International Energy Agency

IEA Refinery Margins

Methodology Notes

Oil Industry and Markets Division

September 2012

The International Energy Agency (IEA) has with the 12 September 2012 Oil Market Report resumed its coverage and estimations of refinery margins.

Global Indicator Refining Margins are calculated for various complexity configurations, each optimised for processing the specific crude(s) in a specific refining centre. Margins include energy cost, but exclude other variable costs, depreciation and amortisation. Consequently, reported margins should be taken as an indication, or proxy, of changes in profitability for a given refining centre. No attempt is made to model or otherwise comment upon the relative economics of specific refineries running individual crude slates and producing custom product sales, nor are these calculations intended to infer the marginal values of crude for pricing purposes.

This document provides an outline of the underlying assumptions and methodology used to calculate the margins. .

Historical Margins are availbale to subscibers on http://www.oilmarketreport.org/refinerysp.asp

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Introduction

The International Energy Agency (IEA) has with the 12 September 2012 Oil Market Report resumed its coverage and estimations of refinery margins. With the help of KBC Advanced Technologies (KBC), we have developed a new set of global indicator refinery margins for primary refined product markets in Northwest Europe, the Mediterranean, the US Gulf Coast and Midcontinent as well as Singapore.

Global Indicator Refining Margins are calculated for various complexity configurations, each optimised for processing the specific crude(s) in a specific refining centre. Margins include energy cost, but exclude other variable costs, depreciation and amortisation. Consequently, reported margins should be taken as an indication, or proxy, of changes in profitability for a given refining centre. No attempt is made to model or otherwise comment upon the relative economics of specific refineries running individual crude slates and producing custom product sales, nor are these calculations intended to infer the marginal values of crude for pricing purposes.

The new refinery margins are based on indicator refinery yields derived from KBC's Petro-SIM simulation. These yields will be used by both IEA and KBC to generate indicative refining margins for these main products markets, to be referenced as "KBC/IEA Global Indicator Refinery Margins".

The IEA uses Argus Media Ltd price input for all refinery margin calculations.

KBC/IEA Global Indicator Refinery Yields for Margin Calculations

KBC Petro-SIM Simulation

KBC develops and markets the industry-leading non-linear refinery simulation software, Petro-SIM™. Petro-SIM is a flowsheet-based simulator with robust unit-specific models to simulate major refinery process units (e.g., Crude/Vacuum Distillation, FCC, reforming, hydrocracking, coking). Standard calibrations of individual process units are available to enable KBC to produce a generic refinery simulation of any configuration and to generate, on an optimised basis, blended refinery yields and energy consumption data on the basis of refining any mixture of available crude oil assays and other refinery feedstocks.

Refinery yields have been predicted using the following process units:

- Crude distillation unit (CDU)
- Vacuum distillation unit (VDU)
- Naphtha splitter, naphtha hydrotreater (NHT), light naphtha isomerisation and heavy naphtha continuous catalytic reformer (CCR)
- Kerosene and diesel hydrotreaters (KHT/DHT)
- High conversion VGO hydrocracker (HC)
- Fluid Catalytic Cracker (FCC), C4 alkylation (alky) and FCC naphtha hydrotreating units
- Visbreaker (VB)
- Delayed Coking unit (DC)
- Gasoline and LPG blender
- Middle distillate and fuel oil blender

Rigorous models, including reaction kinetics, are used for the middle distillate hydrotreater, FCC, VB, DC, HC and naphtha reforming units. Simpler models are used for the naphtha hydrotreating, isomerisation and alkylation units. Unit operating parameters have been varied depending on the geographical location. Individual process units can be turned on or off, depending on the configuration. A number of refinery configurations have been considered. Table 1 below shows the unit in operation for the different refinery types.

Table 1: Refinery Configuration Matrix

Refinery Configuration Matrix

	Refinery Type				
	HS	FCC/VB	HC/VB	HC/FCC/VB	FCC/Coking
Units					
Crude Distillation Unit (CDU)	x	x	x	x	x
Vacuum Distillation Unit (VDU)		x	x	x	x
Naphtha spl, NHT, CCR	x	x	x	x	x
Isomerisation[1]	x	x	x	x	x
KHT, HDT	x	x	x	x	x
Hydrocracker			x	x	
FCC, Alkylation				x	x
Visbreaker		x	x	x	
Delayed Coker					x
Gasoline/LPG Blender	x	x	x	x	x
Middle Distillate/Fuel Oil Blender	x	x	x	x	x

1 No Isomerisation untis for US refineriesm, where octane is currently in surplus

The naphtha reforming model was calibrated using a low pressure CCR unit configuration. However, in order to be more representative for typical reformer operation, which will generate less hydrogen and more LPG than a low pressure CCR unit, the reformer model pressure was increased.

Yield Summary

Refinery yields have been prepared for 23 separate cases on a barrel/barrel volumetric basis (volume percent product yield based on a volumetric intake of one barrel of indicator crude oil). Exceptions are that petroleum coke (petcoke) is reported on a specific mass basis (metric tons per barrel) and natural gas intake, which is used in US cases, is specified on a specific energetic basis (million BTUs per barrel). These yields are used to facilitate calculation of margins using standard product pricing bases.

We wish to note that the yields assumed in these indicator cases are not typical of modern refineries. Constraints imposed by a simplified crude slate, a lack of available feedstocks/blendstocks and a simplified product slate lead to indicative yields that may not be strictly representative of a well optimised complex refinery in today’s market environment. In some cases the constraint of producing simplified “indicator” margins on the basis of a single crude oil assay without the availability of purchased feedstocks, some product specifications have had to be loosened/waived to enable the model to solve. These are discussed in more detail in Appendix 1.

Regional differences:

Operating philosophy and or operating variables are different depending on the on the geographical region. Within a given continent (Europe, Asia, North America) they are assumed to be the same. The isomerisation unit is not used in the US cases which currently have lower octane blending requirements due to mandated ethanol blending, which adds octane to the pool. Middle distillate make is maximised in the European and Singapore cases while the American refineries have historically maximised gasoline. This is reflected in the cut-point settings, as shown in Table 2 below.

Table 2: Regional Differences

Key Regional Configurations

	NWE/MED	Singapore	USGC/US Midcon
Naphtha exports, % wt on crude	0	5	0
Vol% EtOH in finished gasoline	7	0	10
% FAME in finished diesel	5	0	0
Kerosene output (wt% on crude)	7-13	7 min	7-13
CDU/HC naphtha/kero cutpoint, C	145	145	180
FCC naphtha/mid distillate cutpoiint C	160	160	180
CDU and HC kero/diesel cutpoint C	230	240	230
FCC reactor temperature	Base	Base	Base +25 C

Northwest Europe / Mediterranean

Northwest European refinery cases are prepared on a distillate-maximising basis. Yields are set to minimise gasoline production and produce the widest cut of distillates (kerosene, ULSD) without producing fuel oil uneconomically (e.g. marginal kerosene, which is the highest value product, is sacrificed as cutter stock to maximise the combined yield of distillates while producing an economically optimum amount of residue fuel oil. Gasoline produced in the European cases is to a EuroBOB specification (European blendstock for oxygenate blending). The model assumes a 7 percent volumetric (5 percent energetic) blend of ethanol to produce a current average European grade of finished gasoline in compliance with EN228. At present different EU member states have different renewable blending requirements, so 5 percent energetic is seen as a sort of average. It is anticipated that as EU renewables mandates progress toward an EU-wide 10 percent energetic by 2020, the composition of the EuroBOB in this calculation will be adjusted from time to time to accommodate a slightly higher energetic content of renewables. As this specification nears 10 percent, it will likely have to accommodate a combination of bioethanol and ETBE made from bioethanol to meet the renewable energetic content while still meeting other EN228 specifications such as total oxygen content and vapour pressure (RVP). This model does not produce finished gasoline and thus does not have to take account of pricing for ETBE or ethanol.

Diesel produced in the European cases conforms to EN590 ultra-low sulphur diesel, with a specific gravity target of 0.842, which will accommodate post-refinery blending of FAME biodiesel. Biofuel blending for distillates is an increasing requirement of the EU pool. However, finished diesel can be blended either by the refinery or the marketer. This varies from country to country. These yields presume that the refiner would only receive the margin for producing the conventional fossil distillate.

Fuel oil produced for sale generally conforms to international bunker fuel oil quality for low sulphur (LSFO) or high sulphur fuel oil (HSFO).

Refinery fuel in the European cases is assumed to be refinery fuel gas topped up with refinery fuel oil. With natural gas generally priced on a fuel oil equivalent basis, margins would be similar whether fuel oil or natural gas is burned as marginal refinery fuel. Table 3 defines the refined product yields developed from Petro-SIM covering four cases involving two refinery configurations (hydroskimming, FCC/Visbreaker) and two crude oils (Brent, Urals). These are indicative of Northwest European refinery configurations and typical benchmark crude oils.

Table 3: Northwest European Yields

North West European Yields

	HS	HS	FCC + VB	FCC + VB
Volume % Yield	**Brent**	**Urals**	**Brent**	**Urals**
LPG	4.14%	4.41%	6.42%	6.41%
Gasoline	20.85%	13.06%	34.60%	27.11%
Naphtha	0.00%	0.00%	0.00%	0.00%
Kerosene	7.29%	7.60%	13.40%	9.18%
Diesel	32.31%	30.10%	34.03%	37.24%
HSFO	0.00%	41.85%	0.00%	17.53%
LSFO	32.00%	0.00%	8.99%	0.00%

Table 4 defines the refined product yields developed from Petro-SIM for three cases typical of Mediterranean refinery operations, two configurations (hydroskimming and Hydrocracker/Visbreaker), involving two crude oils (Urals and Es-Sider).

Table 4: Mediterranean Yields

Mediterranean Yields

	HS	HS	HC + VB	HC + VB
Volume % Yield	**Es Sider**	**Urals**	**Es Sider**	**Urals**
LPG	2.37%	4.41%	3.96%	5.75%
Gasoline	19.27%	13.06%	23.56%	17.97%
Naphtha	0.00%	0.00%	0.00%	0.00%
Kerosene	7.37%	7.60%	13.67%	14.04%
Diesel	31.90%	30.10%	40.74%	42.80%
HSFO	0.00%	41.85%	0.00%	16.34%
LSFO	35.74%	0.00%	15.01%	0.00%

Singapore

Asian refinery cases are prepared on a distillate-maximising basis, with an emphasis on marginal kerosene, which is a high value product in the Singapore market. Singapore cases produce a naphtha yield of 5 weight percent on crude oil, conforming to a volume yield of 6- 6.5 percent depending on the crude oil used.

Gasoline is produced to a 95 research octane (RON), 10 ppmw sulphur content and is assumed to be 100 percent conventional with no biofuel blending.

Diesel is produced to a ULSD equivalent with 10ppm sulphur, a cetane number of 51 and a maximum specific gravity of 0.845, with no accommodation made for FAME biodiesel blending.

Fuel oil produced for sale generally conforms to international bunker fuel oil quality for low sulphur or high sulphur fuel oil.

Refinery fuel in the Singapore cases is assumed to be refinery fuel gas and fuel oil.

Table 5 defines the refined product yields developed from Petro-SIM covering two configurations (hydroskimmer, Hydrocracker/FCC/Visbreaker) using two marker crude oils (Dubai and Tapis).

Table 5: Singapore Yields

Singapore Yields

	HS	HS	HC/FCC + VB	HC/FCC + VB
Volume % Yield	**Dubai**	**Tapis**	**Dubai**	**Tapis**
LPG	2.52%	1.77%	4.10%	4.14%
Gasoline	10.05%	17.02%	19.52%	26.04%
Naphtha	6.50%	6.08%	6.50%	6.08%
Kerosene	12.41%	20.99%	13.46%	23.42%
Diesel	22.98%	28.93%	37.44%	36.79%
HSFO	42.26%	0.00%	15.63%	0.00%
LSFO	0.00%	21.22%	0.00%	0.37%

US Gulf Coast and Midcontinent

All US cases blend to standard US product specifications; no export quality products are assumed.

US gasoline is blended to an RBOB (reformulated blendstock for oxygenate blending) specification that will yield finished gasoline when blended to 10 volume percent ethanol. The base RBOB conforms with US specifications and is blended to a road octane of 83.7 (R+M)/2 basis. The model does not take account of blending ethanol and thus the gasoline should be valued as RBOB rather than finished motor gasoline.

US diesel is assumed blended to a conventional ultra-low sulphur No. 2 fuel oil product meeting the standard US on-road diesel specification. Biodiesel blending in the US is assumed to be additive to the conventional blend in this refinery model and is assumed to be blended after it is sold from the refinery[1].1 Hence no specific effort is made to incorporate biodiesel in the model cases for US diesel blending. At present US biodiesel blending is on the order of 1-2 percent in most markets, though local exceptions requiring higher blends exist.

As in other cases, fuel oil production is assumed to meet international bunker fuel standards for low-sulphur and high-sulphur fuel oil.

Petroleum coke yields for cases with a delayed coking unit are provided on the basis of metric tons per barrel of crude run.

All US cases assume the use of purchased natural gas as an energy source after refinerygenerated fuel gas. This boosts the refinery's net product yield by around 2 percent (case-dependent)

[1] This may not remain the case as US blending requirements increase. Refiners may be expected to supply product at a specification capable of accommodating FAME blending, taking a 'penalty' in terms of product giveaway to enable the product to be blended to finished diesel specifications while incorporating biodiesel. This situation should be monitored and the model adjusted as required.

relative to other regions. This has a positive impact on the gross refining margin because natural gas prices in the US are far lower than fuel oil equivalence. Natural gas prices can be assumed to be basis Henry Hub. We have provided the yield on a basis of mmBTU per barrel of crude processed.

Table 6 defines the refined product yields developed from Petro-SIM covering two refinery configurations (FCC, FCC/Coker) and four different crude oil combinations representative of refinery intake on the US Gulf Coast. Natural gas import to the refinery is shown as a "negative yield" on a calorific (mmBTUper barrel), enabling it to be priced against Henry Hub (or equivalent) natural gas pricing.

Petroleum coke is priced on a mass basis (metric tonnes of petcoke per barrel of crude oil processed) to enable it to be priced as a solid product.

Table 6: US Gulf Coast Yields

US Gulf Coast Yields

	FCC	FCC	FCC	FCC+ Coking	FCC+ Coking	FCC+ Coking
Volume % Yield	50/50 HLS/LLS	Mars	ASCI[1]	50/50 HLS/LLS	50/50 Mars/Maya	ASCI[1]
LPG	4.25%	6.18%	5.59%	4.88%	6.69%	6.91%
Gasoline	50.24%	41.98%	41.25%	54.33%	46.27%	48.55%
Naphtha	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Kerosene	8.86%	7.53%	7.57%	10.14%	7.62%	8.27%
Diesel	25.85%	11.54%	10.32%	30.14%	29.22%	29.75%
HSFO	0.00%	32.81%	35.09%	0.00%	2.87%	2.60%
LSFO	12.97%	0.00%	0.00%	1.88%	0.00%	0.00%
Petroleum Coke, Mt/bl	0.00	0.00	0.00	0.00	0.02	0.01
Natural gas, mmBTU/l	-0.19	-0.13	-0.12	-0.17	-0.11	-0.12

(1) In the model, ASCI crude oil is a blend of one-third each Mars, Poseidon and Southern Green Canyon (SGC)

Table 7 defines the refined product yields from two different refinery configurations (FCC, FCC/Coker) and three different crude oil slates (WTI, WCS/Bakken and Bakken) for the US Midcontinent. As above, natural gas import to the refinery is shown as a "negative yield" on a calorific (mmBTUper barrel), enabling it to be priced against Henry Hub (or equivalent) natural gas pricing. Petroleum coke is priced on a mass basis (metric tonnes of petcoke per barrel of crude oil processed) to enable it to be priced as a solid product.

Table 7: US Midcontinent Yields

US Midcontinent Yields

	FCC	FCC	FCC	FCC+ Coking	FCC+ Coking	FCC+ Coking
Volume % Yield	WTI	30/70 WCS/Bakken	Bakken Blend	WTI	30/70 WCS/Bakken	Bakken Blend
LPG	5.02%	5.70%	6.64%	5.83%	6.41%	7.07%
Gasoline	52.65%	47.84%	54.71%	56.59%	52.11%	56.85%
Naphtha	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Kerosene	9.97%	7.44%	11.08%	11.17%	9.07%	11.08%
Diesel	21.25%	16.66%	22.15%	25.25%	27.73%	24.35%
HSFO	0.00%	22.72%	0.00%	0.00%	2.87%	2.60%
LSFO	11.88%	0.00%	6.56%	1.88%	0.00%	0.00%
Petroleum Coke, Mt/bl	0.00	0.00	0.00	0.00	0.02	0.01
Natural gas, mmBTU/l	-0.16	-0.14	-0.17	-0.15	-0.13	-0.16

Operating Costs

Refinery operating costs are highly dependent on a number of key parameters, including size and complexity of the refinery, utilisation rate, local wage expectations for refinery workers, employment and environmental regulations. Different countries/regions thus have a wide variation in operating expenditure (Opex), which has a direct impact on refinery net cash margins. Operating costs vary with refinery throughput, as some components of cost are fixed (such as labour, insurance) while others vary with throughput (such as catalyst and chemical consumption). Thus low throughputs on economic or maintenance bases can lead to higher per-barrel Opex. A further difficulty with refinery operating cost information is that it is not necessarily reported on a common basis, possibly including or excluding energy costs, financing costs, maintenance costs, depreciation, etc.

Operating cost indications are usually considered commercially sensitive information, though it is possible in some instances to glean this information from reports from public companies. This is more often the case in the US and to some extent in Europe. It is especially useful to seek this information from “pure play” independent refining companies, since their financial reporting tends to give more detailed information about their refining sector operations.

North America

Regular financial reporting from US independent refiners is one of the most transparent sources of refinery operating cost information. Valero Energy, North America’s largest independent refiner, reports its operating costs on a regional and quarterly basis. Their North Atlantic costs also take into account their Canadian and UK holdings. Valero reports its operating expenses separate from its depreciation and amortisation costs. An extract of these costs appears in Table 8. These were taken from Valero’s latest financial reporting.

Table 9: Valero Energy Operating Expenses

Valero Energy Operating Expenses, US$ per barrel

Excluding depreciation and amortisation

	2009	2010	2011	2012 YTD
US Gulf Coast	$3.73	$3.73	$3.67	$3.53
US West Coast	$4.88	$5.09	$5.32	$5.59
US Midcontinent	$3.66	$3.62	$4.14	$4.64
North Atlantic	$2.30	$3.01	$3.03	$3.37
Total Refining	**$3.72**	**$3.80**	**$3.84**	**$3.87**

Similarly, Marathon Petroleum reports its operating costs broken down by cost components, including “direct Opex”. The costs shown in Table 9 below were taken from Marathon’s latest quarterly report.

Table 9: Marathon Petroleum Operating Expenses

Marathon Petroleum Operating Expenses

1H12, US$ per barrel

Maintenance and Turnarounds	$0.96
Depreciation and Amortisation	$1.39
Other Direct Opex	$3.11
Total	**$5.46**

Numerous other US companies make public indications of their Opex. A selection of current information is included in Table 10.

Table 10: Other US Opex Indications

Other US Opex Indications

Western Refining	Opex, 2Q12	$3.91
Tesoro	Midcontinent, 2Q12	$3.95
Phillips 66	Atlantic Basin ex D&A ex maintenance, 2Q12	$4.00
Phillips 66	Midcontinent ex D&A ex maintenance, 2Q12	$2.20
Phillips 66	Gulf Coast ex D&A ex maintenance, 2Q12	$3.77

The numbers above give some sense of the range of variability in reporting of operating costs. Stripped clean of maintenance costs, which can distort regular long-run operating costs, the US appears to have a range between $2.20 - $4.00 per barrel for regular operating expense, with around $3.30 being perhaps representative. Heavy crude refineries may have higher operating costs as a result of having more process units, which require higher staffing levels and catalyst/chemicals costs.

Europe

Both Phillips 66 and Valero's Atlantic Basin refining costs include their assets in the UK (Pembroke, for Valero, and Humber for Phillips 66). This is possibly useful in assessing European operating costs, which appear to be in the $3.40 - $4.00 range for well run largescale Northwest European assets. European costs, too, tend to vary widely, and are generally higher than in other world markets. Best in class performance for European refiners is in the $3-4 range, while laggards can stretch as high as $7.50 per barrel. Reliable European data is harder to come by because there are fewer independent refiners in Europe, and some do not make their opex particularly clear.

Now-bankrupt Petroplus was a reliable source of transparent information on its refinery operations. In their last public presentation prior to closing, they presented the following operating costs for their European assets for 3Q11:

Table 11: Petroplus Operating Expenses, US$/bbl, 3rd Quarter 2011

Petroplus Operating Expenses, US$/bbl, 3rd Quarter 2011

Coryton	$3.80
Antw erp	$3.31
Petit Couronne	$4.24
Ingolstadt	$3.29
Cressier	$4.13

Finnish refiner Neste Oil details its operating cost breakdown in its regular financial reports. Their most recent report, published in early August, shows an aggregated cost for their two refinery sites (Table 12 below). Costs here vary between $3.90 and $5.00 per barrel, with a 2011 average cost of $4.30 per barrel.

Table 12: Neste Oil Operating Expenses, US$/bbl, 2011-2012 YTD

Refinery Production Cost, Porvoo & Naantali

		1Q11	2Q11	3Q11	4Q11	1Q12	2Q12	2011
Refined Products	Million Barrels	27.4	26.0	28.5	28.8	28.1	24.2	110.8
Exchange Rate	EUR/USD	1.4	1.4	1.4	1.4	1.3	1.3	1.4
Utlities Costs	EUR Million	59.6	57.2	59.1	59.4	64.4	66.4	253.3
	$/bbl	3.0	3.2	2.9	2.8	3.0	3.5	3.0
Fixed Costs	EUR Million	42.0	60.5	43.8	60.9	49.8	58.1	207.3
	$/bbl	2.1	3.4	2.2	2.9	2.3	3.1	2.6
External Sales	EUR Million	-22.2	-21.7	-24.5	-29.8	-27.8	-27.2	-98.2
	$/bbl	-1.1	-1.2	-1.2	-1.4	-1.3	-1.4	-1.2
Total	EUR Million	79.4	95.9	48.5	90.5	86.4	97.3	344.3
	$/bbl	4.0	5.3	3.9	4.2	4.1	5.1	4.3

With the dollar relatively strong against the euro in recent months, dollar-denominated opex for European refineries is likely to be slightly higher than for US refiners. The above indications would suggest a reasonable opex for a European refinery to be on the order of $4.00 per barrel.

Asia-Pacific

Operating costs in Asia vary widely with the scale and age of the refinery and the degree of development of the economy. Because Asia's main refiners are often state-owned, or belong to major energy companies, relatively few Asian companies give a detailed public account of their operating costs. The largest single operating cost in Asia is labour, which varies from $1-3 per barrel depending on the location and scale. Total operating costs tend to range from $3-7 per barrel inclusive of energy ($2.50 - $5.50 excluding energy). Due to its relatively large-scale and well integrated refineries, Singapore refining is believed to operate at the low end of this range.

Thailand's Thai Oil is one company that discloses its operating costs on a public basis. Their latest shareholder presentation suggests operating costs of around $1 - $1.20 per barrel, plus an interest expense of $0.40-0.50. This number is impressively low.

Table 13: Thai Oil Operating Cost, 2008-2012

Thai Oil Operating Cost, 2008-2012, US$/bbl

	2008	2009	2010	2011	1Q12	2Q2012	1H12
Operating Cost	0.9	0.9	1.0	1.1	0.9	1.2	1.1
Interest Expense	0.4	0.5	0.5	0.4	0.4	0.5	0.4
	1.4	**1.4**	**1.5**	**1.5**	**1.3**	**1.7**	**1.5**

Source: http://top.listedcompany.com/misc/PRESN/20120828-TOP-oppDay2Q2012.pdf

Essar Energy indicated in a press release on the completion of a major expansion in June 2012 that their opex costs of $3/barrel were "amongst the lowest globally." We would suggest an indicative cost of $3 per barrel for Singapore margins at this time (September 2012).

Operating Cost Summary

We assume typical operating costs for the margin cases as follows:

Indicative Refininng Operating Costs (Opex), US$/bbl

Excluding energy, depreciation and amortisation

USGC and US Midcontinent	$3.30
NW Europe and Mediterranean	$4.00
Singapore	$3.00

These cases would exclude energy costs (which are figured into the IEA/KBC refining margins), and depreciation and amortisation, which will vary widely with refinery configuration, age and local accounting / tax requirements.

APPENDIX 1: Product Quality Non-Compliance

Because these models are limited in terms of crude oil slate, make no allowance for feedstock or blendstock imports or intermediate product exports, and only produce standard grades of finished products that can be readily priced, some quality specifications have been relaxed to allow the models to solve. The notes below indicate cases where product specifications have been relaxed, along with comment on how refineries would conventionally overcome these quality constraints.

Gasoline aromatics content:

Some of the gasoline blends show high aromatics content. Hydroskimming cases are blending gasoline largely from highly aromatic reformate with some butane and isomerate, yielding highly aromatic gasoline (40-52 percent vol). In total, 6 of the 23 cases yield gasoline with aromatics above regional specifications. In reality, aromatics content would probably be kept on-spec by exporting reformate and importing high octane low aromatics blendstock such as alkylate, or by processing reformate through a BTX fractionation section to feed an aromatics complex. This could be modelled in Petro-SIM but would add complications in pricing BTX products in the refinery models.

Gasoline Benzene content:

The light/heavy naphtha cutpoint is set sufficiently high (78C) to avoid exceeding 1 percent benzene in gasoline for all cases except one (Urals hydroskimming, which has 1.4 percent benzene in gasoline). However, KBC expects that in reality benzene will drop under the 1 percent threshold for this case as well once the aromatics level has been reduced through fractionation.

Diesel specific gravity

Three cases show high diesel specific gravity and one case has a density below the minimum specification. Hydroskimming refineries processing 100 percent Tapis crude would yield diesel that has a specific gravity marginally below 0.820, while FCC/VB refineries may produce diesel with a specific gravity higher than 0.842, which is expected to be the limit of a BOB diesel to which 5 percent FAME has to be blended afterwards. Urals produces a diesel with a specific gravity of almost 0.850.Options to keep export diesel below the maximum specification are crude mix selection, increasing blending of kerosene into diesel and using hydrotreating catalyst that performs a higher level of diesel aromatics saturation, thus reducing diesel blender feedstock SG. These are not modelled in these simplified cases.

Diesel cetane:

Blending cetane is on specification with the exception of the Urals FCC/VB case, for which modelled diesel export cetane is around 49 (vs 51 minimum spec). Again, crude selection or deeper hydrogenation would be expected to help.

Low sulphur fuel oil sulphur content and density:

12 cases process low sulphur crude oil, four of which have a sulphur level higher than 1 percent. Brent crude oil in the FCC/VB case yields fuel containing almost 1.4 percent sulphur. The FCC/Coker refinery on HLS/LLS produces only a small amount of fuel oil which, however, is slightly off spec for low sulphur fuel oil at 1.07 percent. Two of the FCC/Coker low sulphur fuel oils have a high density (0.998). The amount of fuel produced is very limited (<3 percent wt on crude oil).

Sulphur and specific gravity constraints would be overcome by crude oil selection. Some refineries also have VGO hydrotreaters, which will produce lower sulphur and lower density FCC bottoms products. Further it should be noted that fuel made in coking refineries is generally very low viscosity FCC bottoms product, which may be sold as a premium grade product or as a fuel oil cutterstock, rather than bunker fuel.

High sulphur fuel oil sulphur content and density:

11 cases yield high sulphur fuel oil, of which two are FCC/Coker cases that generate fuel oil containing 4-5 percent sulphur. Five of the high sulphur fuel cases have a specific gravity greater than 0.991. Three are FCC/Coker cases generating small amounts of fuel with a very high density (around 1.02). As above, coking refinery fuel oil is very low viscosity FCC bottoms product, which made be sold as a premium grade or as a fuel oil cutterstock, rather than bunker fuel. In addition, the Urals FCC/VB case fuel oil specific gravity is 0.995. The Singapore FCC/HCU/VB case on Dubai crude oil also produces 0.995 specific gravity fuel oil that also is very high in Conradson carbon (21 percent).