisions upfront, so the future remains uncertain. However, refiners have proven in the past, being highly adaptive to changes in market demand.

4. MODELLING METHODOLOGY

The study was carried out with the Concawe EU-wide refining model, which uses the linear programming technique to simulate the whole of the European refining industry, encompassing the EU-28 members, plus Norway, Switzerland and Iceland. The modelling of Europe is segmented into 9 regions, as shown on the figure below, each of which is represented by a composite refinery having the combined processing capacity of all the refineries in the region as well as the complete product demand slate relevant to the region. Some blending streams and some finished product can be transported at a cost from one region to another to simulate real transport links.



Crude oil and feedstocks available to the model represent the expected quality of the European crude slate as well as the imports of feedstocks such as gasoil, kerosene and natural gas. Europe has a structural shortage of middle distillate products and an excess of gasoline and Heavy Fuel Oil (HFO) products. This is represented by allowing imports of gas oil and kerosene as well as exports of gasoline and HFO.

The model is allowed to optimise the distribution of the crude and feedstock imports and gasoline exports among the 9 regions according to the refining capacity and market demand in each region.

The model is generally run with fixed demands, its main degree of freedom being the option of adjusting process unit capacities. The optimisation of the EU refining system is treated by the model as a cost minimisation problem. For the purposes of the simulation, prices are fixed in US dollars for all inputs and outputs (for this study the price is historical, based on 2016 yearly average). Capital costs for new units are provided (in $/t of throughput). Notional operating costs per tonne of unit throughput are estimated from the capital cost of new process units, with the addition of catalyst costs where relevant. CO_2 emissions costs are taken into account

The market demand for Marine fuels product in each region is translated into its energy equivalent and the model is constrained to satisfy the regional demand for each product in energy terms. This means that, if the energy content of a product changed between cases because of re-optimisation of its blend composition or changes to product specifications (e.g. reduced sulphur content), the product quantity in tonnes is adjusted such that the total energy requirement remained fixed. The other products have a fixed demand in weight. Furthermore, as the model is carbon and hydrogen balanced, it is possible to monitor changes in CO_2 emissions due to changes in product specifications, even when the market demand remained unchanged.

Bio-components of gasoline (assumed to be mainly Ethanol and ETBE) are included in the modelling, using last available EU levels (from Fuel quality in the EU in 2016[6]). Bio-diesel is not included in Concawe LP model, however the diesel product qualities of the fossil portion are adjusted to reflect FAME being blended in the final product. LP modelling assumes current EN228 and EN590 specifications would apply to the final gasoline/diesel products.

The model includes a representation of the European chemical steam cracker industry with olefins and aromatics recovery in addition to traditional fuel refining process units, thereby reflecting the important interaction between refineries and petrochemical's complexes. This means that some chemical feedstock streams produced by refining (e.g. naphtha and LPG) are partially consumed by the chemical industry.

[6] Available through https://www.eea.europa.eu/publications.

5. PLANNING BASIS

The first step in this type of study is to assemble a set of assumptions that will be essentially common to all cases and describe the expectations in terms of crude and feedstocks slate, product demand (quantity and quality), refineries configuration and plant capacities and all other relevant constraints that need to be taken into account. The main features and assumptions relevant to this study are summarised below.

5.1. CRUDE OIL SUPPLY

The total supply to European refineries is composed of a large number of crudes and feedstocks. While it is not practical to fully represent this diversity in a model, it is possible to match the average quality of the total slate. Based on data from Wood Mackenzie and EU Commission DG-ENER an average supply quality was estimated for the modelling purpose.

Table 2 2010-2020 Crude slate main properties

	2010	2015	2020
API	34.1	33.7	34.0
SPG	0.855	0.856	0.855
Sulphur, %m/m	0.98	0.99	0.98
180-350°C yield, %m/m	29.9%	30.0%	30.0%
350+°C yield, %m/m%	45.2%	45.8%	45.6%
550+°C yield, %m/m	17.1%	17.4%	17.3%

The model allows import of 5 crudes, 1 condensate, 1 long residue and 1 short residue. A combination of these 8 components matching the above properties was determined through linear optimisation. The crude mix ratios obtained were then fixed for the entire model (per year). Each region can process a different mix, as long as the weighted mix for the 9 regions satisfies the overall quality. The crudes being limited to 5, each of them are representative of a region and quality, and it does not represent the quantity of the individual crude by itself.

Table 3 2020 Crude slate composition for quality modelling

	2020
Brent	41.2%
Forcados	7.0%
Russian Export	27.0%
Iranian Light	8.0%
Kuwait	13.1%
Algerian Condensate	0.5%
Brent Short Residue	3.2%

5.2. IMPORTS / EXPORTS

Product import / export assumptions are mainly based on Wood Mackenzie historical data adjusted by Concawe. The model is free to spread imports and exports amongst regions as long as the total specified volumes are respected. Overall volumes are shown in the table below.

Table 4 2020 Imports / Exports assumptions

2020 Imports, MTPY	
Natural Gas	≤ 6.7
Ethane (for SC)	Limited by SC feed ratio
LPG	≤ 15.2
ETBE	Fixed content in gasoline as per 2020 forecasts
MTBE	Fixed content in gasoline as per 2020 forecasts
Ethanol	Fixed content in gasoline and ETBE/TAEE production capacities
Methanol	Limited by MTBE production capacities
Jet	≤ 17.4
Heating Oil	≤ 12.1
Russian M100	≤ 34.6
2020 Exports, MTPY	
Chemical Naphtha	≤ 7.3
Gasoline (US market)	≤ 18.5
Gasoline (Others market)	≤ 33.0
Heavy Fuel Oil	≤ 27.0

- **Natural gas**: 2016 value is assumed for 2020 (Eurostat data).
- **Ethers**: ETBE imports are based on the ethanol equivalent content of the gasoline pool (see product specification section). MTBE imports are limited by the fixed MTBE content (1.1 %m/m as estimated by Concawe from fuel market surveys) of the local demand of gasoline grades.
- **Ethanol**: Ethanol content is limited by the fixed content in the gasoline pools and the ETBE/TAEE production capacities. Similarly, **methanol** is limited by the MTBE production capacities.
- **Chemical Feed Naphtha:** the export amount is to be considered in addition to the actual requirements for the Steamcracker (petrochemicals demand).
- **Jet fuel and gasoil/diesel:** the strong demand for middle distillates will result in increased imports. The allowed maxima were set on the basis of forecasts by Wood Mackenzie (gasoil/diesel assumed to be heating oil quality).

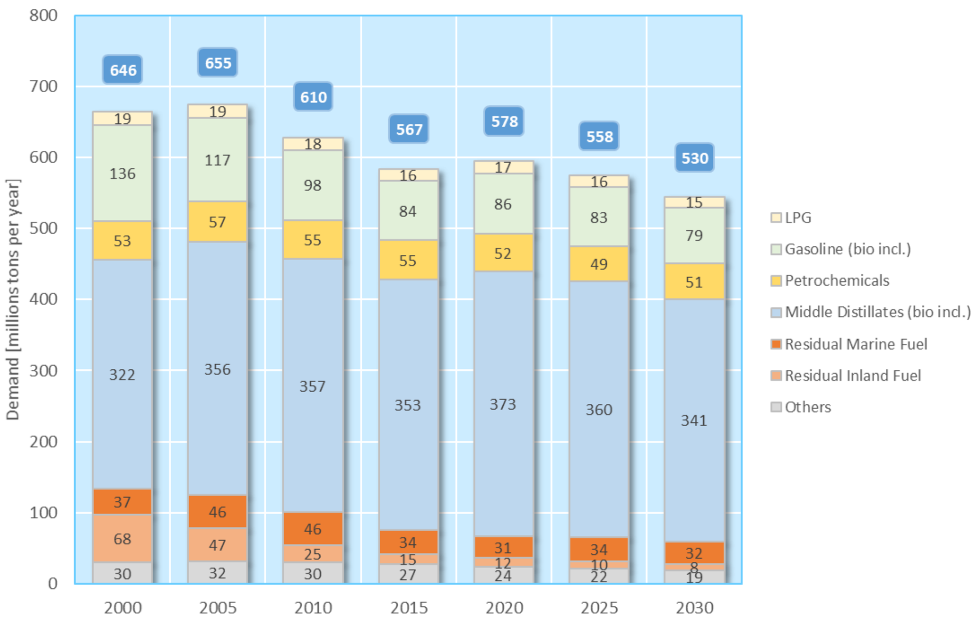
- **Gasoline and Heavy Fuel Oil:** the allowed maxima were set on the basis of forecasts by Wood Mackenzie.

- **M100 (Russian fuel oil):** imports were estimated from Eurostat data.

5.3. PRODUCT DEMAND AND SPECIFICATIONS

For future product demand, Wood Mackenzie forecasts (2019) were the main source of data supplemented by more detailed information from Eurostat, CEFIC [4] (for petrochemicals). The consolidated data are shown below.

Figure 1 2000 – 2030 Main products demand



Aggregating the products, the heavy fuels("Residuals" + "Others") demand shows a -12% decrease while the middle distillate demand is at +5% increase between 2015 and 2020.

Product specifications were set in accordance to legislation as per 2020. Appropriate and usual blending margins (difference between blending target and specification, e.g. based on analytical method repeatability) were included in the model to reflect the real refinery constraints and, for road fuels, the impact of incorporating biofuels. Marine fuels specifications are discussed below.

Specific provisions for marine fuel grades:

The main grade is a Residual Marine Fuel (RMF) with a current maximum sulphur content of 3.5%m/m. This is set to be reduced to 0.5 %m/m in 2020. However, the legislation applies to ship stack emissions rather than to the fuel they use. This makes it possible to comply by installing Exhaust Gas Cleaning Systems, commonly referred to as "scrubbers". The proportion of ships that might choose this route depends on technical as well as economic factors and is a matter of some debate. In their complementary feasibility study for IMO's MEPC 70 [5], Latest Wood Mackenzie forecasts assumed that, by 2020, 14% of the total marine fuel demand (including Middle Distillates) will still be high sulphur. This is modelled by creating an “export” residual marine fuel grade with unchanged specification

(except for the maximum sulphur content which is now not limited to 3.5 %m/m, but freely open[7]).

Compliance with the 0.5%m/m sulphur for all marine fuels will have to be achieved through a combination of desulphurisation of residual components and dilution with desulphurised Middle Distillate components. Stability considerations limit the proportion of the latter components that can be added to the residual streams[8]. In order to provide an additional degree of flexibility in the way the new specification could be met, we have introduced a Distillate Marine Fuel grade (DMF) with the same 0.5% sulphur limit (but with otherwise distillate properties) which makes it possible to segregate potentially incompatible components.

Blending of kerosene type material into fuel oils is allowed but limited by the Flash point specification. But as blending rules for this parameter are inaccurate, a maximum limit of 5 %m/m kerosene material in the blend is adhered to based on practical experience.

There is also an existing Diesel Marine Fuel grade with a maximum sulphur content of 0.1 %m/m. Since 2015, this incorporates fuel burned in the so-called Emission Control Areas (ECA).

Demand and specifications for all marine fuel grades are shown in **Table 5.**

7 DIRECTIVE (EU) 2016/802 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels, article 5: “In order to ensure a minimum quality of fuel used by ships either for fuel-based or technology-based compliance, marine fuel the sulphur content of which exceeds the general standard of 3,50 % by mass should not be allowed for use in the Union, except for fuels supplied to ships using emission abatement methods operating in closed mode“

8 Residual fuels stability is a crucial issue for users. Residual streams contain heavy compounds so-called “asphaltenes” which need to be maintained in a dispersed state by lighter components with a sufficient level of solvency (i.e. of an aromatic nature). Failure to provide the required environment causes precipitation of the asphaltenes leading to serious problems such as plugging of filters and fuel supply systems. Cracking and desulphurisation makes the remaining asphaltenes more difficult to keep in solution while desulphurised distillates tend to have lower solvency which exacerbates the problem when backblending such components into residuals bases.

Stability and the blending behaviour of components cannot be easily modelled except through blending limits considerations.
Compatibly of the different fuels on the market may be an issue, but here as well the LP model cannot predict the behaviour of these fuels.

Table 5 Marine Fuels demand and specifications

	Diesel Marine Fuel	Distillate Marine Fuel	Residual Marine Fuel	Residual Marine Fuel 'Scrubbed'
2020 Demand, MTPY	18.1	23.6[1]		6.8
Specific Gravity	0.800 - 0.900	0.800 - 0.900	0.900 - 0.991	0.900 - 0.991
Sulphur, %m/m	≤ 0.1	≤ 0.5[2]	≤ 0.5[2]	-
Viscosity @ 40°C, cSt	≤ 10.8	≤ 6.0		
Viscosity @ 100°C, cSt			≤ 35.0	≤ 35.0
Cetane Index	≥ 40	≥ 40		
Pour Point, °C	≤ 0	≤ 0	≤ 30	≤ 30
Kerosene Content, %m/m	≤ 10	≤ 10	≤ 5	≤ 5

(1) A mixture of the both grades will be required in most cases. Actual total tonnes will vary with the heating value of each grade to correspond to a fixed total energy content.
(2) Modelled as 0.45 to take account of blending margin.

5.4. PRICES

The LP model requires a set of prices to generate an optimum solution as it is an economic model that uses production costs and product prices. The prices used for the simulation are historical, based on 2016 averages. In the modelling studies undertaken by Concawe, the model is generally severely constrained by forcing product demands so that the prices are not crucial to the outcome. This is also the case in this study with the exception of the set of sensitivity cases where the impact of the price differential between HFO and distillate is specifically explored (see section 7.2). The full set of prices used in this study is shown in Appendix; they are yearly 2016 figures, supplied by Thompson Reuters.

5.5. REFINERY PROCESS UNITS CAPACITIES

As mentioned in section 3, the model consists of 9 theoretical refineries each having, for every main process, the aggregated capacities of actual installations in a certain region. This simplified representation of a more complex and diverse reality inevitably leads to a level of optimisation that is not achievable in practice where each individual refinery has to operate within its own constraints and limitations.

In order to reduce the impact of this potential "over-optimisation" on the outcome of the modelling, we calibrate capacities as follows:

- The model is first run with all inputs (refining capacities, imports/exports, product demands/specifications) representing a certain year (in this case 2020), without any change in Marine Fuel sulphur specifications.
- The key assumption is that the resulting utilisation rates of process units represent their practically usable capacities (in other words assuming that the European refining system operates close to its maximum capability).
- The model capacities are then trimmed accordingly, taking into account expected capacity changes in future years.

An additional constraint is imposed to ensure that existing capacities are at least 60% utilised.

The resulting capacities for 2020 are shown in table below. This is the basis that each study case starts from. Depending on the objective of individual cases, the model may be allowed to add capacities in order to find an optimum solution.

Table 6 Calibrated European refinery process unit name-plate capacities for 2020

Process Unit	Capacity MTPY
Crude Distillation	625
Vacuum Distillation	272
Visbreaking / Thermal Cracking	50
Delayed Coking	30
De-Asphalting	3
Fluid Catalytic Cracking	100
Hydrocracking (incl. VGO pretreat.)	132
Residue Desulphurisation	4
Residue Conversion	10
Naphtha Hydrotreating	103
Naphtha Reforming	76
Aromatic Extraction	11
Alkylation	9
Isomerisation	14
MTBE/ETBE/TAEE	3
Kerosene Hydrotreating	34
Distillate Hydrodesulphurisation	144
Lube Base Oil	6
Bitumen	17
Petrochemicals (Steamcracking)	62
Hydrogen (Steam Reforming)*	2
Hydrogen (POX)*	1

* Expressed as hydrogen produced

5.6. ENERGY CONSUMPTION AND CO_2 EMISSIONS

Each process unit and, where applicable, each operating mode has an allocated energy consumption factor (GJ per tonne of feed) as energy consumption may vary with operational severity and/or feed quality. A number of components may be used by the model as refinery fuel (within a maximum sulphur content for the entire fuel pool) each with a certain heating value and carbon content. The model can then calculate the total CO_2 emissions due to fuel burning.

For this study, all energy consumption factors were adjusted so that the total CO_2 emissions for 2016 matched the published Eurostat figure for that year. Based on Concawe estimations, 3% energy efficiency improvement were considered between 2016 and 2020. This improvement has been applied on each refining process unit (Petrochemicals excluded) energy consumption factor.

6. STUDY CASES

The first step was to ensure that the model, as described above, was capable of delivering all demands, including Marine Fuels at the current specification (Case 0000).

Without additional capacities, the model could find a feasible solution to produce the entire marine fuels demand at the new sulphur specification, without any additional investment, in a unique pool of Residual MF 0.5%S product (Distillate MF 0.5%S was not segregated in the model).

As discussed in section 5.3 producing the marine fuel demand at the 0.5% sulphur level requires a combination of desulphurisation of residual streams and addition of desulphurised Middle Distillate components, the latter option being limited by stability considerations. The distribution of components between the main RMF grade and the DMF is crucial to ensure that the resulting blends are likely to be acceptable from this point of view, and to highlight/inform that the products available on the marine bunker market will most likely vary from light distillate to heavy fuel oil. We explored 3 cases with different split between RMF and DMF, i.e. 90/10, 50/50 and 37/63 (Cases 0100/0200/0300). Case 0300 appears to be the minimum proportion of RMF that the model can deal with, without considering any major investment in conversion and/or desulphurisation units.

In some cases, Hydrogen Manufacturing Units (HMU) and Sulphur Recovery Units (SRU) became bottlenecks. Investments in these two types of units were allowed so as to obtain feasible solutions. These units are not the driver for a refinery, which configuration and performance depend on other main units. Therefore, SRU and HMU are adapted to the overall configuration in order not to be a constraint. As a result, the accuracy for available capacity is not well known (revamps or upgrades are not publicly announced). Therefore, allowing the model the flexibility to invest is a good proxy of the reality.

The crude slate (and in particular its sulphur content) is obviously an important parameter with regard to the feasibility of producing low sulphur marine fuels. Although we made every effort to use a crude slate representative of European supply, there is a degree of uncertainty in this respect. In order to assess the potential impact, we ran extra cases where the proportion of each crude is allowed to vary with ± 10% of its previously fixed value. This is showed in the cases 0210 with RMF/DMF 50/50 split and 0310 with RMF/DMF 20/80 split. Thanks to the crude slate flexibility, RMF/DMF 50/50 split could be reached without any additional investments, and with SRU & HMU investments, the RMF portion could be reduced to 20% (37% with the fixed 2020 crude slate assumption).

Refining system operation constantly evolves to adapt to the products demand. To avoid providing conclusions for a specific year, as a sensitivity we ran an additional case at 2025 horizon (Case 0220 with RMF/DMF 50/50 split). According to latest Wood Mackenzie forecasts, scrubber MF demand would be higher: about 20% of Marine Fuels demand vs. 14% in 2020 for Europe. In addition, to the scrubber penetration assumption, a complete 2025 set-up was implemented: assumptions update for products demand and imports/exports around EU.

European refiners are obviously under no obligation to produce the full marine fuel demand, as they are not the “obligated party” of the Regulation. An alternative way of looking at this issue is therefore to explore the economic conditions that would make it attractive for refineries to continue producing such fuels. With all other constraints remaining unchanged, we explored the effect of hypothetical price differential between marine fuel and middle distillates on the amount of marine fuel made: two series of runs were performed, one on the 2020 base case (collectively referred to as Case 0200 PriceDifferential) and one on the 2025 sensitivity (Case 0220 PriceDifferential).

7. RESULTS

7.1. MAIN RESULTS

The main outcomes from the studied cases are shown in the table below.

Table 7 Results summary

CASES	2020 Calib.	0100	0200	0300	0210	0310	0220
Case definition							
Crude slate (2020 forecasts)	Fix	Fix	Fix	Fix	±10%	±10%	Fix
Demand and Imports/Exports year	2020	2020	2020	2020	2020	2020	2025
Scrubber HSFO, %m/m of total MF	-	14%	14%	14%	14%	14%	20%
RMF 0.5%S / DMF 0.5%S split, %m/m	-	90/10	50/50	37/63*	50/50	20/80*	50/50
Marine Fuels, MTPY	49.1	48.4	48.2	48.0	48.3	47.8	47.5
Diesel MF 0.1%S	18.1	18.1	18.1	18.1	18.1	18.1	14.4
Distillate MF 0.5%S	-	2.4	11.7	14.6	11.7	18.4	11.6
Residual MF 0.5%S	-	21.2	11.7	8.6	11.7	4.6	11.6
Residual MF High S (Scrubber HSFO)	31.0	6.8	6.8	6.8	6.8	6.8	9.8
Overall composition, %m/m	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
SR MD	4.8%	5.0%	5.0%	5.0%	5.0%	0.2%	5.0%
SR VGO	9.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SR Resid.	7.2%	0.0%	0.0%	0.0%	0.0%	1.5%	13.2%
Conversion MD	1.5%	12.6%	1.5%	0.2%	1.6%	0.0%	7.0%
Conversion VGO	17.3%	19.5%	26.9%	22.7%	26.1%	38.6%	15.5%
Conversion Resid.	54.7%	40.3%	50.3%	71.2%	50.9%	59.2%	47.0%
Misc. (asph, lubes extract)	5.3%	22.7%	16.4%	1.0%	16.4%	0.5%	12.3%
Main properties**							
Distillate MF 0.5%S							
SPG	-	0.875	0.859	0.857	0.869	0.859	0.875
Sulphur, %m/m	-	0.45	0.45	0.45	0.45	0.45	0.45
Cetane Index	-	41	46	46	43	46	41
Cloud point, °C	-	0	0	0	0	0	0
Residual MF 0.5%S							
SPG	-	0.965	0.990	0.989	0.991	0.991	0.991
Sulphur, %m/m	-	0.45	0.45	0.45	0.45	0.45	0.45
Viscosity @ 100°C, cSt	-	23	34	35	30	34	32
Pour point, °C		30	29	29	29	29	29
Residual MF High S (Scrubber HSFO)							
SPG	0.991	0.991	0.991	0.991	0.991	0.991	0.991
Sulphur, %m/m	2.05	3.20	2.34	1.05	2.12	0.88	3.20
Viscosity @ 100°C, cSt	35	35	35	35	35	35	35
Pour point, °C	22	16	23	27	25	28	15
CO_2 Emissions, MTPY	**174.4**	**174.9**	**179.7**	**195.4**	**174.3**	**206.4**	**163.6**
New capacity, % of existing							
Sulphur Recovery Unit	-	-	-	+9%	-	+1%	-
Hydrogen Plant	-	-	+12%	+100%	-	+250%	-

** RMF minimised*
*** Constraining properties highlighted in red*

In **Case 2020 Calibration**, the full RMF demand is produced, at the current specification (i.e. 3.5% S max).

Full compliance with the new specification is achieved in all other cases. The remaining 6.8 MTPY of high sulphur RMF correspond to the use of on-board scrubbers. New capacities may be required for hydrogen manufacturing and sulphur recovery. For hydrogen, the required extra capacity is a direct function of the proportion of DMF in the total marine fuel pool (DMF is a lighter fuel with a higher hydrogen to carbon ratio than RMF). Sulphur recovery capacity is also affected by the RMF/DMF ratio, but more flexibility is currently available in the system.

The increased proportion of lighter products in the total refinery output is achieved by higher conversion which causes higher energy consumption. CO_2 emissions increase through both additional fuel burning and increased hydrogen production (which releases CO_2 as part of the chemical reaction).

The 0.5% S RMF limit is achieved by addition of a considerable proportion of light material which results in significant viscosity and density giveaway. Whereas this is not considered to be a major issue, there are serious questions regarding fuel compatibility. As mentioned in section 5.3, stability behaviour cannot be accurately modelled. A heavy fuel oil blend containing only one third of residual components and about 50% hydrotreated distillates is very much unchartered territory in this respect. Even if such fuels could be satisfactorily blended within the confines of a given refinery, there would be serious risks of incompatibility between fuels of different sources resulting in unstable blends in ship's bunker tanks[9]. Cold properties (commonly measured by the Pour point), could also be affected in unpredictable ways.

In Cases 0300 and 0310, RMF is minimized so as to identify the limits of the refining system. As investments in Hydrogen plant and Sulphur Recovery were allowed, the limits of the system are mainly residue conversion towards middle distillates and middle distillates hydrotreament. RMF production was minimised till a solution could not be reached anymore. Therefore these cases are extremely constrained, and probably could not be achieved in the real EU refining system. It is confirmed by the very high Hydrogen requirements and consequently very high CO_2 emissions of these two cases.

In Cases 0210 and 0310, ±10% flexibility was allowed on the crude slate proportions. The purpose of these cases is to evaluate the impact of a potential change in the crude slate. If Case 0210 is compared to Case 0200 (similar case but with fixed crude slate), about 3% less CO_2 is emitted, confirming that a change in a crude slate can help achieving the switch to 0.5%S. This CO_2 reduction is directly linked to the sulphur removal requirement: the optimised crude slate sulphur content is reduced by 4% in case 0210 compared to case 0200.

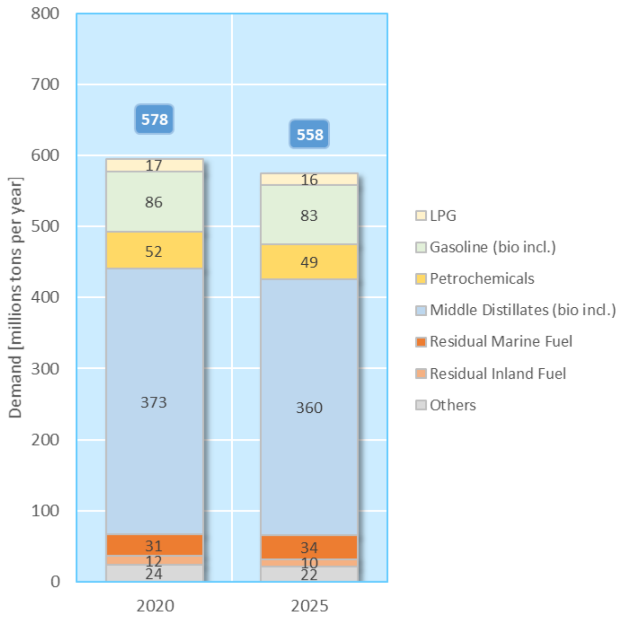
Scenario for 2025, hypothesis update:

According to latest (August 2019) Wood Mackenzie forecasts, scrubber penetration could be quite fast, from 14% of total Marine Fuels demand in 2020 to about **20% in 2025 (for EU region).** It was then decided to run a case (0220) for this 2025 horizon. As can be seen on the figure below, between 2020 and 2025, overall products and

[9] For more information, see the Joint Industry Guidance on the supply and use of 0.50% sulphur marine fuel
https://www.ipieca.org/resources/good-practice/joint-industry-guidance-on-the-supply-and-use-of-050-sulphur-marine-fuel/

middle distillates demands decrease, allowing for more flexibility to produce 0.5%S MF in 2025 than in 2020. As expected, CO_2 emissions decrease as the system is less constrained. Compared to 2020 case, the 12% additional investments in Hydrogen plant capacities are no longer required. However, it has to be reminded that these investments are relative to 'calibrated' capacities and the actual requirements need to be assessed more precisely on a refinery by refinery basis.

Figure 2 Refinery products demand forecasts, 2020 - 2025

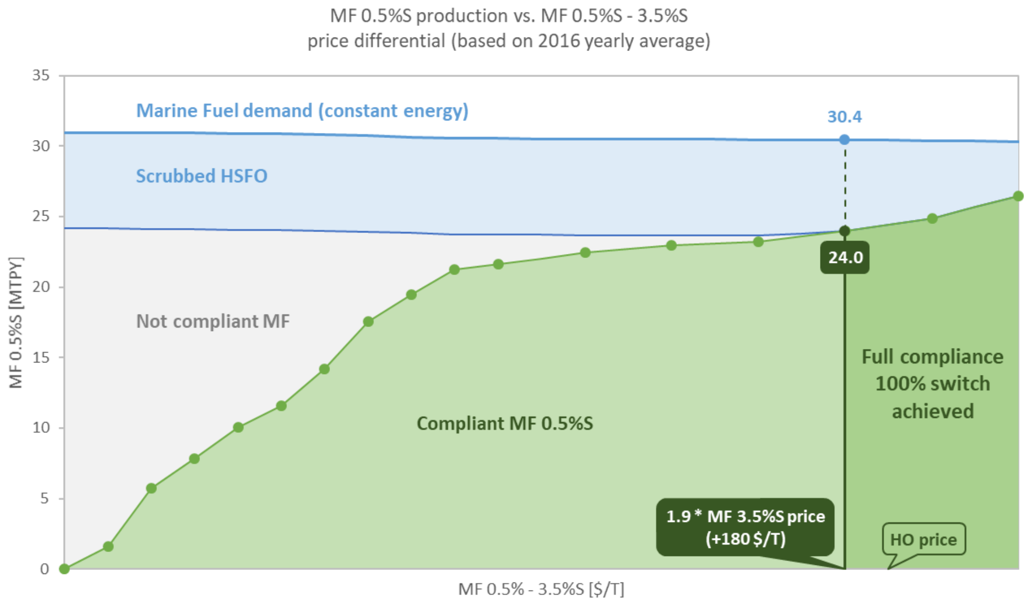


7.2. MODEL SENSITIVITY TO PRICE DIFFERENTIALS

The main outcome of Case 0200 Price Differential ('economic condition') is illustrated in the figure below. Economic production of the whole RMF demand at 0.5% S would require a virtual doubling of RMF price, taking it to the level of heating oil or even higher. This highlights the dilemma facing both refiners and ship owners. The new sulphur specification is likely to push the price of low S RMF towards that of middle distillates, which would in principle, create an incentive for refiners to invest. However, this would also increase the incentive for ship owners to install on-board scrubbers thereby reducing the demand for low S RMF (and potentially its price) making investments in desulphurisation less profitable or even redundant. Depending on the scenario considered, the outcome and conclusion may be very different. That is why the different stakeholder have individual strategies potentially conflicting each other… For others wait and see is the option considered.

Concawe incentivised the model to produce 0.50% sulphur RMF by increasing the differential price for 3.5% sulphur RMF, based on 2016 average prices. The figure below shows this step-by-step analysis.

Figure 3 Impact of low-high sulphur Residual Marine Fuel price differential on low sulphur RMF production economics - step by step analysis - 2020



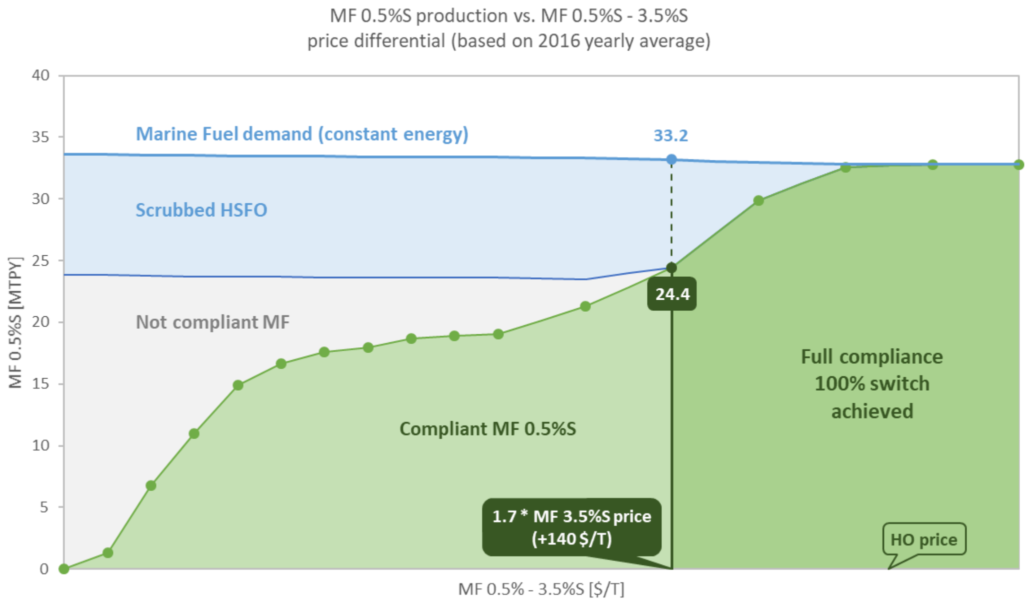
It should be noted that the Marine Fuel demand[10] of the figure above does not include the Diesel Marine Fuel at 0.1%S, as it is not concerned by the sulphur specification change.

The model shows a highly constrained system, as the model needs a high incentive to reach full compliance (i.e. production of 24 MTPY of 0.5%S MF). It also shows a potentially significant gap between demand and production, which may be an indication of the level of 'non-availability' of compliant fuel. On an open and balanced market driven by supply-demand, which is the case for petroleum products, the differentials between products is a fine equilibrium between the product demand and the incentive for the refiner to produce.

As explained above, 2025 system is less constrained, due to lower overall and middle distillates demands and to higher scrubber penetration assumption. Consequently, full compliance is reached at a lower 0.5%S – 3.5%S MF price differential (+140 $/t vs. +180 $/t, based on the 2016 economic assumptions).

[10] In the model, the demand is expressed in terms of energy; therefore, the demand in tons is a result and depends on the blending composition. This is why the blue lines on the graphs are not constant as the Y axis is in tons (MF demand is constant in Energy)

Figure 4 Impact of low-high sulphur Residual Marine Fuel price differential on low sulphur RMF production economics - step by step analysis - 2025



7.3. EVOLUTION TOWARDS MIDDLE DISTILLATES

The figure above may also indicate that, as refiners increasingly blend more and more middle distillate molecules to increase the production of 0.50% sulphur RMF, the price differential (0.50%-3.50%) may increase and get closer to a typical heavy fuel versus middle distillate differential, in order to reach the 100% compliance case.

The demand for high-sulphur marine fuels (burned in ships equipped with scrubbers) in 2020 is around 6.8 MTPY; maximum density and viscosity remain constant, but sulphur content goes up from 2.05% to 3.20%. It shows that sulphur having a value across the full range of refinery products, there is an incentive to segregate the heavy fuels streams with the highest sulphur content towards HS marine Fuel pool. This trend and potential evolution has to be considered when designing the scrubbers.

The blending of 0.50% sulphur marine fuel (24 MTPY in 2020) results in multiple products, which can be divided, to simplify, into two categories:

1. **Heavy fuels at 0.50% sulphur:**

   - Will most likely represent 30-50% of the demand.

   - Quality: pour point and sulphur will be maximised, density will be around 0.99 and viscosity above 30 cSt at 100°C. This is a similar quality as the current Bunker fuel, but with lower sulphur content.

2. **Distillate type:**

- Will most likely represent 50–70% of the demand
- Quality: sulphur will be maximized, density will be around 0.87 and cloud point will be around 0°C.

In 2020, the ship operator/owner will order marine fuel containing 0.50% sulphur. The refiner/supplier will then supply the fuel at a quality, which will depend on its own process and economic incentives. The study indicates that the range of quality will vary from heavy fuel (typically produced by a refiner having either a very low sulphur crude slate or having residue desulphurisation capabilities) to a much lighter marine fuel with properties very similar to those of distillate fuels (such as Diesel Marine fuel (or MGO)). Refiners might be tempted to bring to the market a very light fuel to supply the demand for 0.50% sulphur RMF if the differential vs distillate makes this practical. This would evidently be the individual refiner's decision.

8. CONCLUSIONS

The introduction of a 0.5% sulphur limit on all marine fuels represents a step change for both the shipping and refining industries. Full compliance with new specification will not be straightforward, it requires industry efforts and adaptation:

- SRU and HMU capacities are seen as a constraint by the Concawe model (both the “EnSys-Navigistics Supplemental Study” and the “CE Delft” at IMO also highlighted major deficits of H2 and SRU capacity). However, in practice, being a “commodity unit”, it should not be a primary constraint in a modelling study.

- Main conversion and hydrotreating units will need to be maintained at a high throughput.

- The model indicated that there will need to be a strong incentive for refiners to supply the demand for marine fuel at 0.50% sulphur.

- A key uncertainty will be world region trade flows (middle distillates imports and HSFO exports).

- The speed of on-board scrubber penetration (impacting the ratio of Demand of HSFO versus MF0.50%S).

It will require more hydrotreating in refineries which can only be provided through investments in hydrogen manufacturing (HMU) and sulphur recovery (SRU) capacities. As a corollary, energy consumption and CO_2 emissions will increase possibly by some 4% (higher if middle distillate Marine Fuel production is maximised).

Compliance within reasonably economic terms will drive low sulphur marine fuel prices closer to that of middle distillates (MGO, Marine Gasoil). However, as the scrubber uptake will increase (2025 hypothesis at 20% of the demand in EU), the tensions and strength in refinery operation and market will reduce and adapt to a new equilibrium.

The crude slate ratios in the Concawe model are fixed. Nevertheless sensitivity analysis has been performed. This does not lead to changing conclusion. The switch to 0.50%S MF is not straightforward and many constraints remain in the model.

The composition of the low sulphur residual fuels will be very different from what it is today with significantly more distillates components, the majority of which is hydrotreated in some way. As a result, fuel quality will be an issue particularly with regard to stability/compatibility and possibly cold properties. This will create new challenges for blending and is likely to create some compatibility issues between fuels from different origins. The new marine fuels blending formulations should be treated with some caution, bearing in mind that the LP model is ‘blind’ with regard to issues such as compatibility, stability, lubricity and cold flow properties. Some learning by experience is expected. Most of refiners have anticipated and performed lab testing (internal streams compatibility) to develop new internal procedure and blending rules to guarantee fuel stability.

The compatibility concerns have been addressed through ISO/TC 28/SC 4/WG 6 with the active collaboration of Concawe and its member Companies. The recommendation have been issued through an ISO PAS 23263[11] (Publicly Available Specification) and a Concawe public report[12].

The degree of on-board scrubber uptake will be crucial and within its technological challenges, may be driven by the market price differential between low and high S grades. Refiners may be unwilling to invest for low S MF in an uncertain long-term environment where scrubber uptake may increase. Refiners have invested in internal logistics, piping, tank farms to deliver MF 0.50%S to their clients. Investments that are more significant would remain individual strategic decision, with scrubber uptake hypothesis a key component of the opportunity assessment.

[11] ISO/PAS 23263:2019: "Petroleum products — Fuels (class F) — Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0,50 % sulfur in 2020"

[12] Concawe Rpt 19-11 « Study to evaluate test methods to assess the stability and compatibility of marine fuels in view of the IMO MARPOL Annex VI Regulation 14.1.3 for 2020 Sulphur requirements"

APPENDIX: PRICE SET

Table 8 2016 Price set (Source: Thompson Reuters)

Purchases	$ / t, 2016
LS Crude	336
WA Naphthenic Crude	327
FSU Export Crude	298
ME Light Crude	316
ME Heavy Crude	297
Condensate	383
Long Residue (Imported)	220
Vacuum Residue (Imported)	228
C1 Natural Gas	219
Ethane	219
Ethanol	762
Methanol	562
ETBE	754
MTBE	554
Chemical Feed Naphtha	383
Jet import	426
Heating oil import	398
Imported Russian M100	220
LPG	315
Sales	**$ / t, 2016**
LPG	305
Methanol	562
Ethylene	928
Propylene	628
Butylene	813
Benzene	677
Toluene	561
Xylenes	596
Chemical Naphtha	370
Premium 95	462
Super 98	472
Mogas US Export	452
Mogas Other Export	449

Jet	417
Road Diesel	397
Non-Road Diesel	397
Rail Diesel	397
Heating Oil	391
Inland waterways Diesel	391
Diesel marine fuel	391
HFO low sulphur	216
HFO high sulphur	202
Export HFO	213
RMF General	202
RMF Scrubber	202
ube base oil	303
Wax	303
Bitumen	202
Pet Coke HS	57
Pet Coke LS	57
Sulphur	22

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