CONCAWE
Marine Fuels study

Symposium, 21st March 2017

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ENVIRONMENTAL SCIENCE FOR THE EUROPEAN REFINING INDUSTRY

Supply of 0.5% Sulphur Marine Fuel and impact on refining industry in Europe 28+3 area

On-going study, preliminary results

Coordinated by CONCAWE Refinery Technology Support Group (RTSG) under the guidance of Refinery Management Group (RMG)

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CONCAWE LP Model

2014 Calibration

2020 Main Assumptions

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Highly sophisticated model run and maintained by Expert consultant

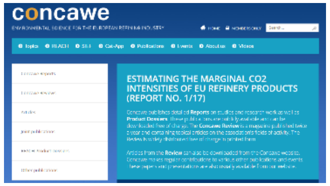
- Linear Programming (LP) is a **mathematical tool** that helps the decision-making process
- LP consists in an optimization driven by an **objective function** (profit maximization or costs minimization), where variables involved are constrained by means of linear equations
- CONCAWE LP Model main features
  - Approximately 90 000 columns (variables) and 20 000 rows (equations)
  - Divided into **9 regions** (1 period of 1 year) representing EU 28+3
  - More than **40 process unit** types
  - 6 reference crude, various intermediate product imports, natural gas
  - More than **35 finished products** (including exports and main petrochemical intermediates)
  - **Mass, Carbon, Hydrogen and Sulfur balances** ensured across the whole model (allows accurate calculations of CO_2 emissions)
  - Capacity investment structure

Mass Balanced model with flexible structure

- Model strengths
  - **Comprehensive** process modeling
    - *Generated from rigorous simulators*
  - **Entirely linear**
    - *Reduces risk of local optima*
    - *Improves the optimization speed*
    - *Sufficient accuracy ensured with an extensive "modes" modeling*
      - e.g. Hydrocracker has 82 modes of operation depending on the severity / feedstock
      - More than 1250 individual streams
  - **S, C, H**, (N, Ni, V) **balanced**
    - *All process units, all streams*
    - *Ensures any impact on the refining system to be correctly reflected*
    - *RF burning CO_2 emissions from C content*
      - More than 300 streams in the RF system

Adapted to meet requirements for each study

- Flexibility – modular structure
  - Regions can be (de)activated
  - Investment module can be (de)activated
  - Demand can be set in energy basis rather than standard volume/mass
- Example of **adaptability to a specific study** (<u>published Jan. 2017</u>)
  - **New methodology** to generate **finished product CO_2 intensities**
    - *<u>Marginal CO_2 intensities</u>, satisfying additivity criterion (describe the total CO_2 emissions of the refining system)*
  - EU27 (2010 reference year) as 1 region
  - Special LP program to extract CO2 marginal contents
  - **LP report customization** to implement the full allocation methodology
  - Full report available on CONCAWE website



<u>Estimating the marginal CO2 intensities of EU refinery products - report no 1/17</u>

Core competencies in calibration and exhaustive EU refinery capacity database

- General methodology for studies based on LP model
- **Calibration** on a reference year
  - To ensure the refinery modelling can achieve the demand on specs from the corresponding feedstock
  - To ensure CO_2 modelling consistency with actual refining CO_2 emissions
  - To minimize the overoptimization associated with aggregated models
- **Supply / demand forecast** mainly based on Wood Mackenzie data
- **Capacities** and projects/closures based on internal CONCAWE data
- Scenarios defined for the study mainly **driven by the demand**
- Investment structure available to solve potential infeasibilities
- Detailed results available per region, aggregated for reporting

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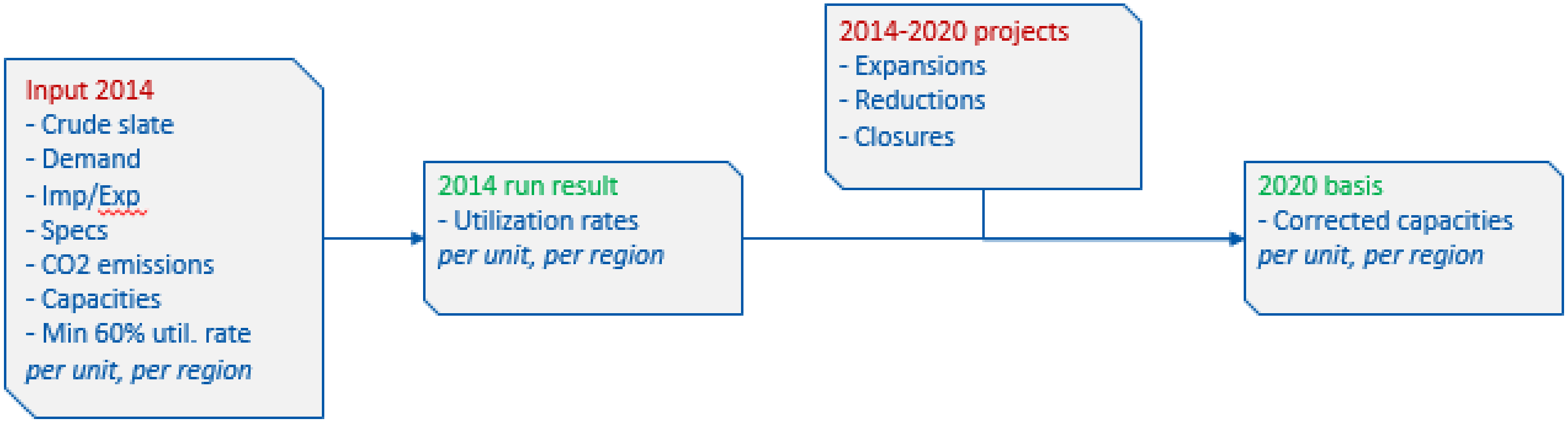
2014 Calibration: minimizing over optimization

- Focus on **capacities calibration**
  - **Aggregated capacities** of most of the process units within a region lead to **overoptimization**
  - **Limiting available capacity** is a way of minimizing overoptimization



Example: Central Europe Delayed Coker

2014 capacity
1.5 MTPY

2014 run result
0.9 MTPY (60%)

2014-2020 expansions
+ 1.2 MTPY

2020 basis
max 2.1 MTPY
(85% of 2020 cap)

Capacities adjusted per region and Fuel Consumption match real CO2 emission

- Capacity limitation results – main units
  - Results presented aggregated, but different calibrated values different for each region
  - Capacities calculated on 340 days operation (93%)

2020 Process units capacities	Calibrated / Nominal
Crude Distillation	90%
Vacuum Distillation	88%
Visbreaker	72%
Delayed Coker	75%
(R)FCC	86%
VGO HCK	100%

2020 Process units capacities	Calibrated / Nominal
VGO HDT	63%
Resid HDS	100%
Resid HCK	84%
Kero/Diesel HDS	63%
SRU	52%
Steam Reformer	76%

- **CO_2 calibration**
  - Process units fuel consumption factors adjusted to reach Eurostat refining fuel burning CO_2 emissions

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2020 forecast from different reliable sources (+ cross checking data)

- Crude slate
  - Based on WM forecast (adjusted with Eurostat data)
  - **Fixed ratios** for EU28+3 globally, distribution over the 9 regions driven by optimization
- Imports / exports – **floating** within **limited ranges**

IMPORTS	Forecast
Ethane	CEFIC 2010 estimation
Natural Gas, M100 (Russian FO)	Eurostat 2010-2014 average
ETBE, Ethanol	Fleet & Fuels CONCAWE internal model
Naphtha, Kerosene	WM
Gasoil (as Heating Oil)	WM 2015

EXPORTS	Forecast
Gasoline US / Other, HSFO	WM

Gasoil import and Heavy fuels export assumptions are critical for modelling results

- Imports / exports – critical assumptions
  - **Gasoil imports**
    - *Gasoil imports help satisfying 0.5%S MF demand*
    - *Conservative approach – imports similar to current situation*

IMPORTS, MTPY	2014 (Calibration)	2020
Gasoil (as Heating Oil)	16.9 (Eurostat)	13.2 (WM 2015)

  - **HSFO exports** (High Sulfur Heavy Fuel Oil)
    - *Conservative approach – 2020 forecast lower than current situation*

EXPORTS	2014 (Calibration)	2020
HSFO (3.5%S)	14.3 (Eurostat)	10.0 (WM 2020)

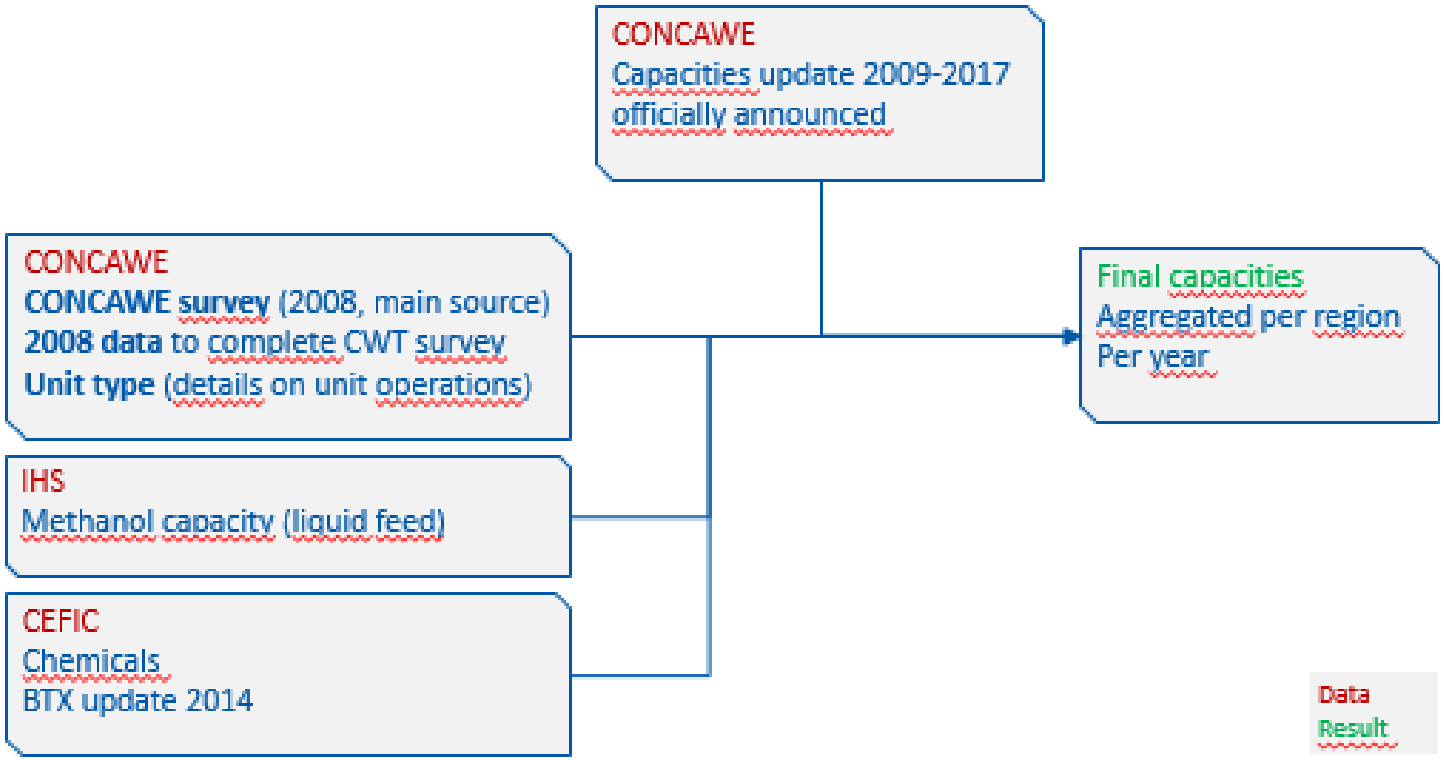
Products demand: in depth analysis and database build from reliable sources

- Product demand – **fixed**
  - **Main driver** of the optimization

	Forecast
Methanol (liq. feed)	IHS 2014
Ethylene, Propylene, Butadiene Benzene, Toluene, Xylenes	CEFIC 2014 O&G Journal Ethylene survey 2014 CONCAWE capacity database 2014
LPG	WM + correction Chemical feed
Gasoline R95 / R98	WM EU Fuel quality monitoring (95 / 98 - 2015) Fleet & Fuels (Ethanol as ETBE / Ethanol, fossil fuel norm.)
Jet, Diesel Marine Fuel LS HFO, RMF Seca, RMF General Lubes, Bitumen	WM
Road Diesel	WM Fleet & Fuels (fossil fuel norm.)
Heating Oil, Rail Diesel Non-Road Diesel Inland waterways Diesel	WM IEA (grades split 2010)
Wax	WM IEA (ratio / Lubes 2010)

Core knowledge: process unit capacities for each individual refineries (confidential database)

- Process unit capacities
  - **Accurate** data from **CONCAWE members survey**
  - Limited by Calibration step



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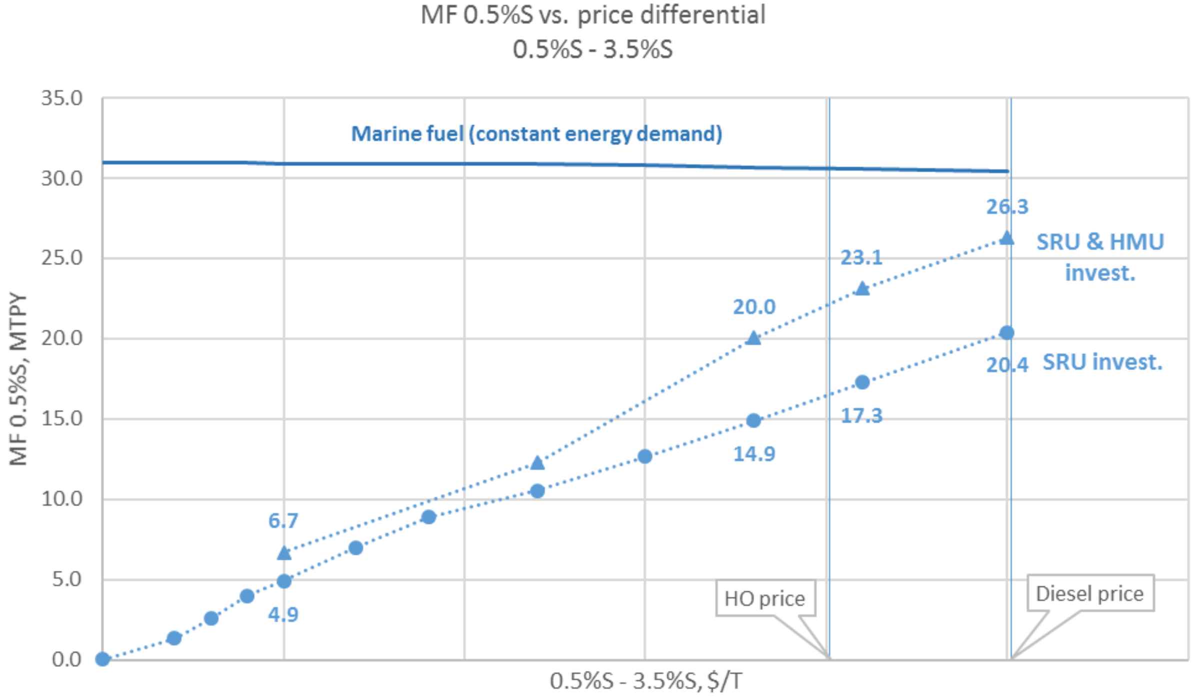
Full switch to 0.5% leads to model infeasible solution

- 2020 demand, **100% MF @ 0.5%S**, no additional investment
  - No investment except what has been publicly announced
  - About 30 MTPY of RMF to switch from ~3.0%S to 0.5%S
  - This represents around 0.75 MTPY of additional S to be removed, ~13% of the S entering the refining system
  - Full switch infeasible as per our assumptions
    - ***Desulfurization capacity, H_2 availability and S removal on constraint***

- If full switch infeasible, how much can be switched?

LS marine fuel production from EU refineries up to 85% of the EU demand

- How much can be switched? 0.5%S – 3.5%S price differential study



- 0.5%S MF at MD price ⇒ from **60% to 85% of the full switch produced**
- ⇒ **SRU** required capacity increase till +22%
- ⇒ **HMU** required capacity increase till +35%
- ⇒ **CO_2** emissions increase ~4%

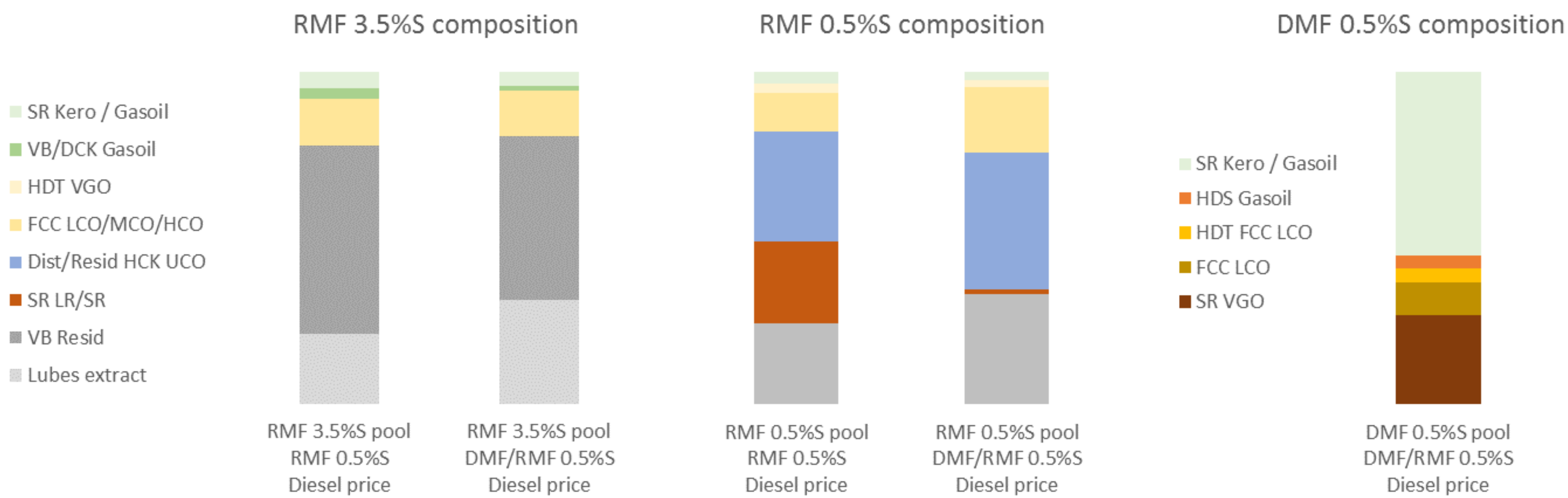
Increasing demand for H2 and for S recovery units

- 0.5%S – 3.5%S price differential study
- Main mechanism **to produce 0.5%S**
  - Increase of HDS/HCK units throughput
    - *Distillate and Resid Hydrocrackers*
    - *Resid HDS*
  - To close the balance, slight reduction of VDU / VB throughput
  - **More hydrogen** required, **more sulfur** to be removed
    - *Investments in H_2 plant and SRU*
  - Some **units at full capacity**, i.e. high throughput to be maintained
    - *Delayed Coker*
    - *Kero/Distillate HDS*
    - *Resid HDS*
    - *Hydrocrackers*
    - *SRU/H_2 Plant*

LS Marine fuels: split between Residual and Distillates qualities

- Marine fuels pool – "max" 0.5%S switch
  - **2 sensitivities**
    - *Switch as RMF only*
    - *Switch as DMF / RMF (40/60)*

Sensitivity case	RMF 0.5%S Diesel price	D/RMF 0.5%S Diesel price
TOTAL MF, MTPY	30.2	30.0
RMF 3.5%S, MTPY	3.9	3.9
RMF 0.5%S, MTPY	26.3	15.6
DMF 0.5%S, MTPY		10.5
RMF avg %S	0.8	0.8



Marine fuels and HS heavy fuel

- Marine fuels pool – "max" 0.5%S switch
  - **2 sensitivities**
    - *Switch as RMF only*
    - *Switch as DMF / RMF (40/60)*

RMF 0.5%S	RMF 0.5%S Diesel price	D/RMF 0.5%S Diesel price
SPG	0.957	0.970
Sulfur, wt%	0.4000	0.4000
Conradson carbon, wt%	8.5	10.9
Visc. @ 100°C, cSt	20	22
Kero, wt%	3.5	2.5
Pour point, °C	30	30

RMF 3.5%S	RMF 0.5%S Diesel price	D/RMF 0.5%S Diesel price
SPG	0.988	0.987
Sulfur, wt%	3.2000	3.2000
Conradson carbon, wt%	18.0	15.8
Visc. @ 100°C, cSt	35	35
Kero, wt%	5.0	4.1
Pour point, °C	14	18

DMF 0.5%S	D/RMF 0.5%S Diesel price
SPG	0.869
Sulfur, wt%	0.4000
Cetane index	43.2
Visc. @ 40°C, cSt	5.9
Cloud point, °C	0
Pour point, °C	0
Kero, wt%	10.0
LCO, wt%	10.0

Marine fuel demand may be satisfied following increased Distillate import or crude slate change

- Check cases
- Case with **Heating oil imports increase**
  - HO imports increase by 7 MTPY
  - ~25% of the switch, ~50% of HO imports original assumption
  - Required SRU capacity increase by ~15%
    - *i.e. ~2/3 of the additional S to be removed are handled by the SRU investments, ~1/3 by the existing capacity*
  - This case is similar to a change in crude slate that would give a higher middle-distillate yield
- Case with **crude slate change**
  - A crude slate ratios change within a range of +/-10% allows full compliance
  - As expected, the crude slate obtained has a higher API (34.4 vs. 34.0) and a lower S content (0.92 vs. 0.98)
  - Required SRU capacity increase by ~10%

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Preliminary Conclusions _ LP model simulation

- On a whole EU28+3 refining system, **full 0.5%S MF compliance by 2020 is not straightforward**
  - SRU and HMU investments would probably be required
  - Main conversion / HDT units to be maintained at a high throughput
  - A high differential price vs. HSFO would be required to make this change-over profitable for refining industry (according to model)
  - As mentioned in other papers (e.g. EnSys/Navigistics, VPS at Platts 7th MD conf.), **new fuel formulation should be taken cautiously**
    - *Compatibility, lubricity, flash point, cold flow properties, sedimentation…*
  - **Scrubbers** are expected to concern **14% of Marine fuels** by 2020 (EnSys)
    - *If scrubber share increases, refiners may be reluctant to invest if they can produce HSFO again in the near future*

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