Crude Oil processing and Base Oil production

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MOL Downstream

Technology Process Development






MŰEGYETEM 1782

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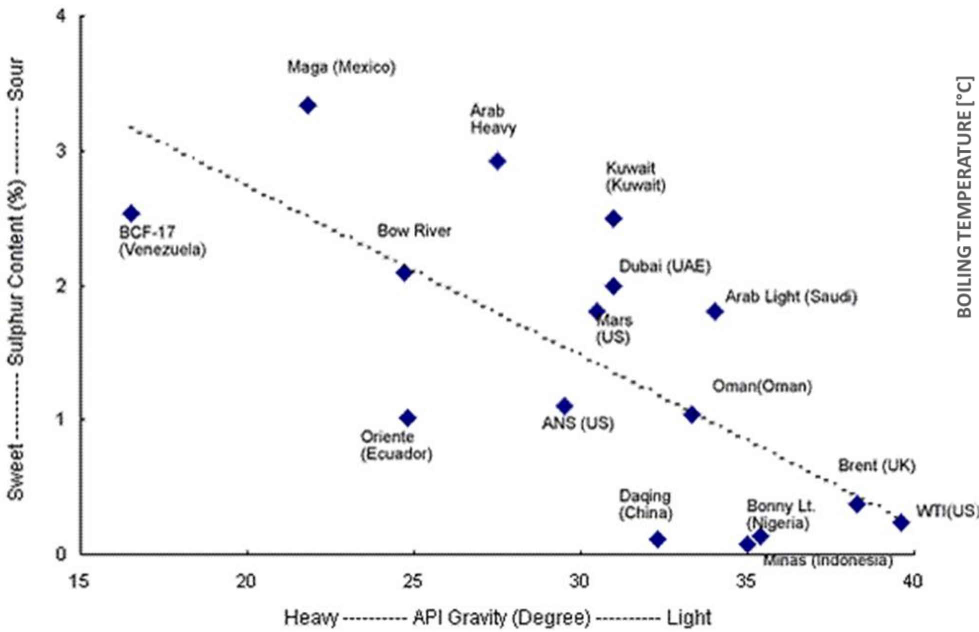
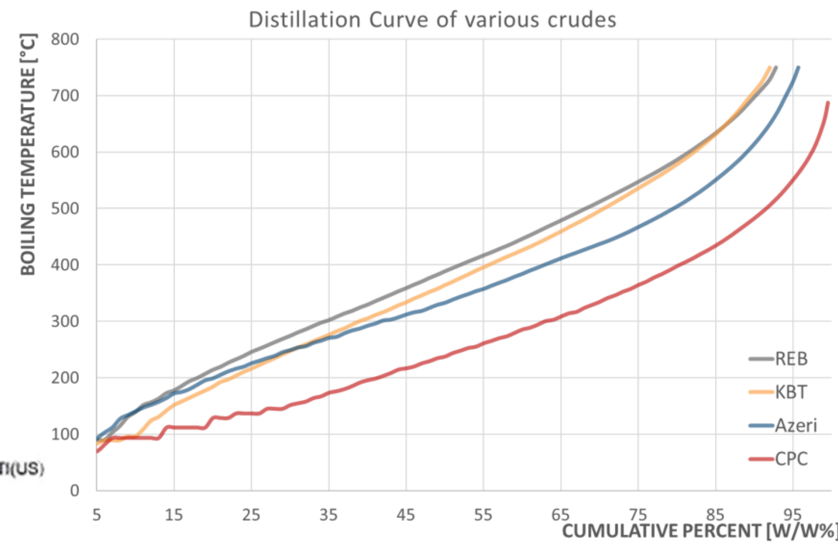
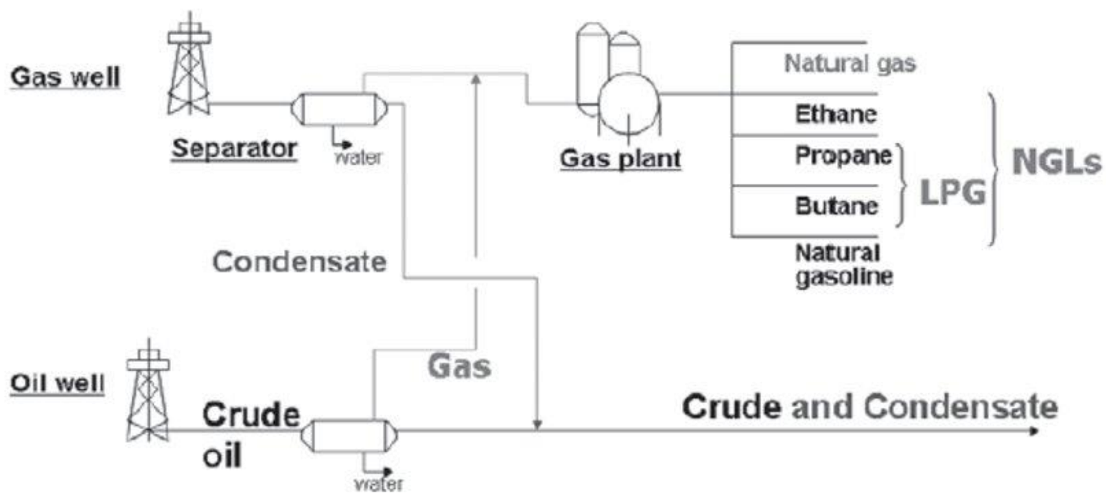
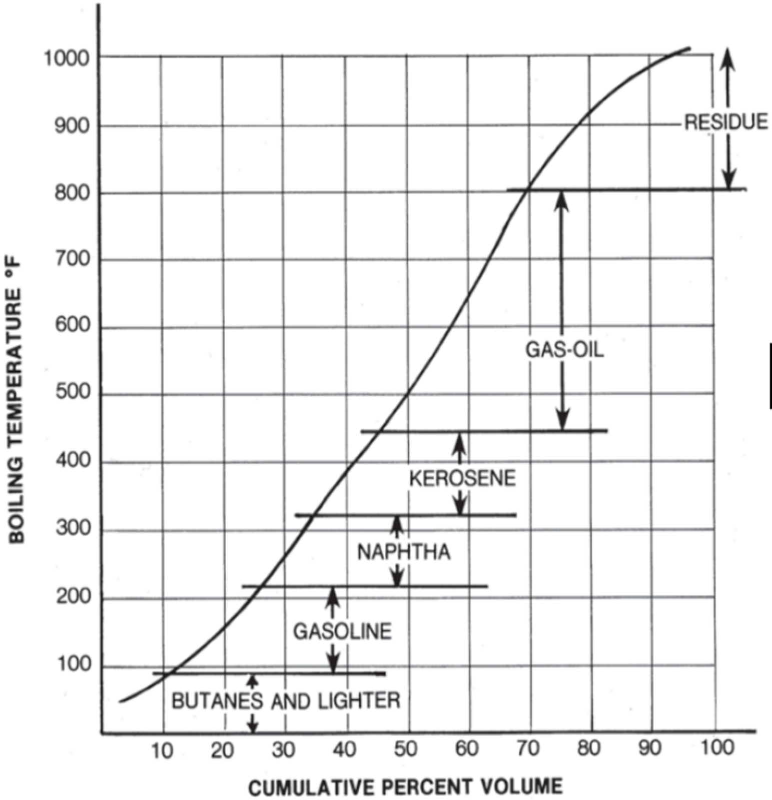
Crude Oil


Maga (Mexico)
Arab Heavy
Kuwait (Kuwait)
BCF-17 (Venezuela)
Bow River
Dubai (UAE)
Arab Light (Saudi)
Mars (US)
Oman(Oman)
Oriente (Ecuador)
ANS (US)
Brent (UK)
Daqing (China)
Bonny Lt. (Nigeria)
WTI(US)
Minas (Indonesia)
Sweet --------- Sulphur Content (%) --------- Sour
Heavy --------- API Gravity (Degree) --------- Light
0
1
2
3
4
15
20
25
30
35
40


Distillation Curve of various crudes
BOILING TEMPERATURE [°C]
CUMULATIVE PERCENT [W/W%]
0
100
200
300
400
500
600
700
800
5
15
25
35
45
55
65
75
85
95
REB
KBT
Azeri
CPC

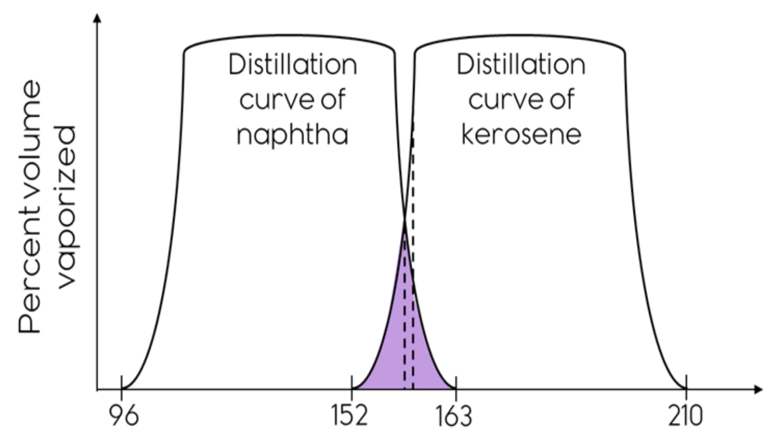

Gas well
Separator
water
Gas plant
Natural gas
Ethane
Propane
Butane
Natural gasoline
LPG
NGLs
Condensate
Oil well
Crude oil
Gas
water
Crude and Condensate

Crude Oil fractions



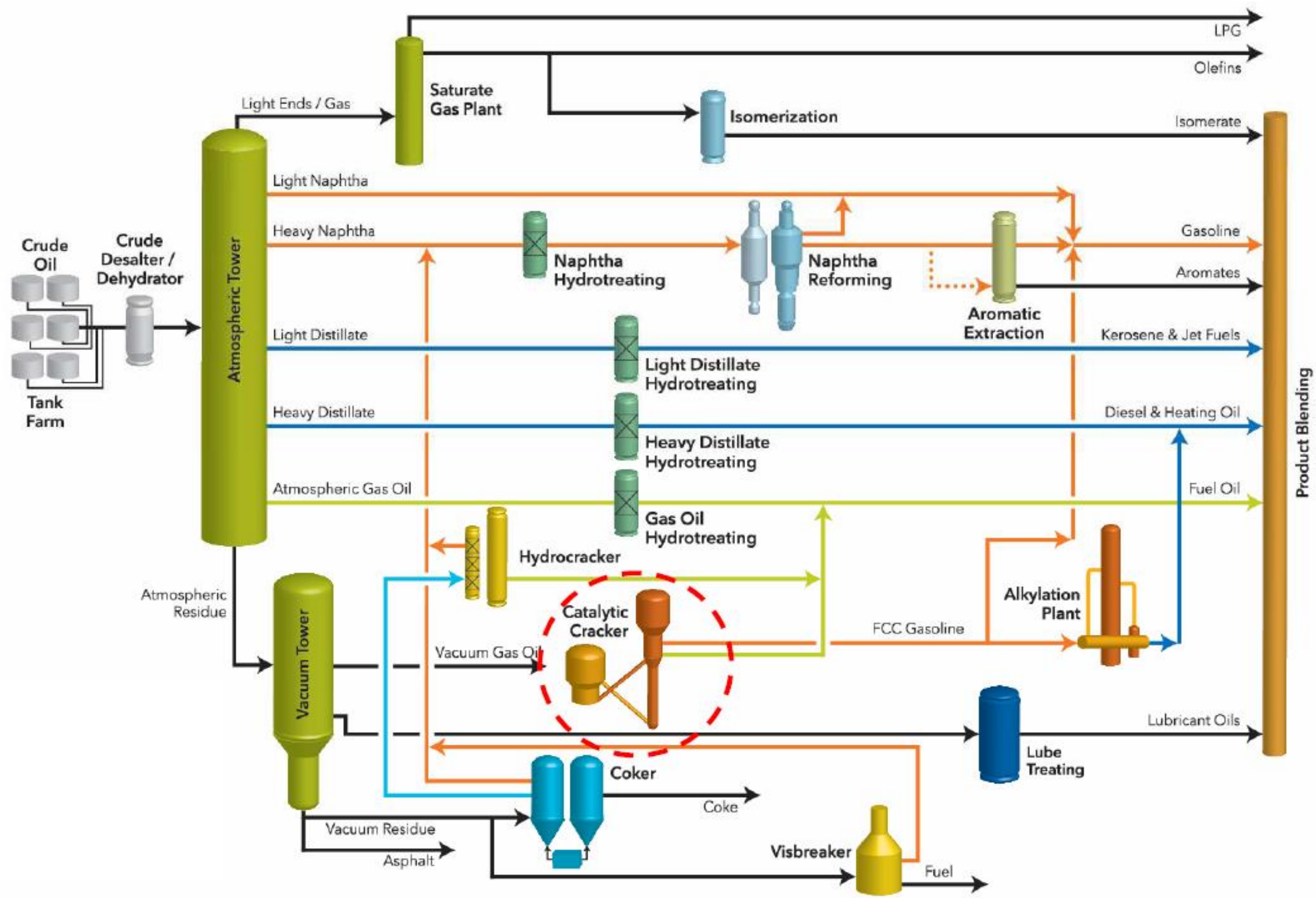
SI

Temperature [°C]	Fractions/Cuts
< 32	Butanes and lighter
32-104	Gasoline
104-157	Naphtha
157-232	Kerosene
232-427	Gas oil
>427	Residue

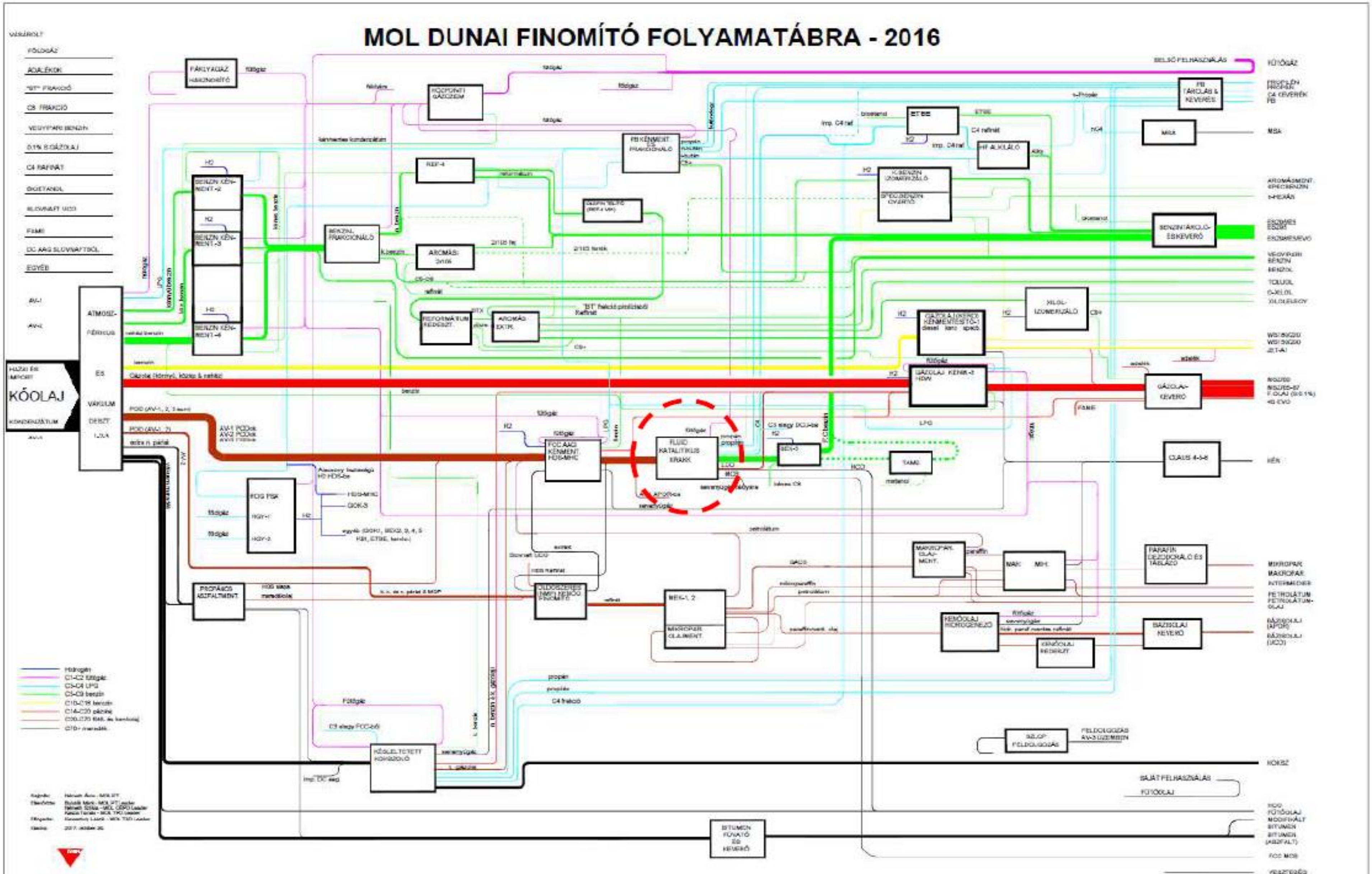


Fractions – all the compounds that boiling between two given temperatures

Refinery Overview



Danube Refinery

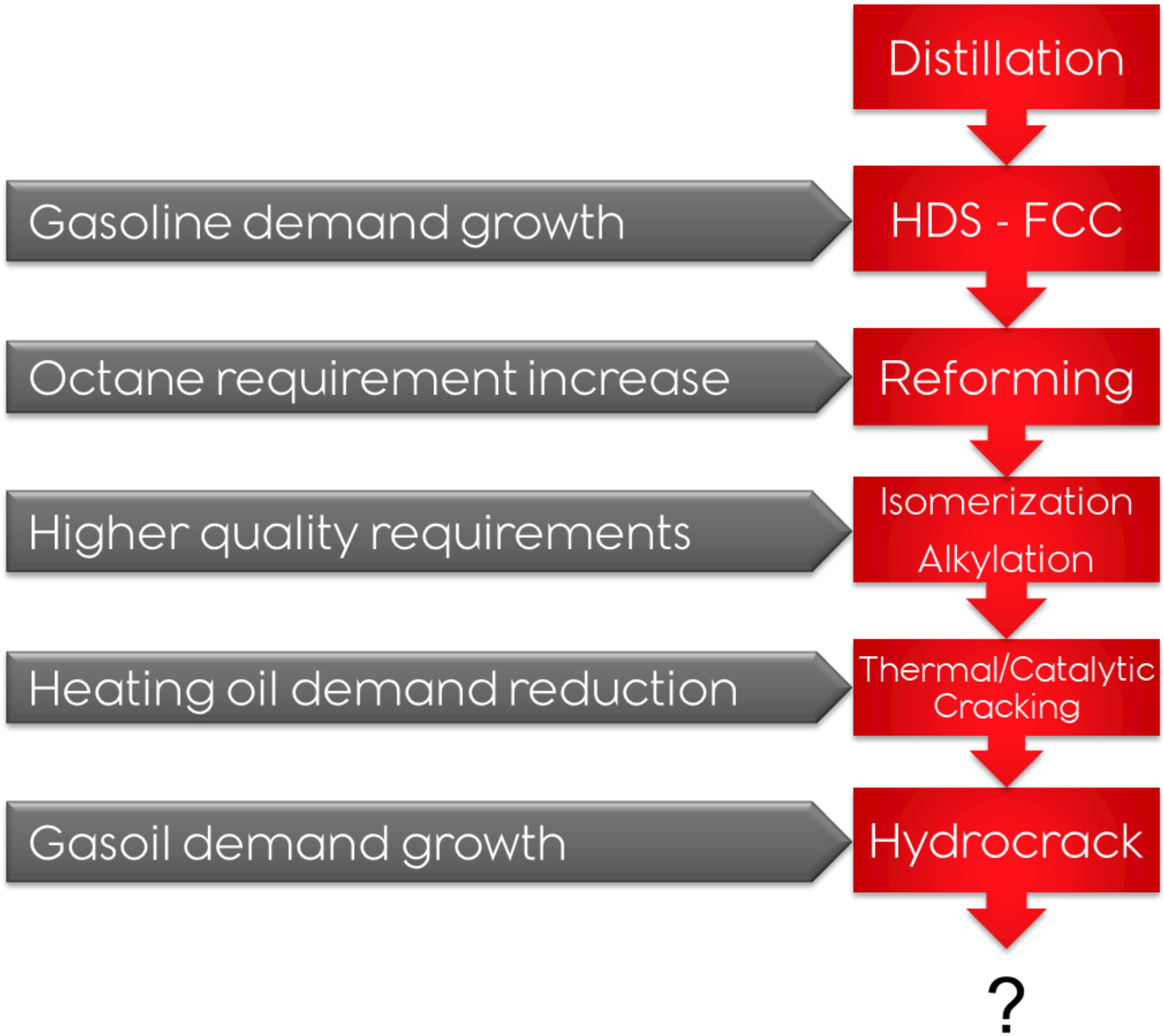


Danube Refinery – Key Figures

Danube Refinery

Key figures	
Area:	800 hectares
Distillation capacity:	8.1 Mt/year
Processed crude:	7 Mt/year
Number of plants:	49
Nelson complexity index :	10.6
Number of employees:	cca. 1300

Major Conversion Technologies



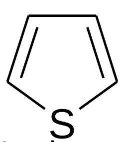
Sulphur

Sulphur containing compounds

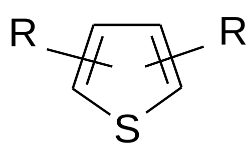
- **H_2S** (hydrogen-sulfide);
- **Mercaptanes**: R-SH (R: <3-30);
- **Mono- and disulfides**: R-S-R’ (R, R’: alkyl groups);

CH_3-S-CH_3	C_2H_5-S-CH_3
dimethyl-sulfide	ethyl-methyl-sulfide
CH_3-S-S-CH_3	C_2H_5-S-S-C_2H_5
dimethyl-disulfide	diethyl-disulfide

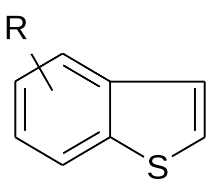
- **Thiophenes**



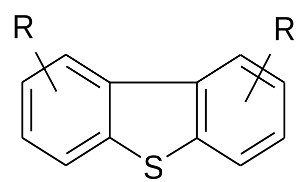
thiophene



alkyl-thiophenes



benzothiophenes



dibenzothiophenes

R: alkyl groups

Product requirements - Gasoline

STANDARD REQUIREMENTS OF GASOLINES

Properties	European Union			
	EN 228 „Euro 2” (1993)	EN 228 „Euro 3” (2000)	EN 228 „Euro 4” (2005)	EN 228 „Euro 5” (2009)
sulphur content, mg/kg, max	500	150	50 / 10 [1]	10
aromatic content, v/v%, max	-	42	35	35
olefin content, v/v%, max	-	18	18	18
benzene content, v/v%, max	5.0	1.0	1.0	1.0
oxygen content, %, max	-	2.7	2.7	2.7
Reid vapour pressure, kPa	35-100	60/70 [2]	60/70 [2]	45-105 [2]

[1] maximum sulphur content is 50 mg/kg, but 10 mg/kg sulphur content has to be regionally available
[2] summer / winter quality
- no regulation

Product requirements - Diesel

STANDARD REQUIREMENTS OF DIESEL FUELS

Properties	European Union			
	EN 590:1999	EN 590:2000	EN 590:2005	EN 590:2009 +A1:2010
cetane number, min	48	51	51	51
density at 15°C, kg/m^3	820-860	820–845	820–845	820–845
total aromatic content, %, max	-	-	-	-
polyaromatic content, %, max	-	11	11	8
distillation recovery (95%) temperature, °C	370	360	360	360
sulphur content, mg/kg, max	500	350	50.0 / 10.0 [1]	10.0

[1] maximum sulphur content is 50 mg/kg, but 10 mg/kg sulphur content has to be regionally available

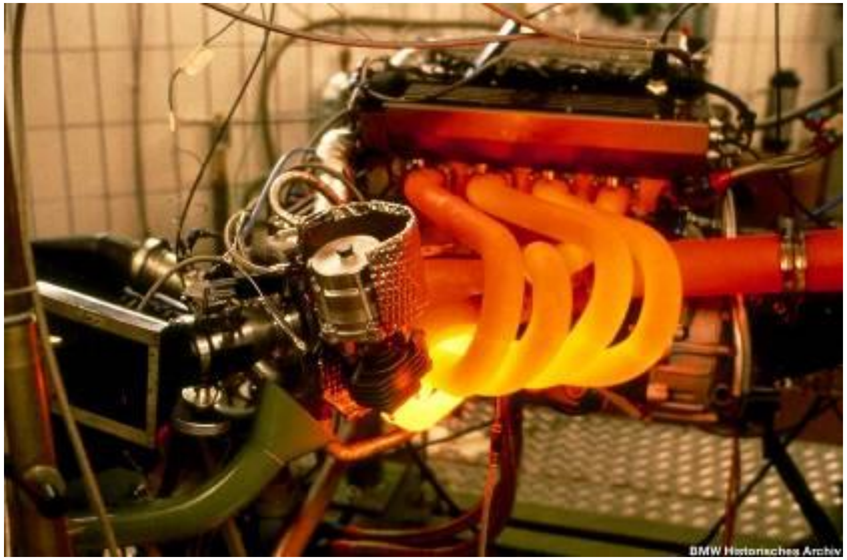
-no limitation

Lubricant Story

- 1400 BC, beef and mutton fat (tallow) being applied to lubricate chariot axles. Very little changed over the next 3000 years except, that the oils sometimes came from more exotic animals such as whales.
- In 1852 petroleum-based oils first became available. They were not widely accepted at first because they did not perform as well as many of the animal-based products. Raw crude did not make very good lubricant.
- But as the demand for automobiles grew, so did the demand for better lubricants.
- Lubricant manufacturers learned soon which crudes made the best lubricants.
- By 1923 the Society of Automotive Engineers classified engine oils by viscosity: light, medium, and heavy. Engine oils contained no additives and had to be replaced every 800-1000 miles.
- In the 1920s more lubrication manufacturers started “processing” their base oils to improve their performance.
- HC technologies were commercialized for lube production in late ’50 and dewaxing was in ‚’70

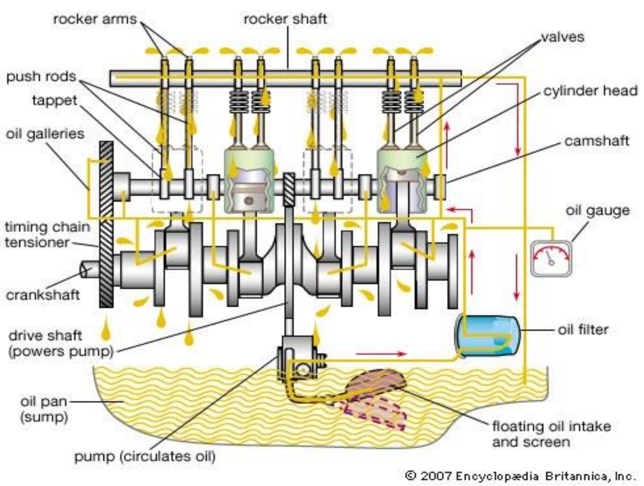
Lubes

- Automotive: engine oils, automatic transmission fluids (ATF’s), gear-oils
- Industrial: machine oils, greases, electrical insulating oils, gas turbine oils
- Pharmacy/cosmetics: white oils, paraffinicum liqudicum
- Provisioning: food grade oils, lining of food containers, cover of food, etc.



Lube Refinery

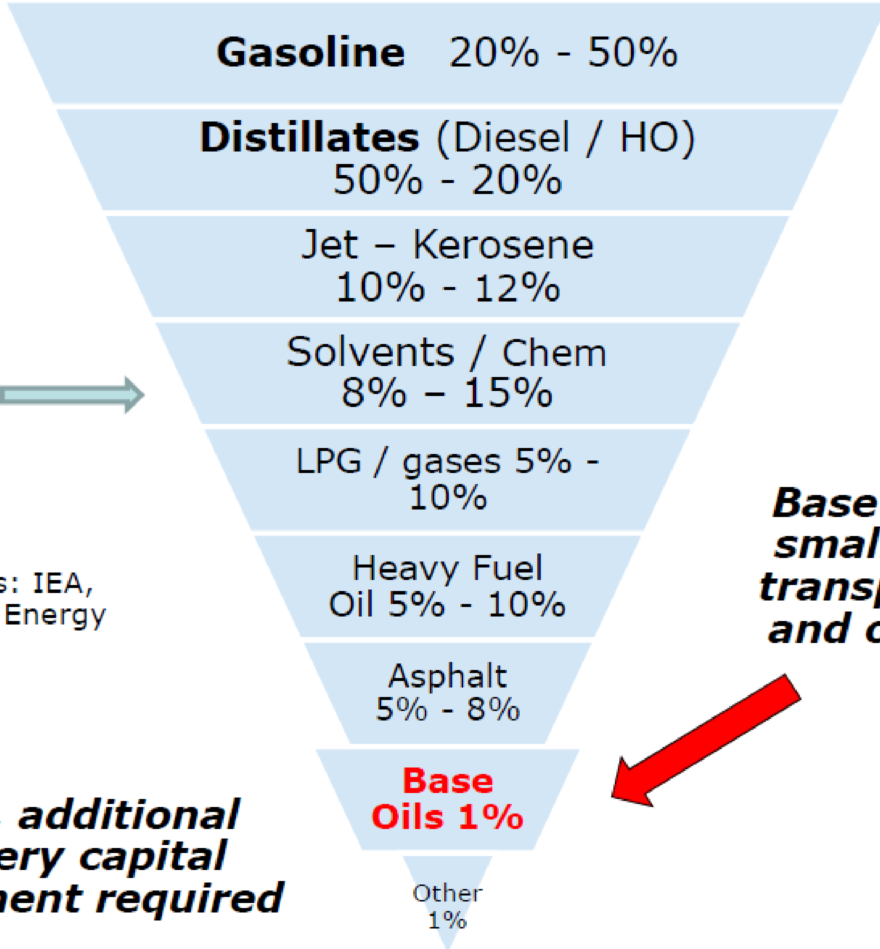
- Why beneficial to produce base stocks and waxes?
- What are the products and which properties are important?
- Which types of processes?
- Global market and changes

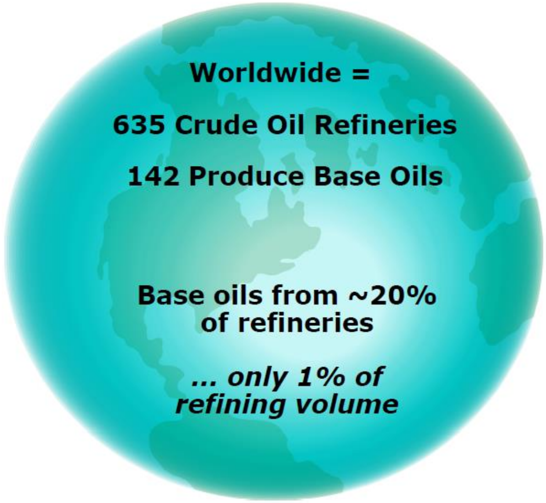


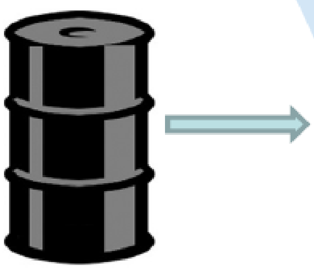
Refinery Outputs

ICIS

Refinery output = global demand







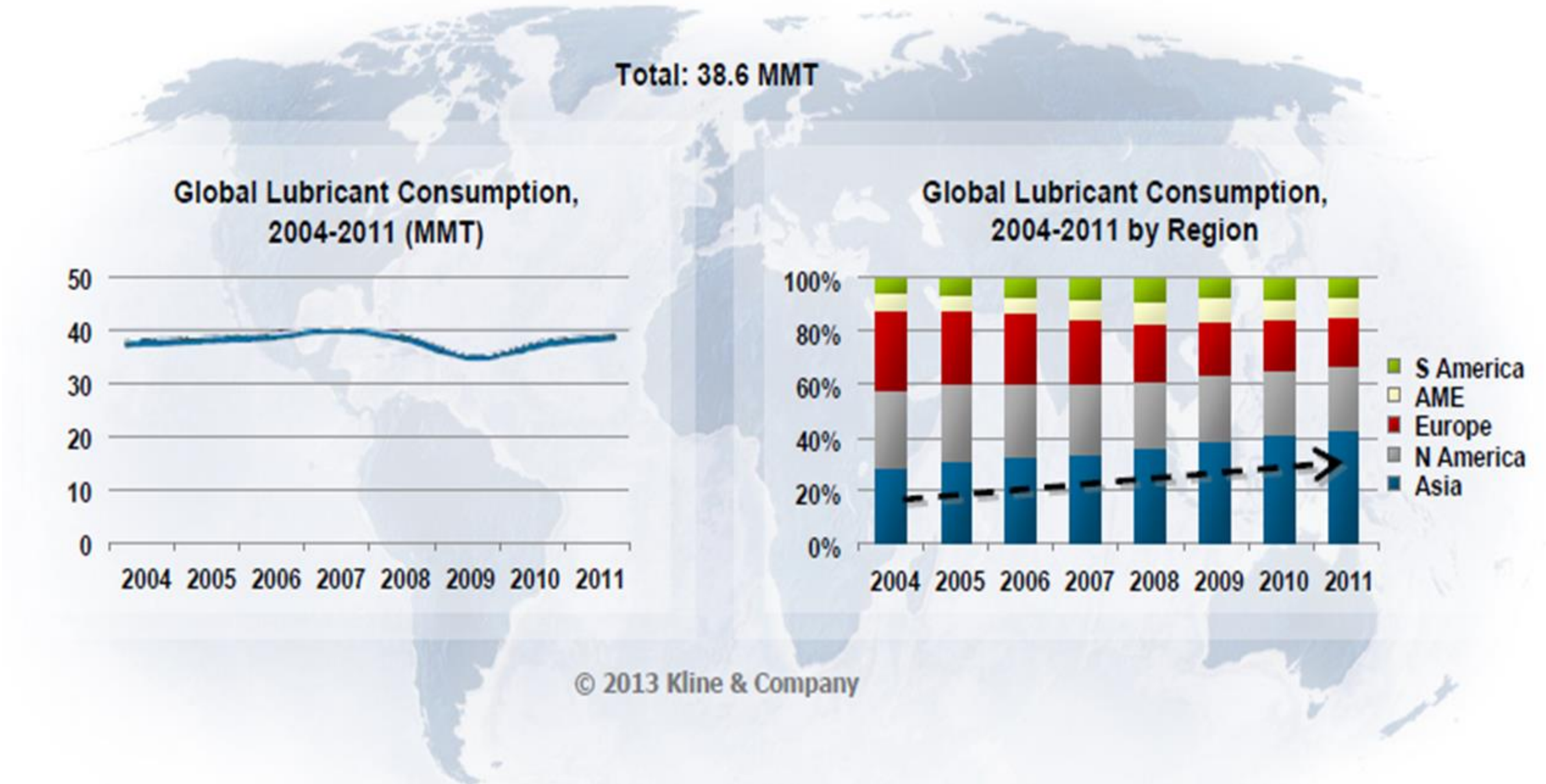
Sources: IEA, EIA, My Energy

Base oil demand is small compared to transportation fuels and other products

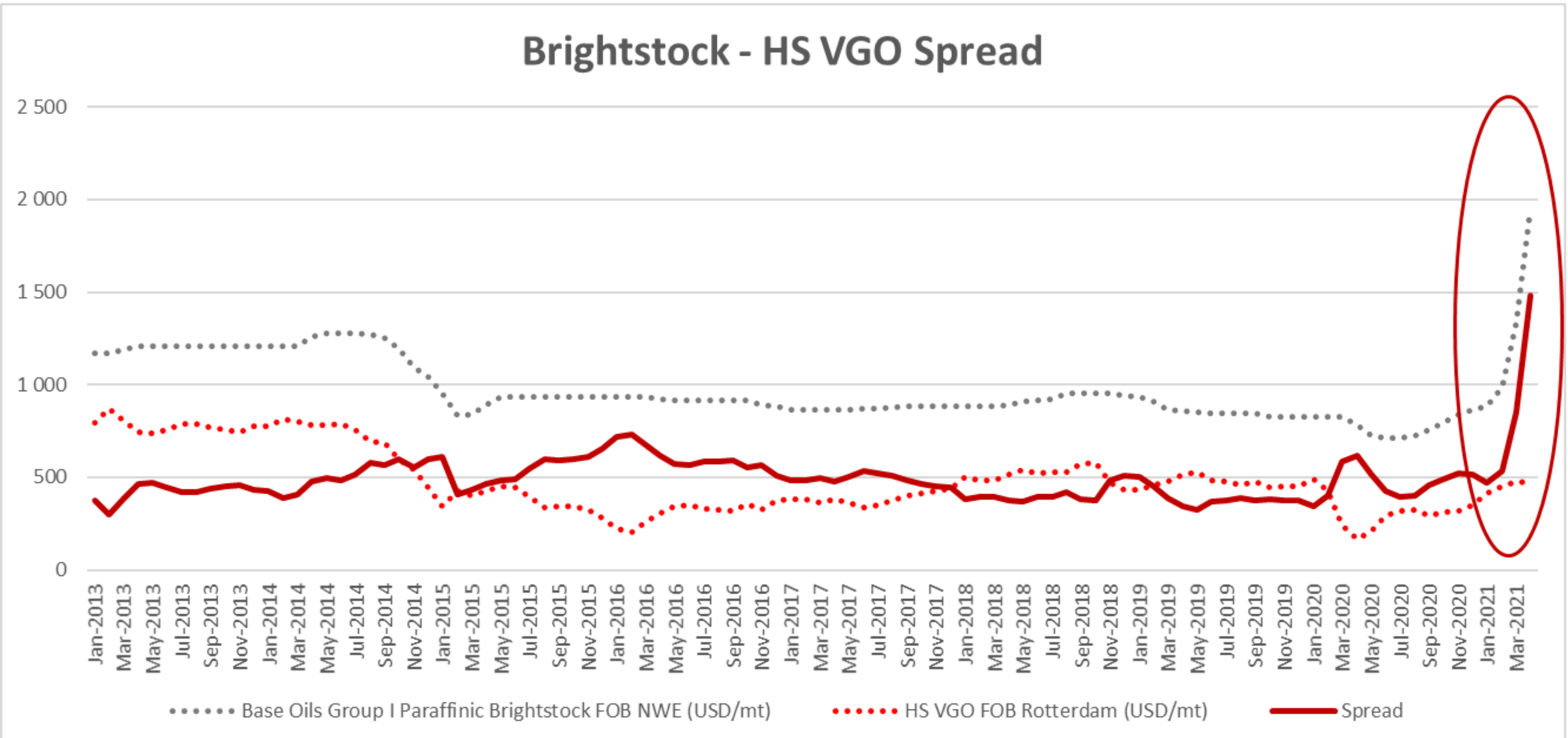
And .. additional refinery capital investment required

Demand & Consumtpion

Global Lubricant Consumption by Region

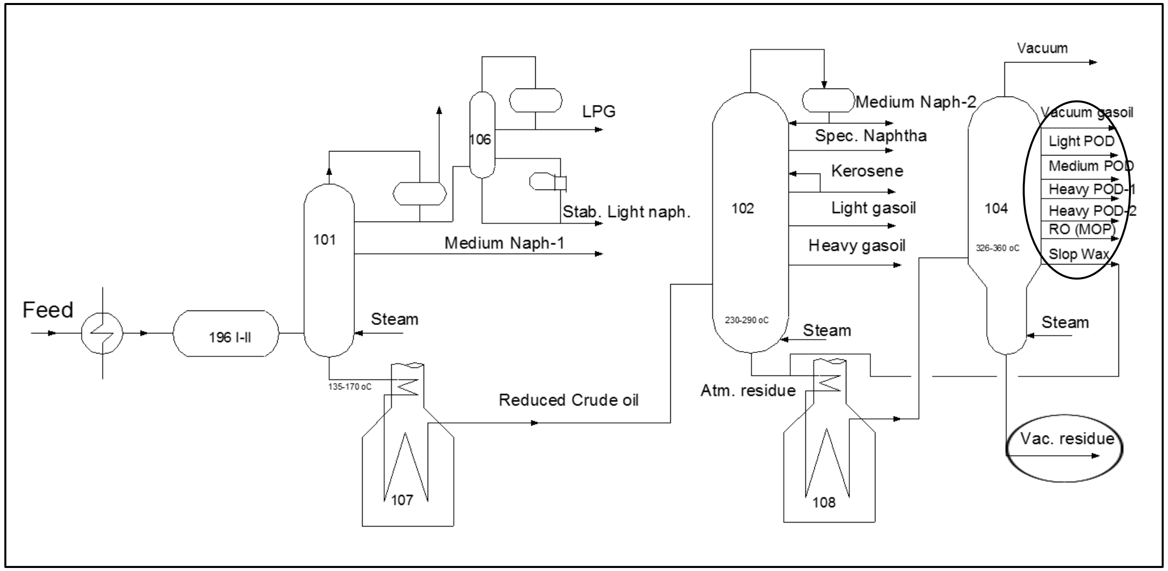


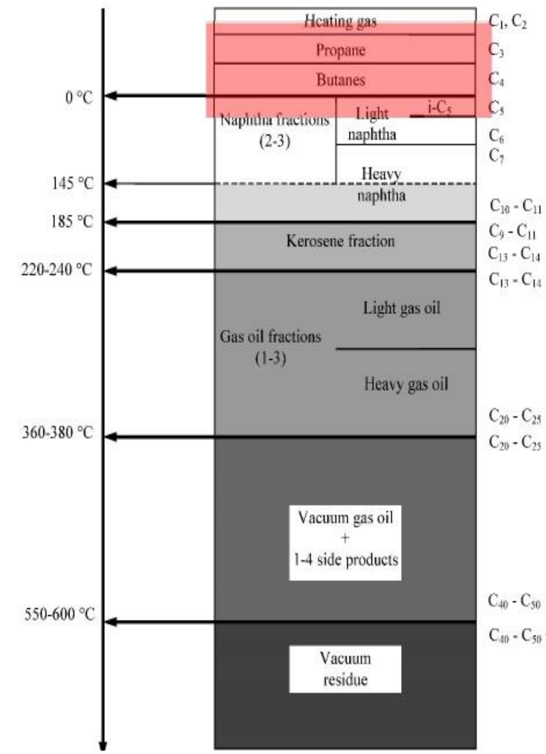
Prices and spread



Feedstocks and product portfolio

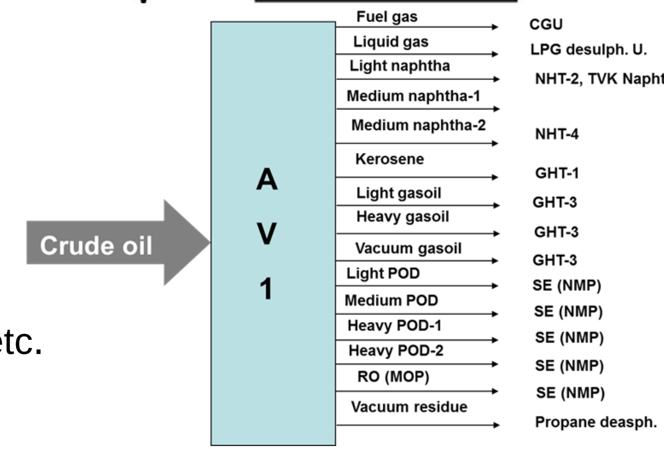
Feedstocks: Vacuum distillates and residues





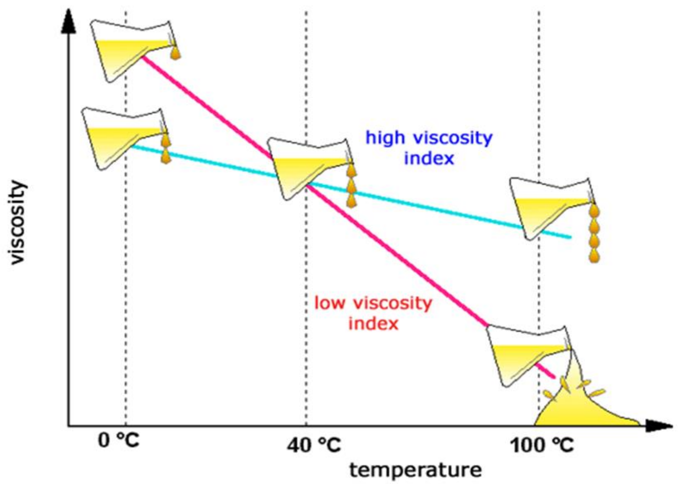
Products and intermediers:

- Base oils
- Waxes
- Paraffins
- Slack-waxes
- Foots oils
- Others: Side products, solvented distillates, dewaxed distillates, etc.



Product properties

Main quality prameters:



Viscosity index

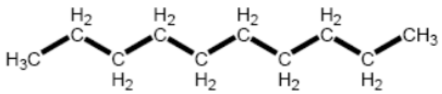
- Viscosity
- Volatily (Noack)
- Viscosity index (VI)
- Pour point: the temperature at which the fluid ceases to pour and is nearly a solid (typically the pour point ranges from -6 to -24°C for heavy to light neutrals)
- Cloud point: the temperature at which the first wax crystals appear
- Saturates, aromatics, naphthenes content
- Color (change appearance in presence of light)
- Stability (change appearance in presence of heat)
- Melting point (waxes)

Base Oils API Groups

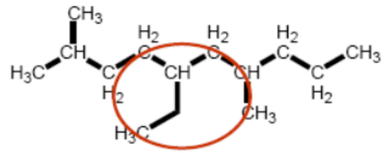
API Group	% saturates	% sulfur	VI
I	< 90 % sats ***and/or***	> 0.03% S	≥ 80 and <120
II	≥ 90 % sats ***and***	≤ 0.03% S	≥ 80 and <120
III	≥ 90 % sats ***and***	≤ 0.03% S	≥ 120
IV	Poly-alpha-olefins (PAO)		
V	Basestocks not included in Groups I – IV		

Source: API 1509 Appendix E

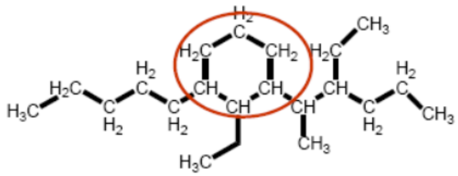
Feedstock composition



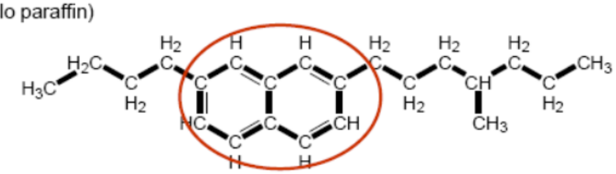
n-Paraffin (straight chain)

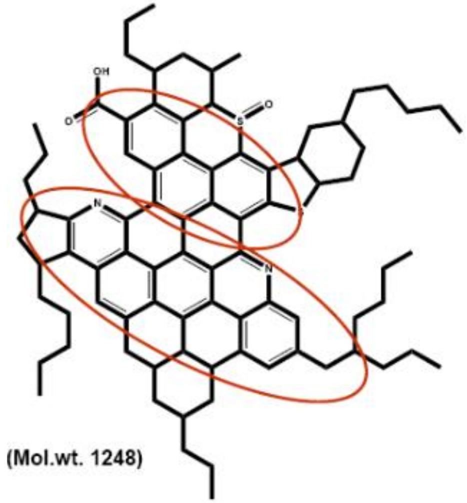


iso-Paraffin (branched chain)

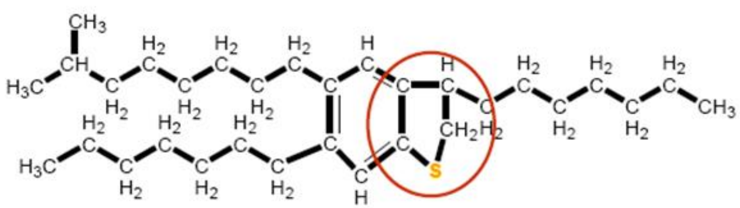


Naphthene (cyclo paraffin)

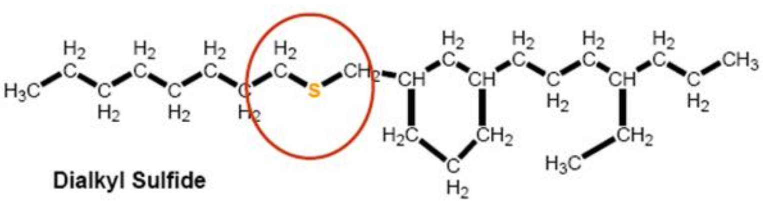




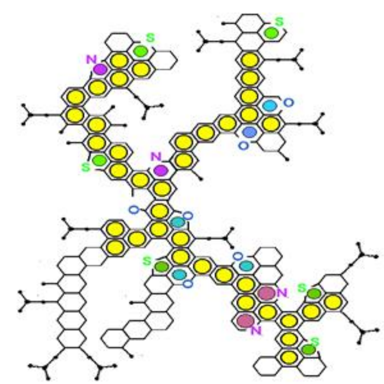
(Mol.wt. 1248)



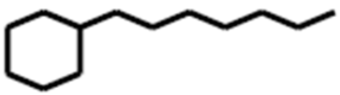
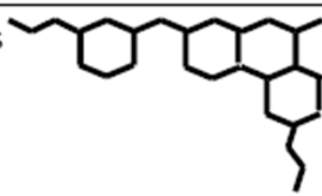
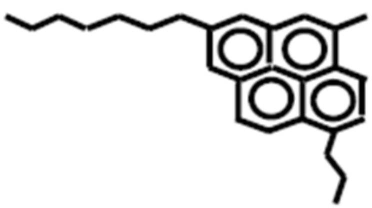
Benzothiophene (sulfur hetrocyclic)



Dialkyl Sulfide



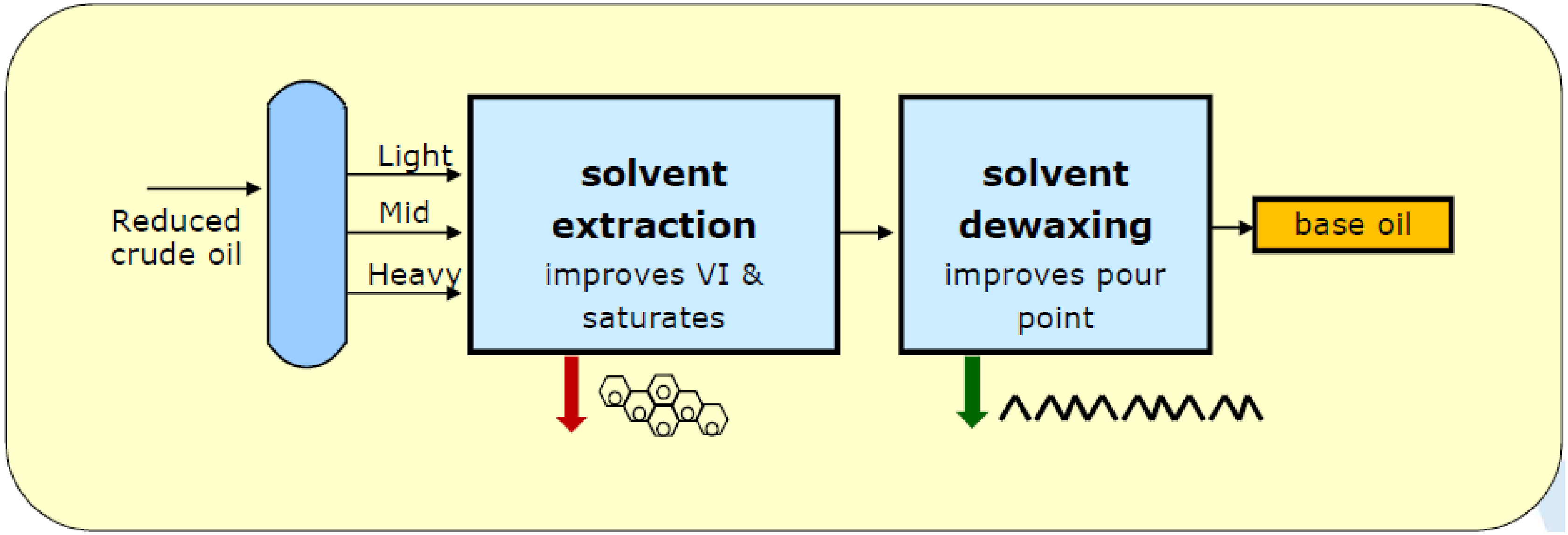
Effect of molecular types

Designation	Viscosity Index	Pour Point	Resistance to Oxidation	Value as Base Oil
n-paraffins 	✓✓✓✓	✓	✓✓✓✓	✓✓✓
iso-paraffins 	✓✓✓	✓✓✓	✓✓✓✓	✓✓✓✓
Mono-naphthenes 	✓✓	✓✓	✓✓✓	✓✓✓
Poly-naphthenes 	✓✓	✓✓✓	✓✓	Nil
Aromatics 	✓	✓✓✓	✓	Nil

Solvent processes

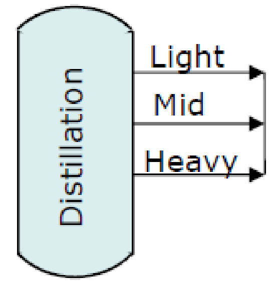
Main three process steps

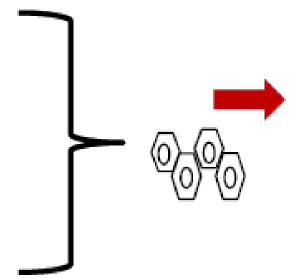
- Crude distillation to Light-, Medium- and Heavy feed fractions
- Remove the unwanted aromatics – solvent extraction
- Remove paraffins and waxes – solvent dewaxing



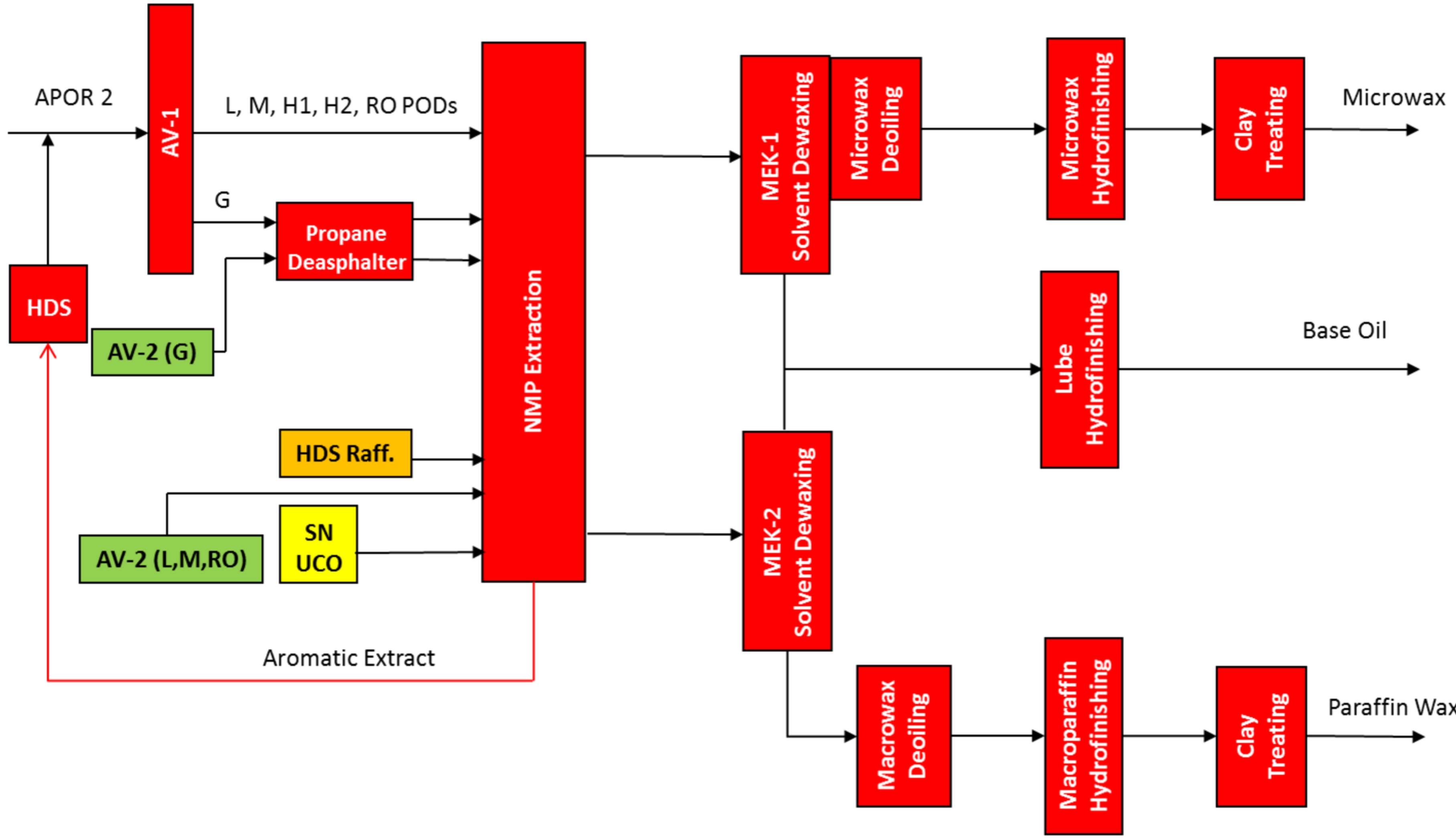
Quality parameter controls

Property	Where controlled
Viscosity	Crude distillation isolates heavy molecules and creates primary viscosity grades
VI (higher is better)	Solvent extraction (aromatics removal) + VI increases as aromatics are removed
Saturates (higher is better)	Solvent extraction (aromatics removal) + Saturates increase as aromatics are removed
Pour Point (lower is better)	Solvent dewaxing (wax removal) + Pour point decreases as wax is removed



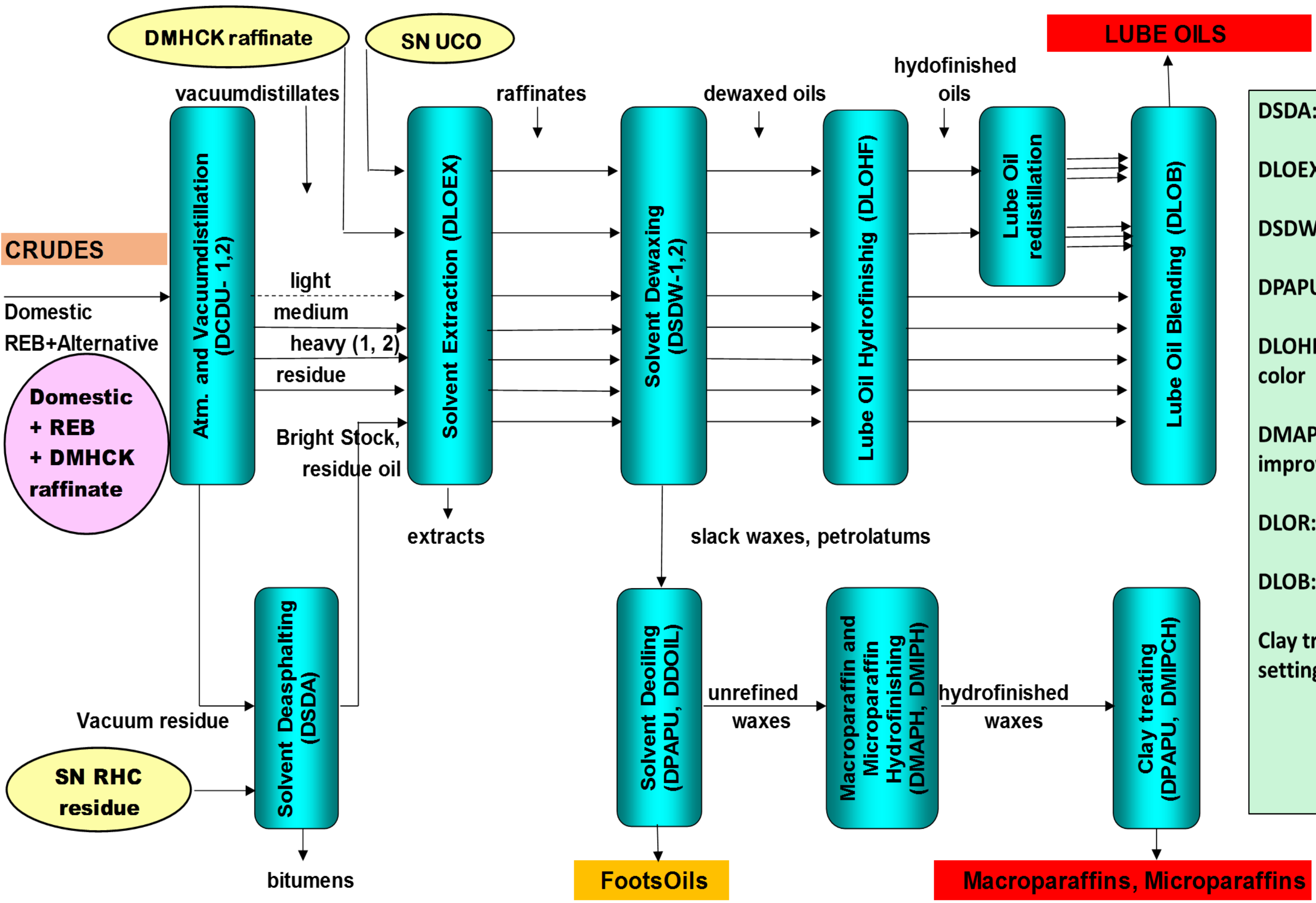


Base Oil production in Danube Refinery



Base Oil production in Danube Refinery

MOL



DSDA: remove asphaltenes and metals

DLOEX: reduce aromatics (di, tri)

DSDW: separate oils and paraffins

DPAPU, DDOIL: remove oil content

DLOHF: reduce sulfur content, improve color

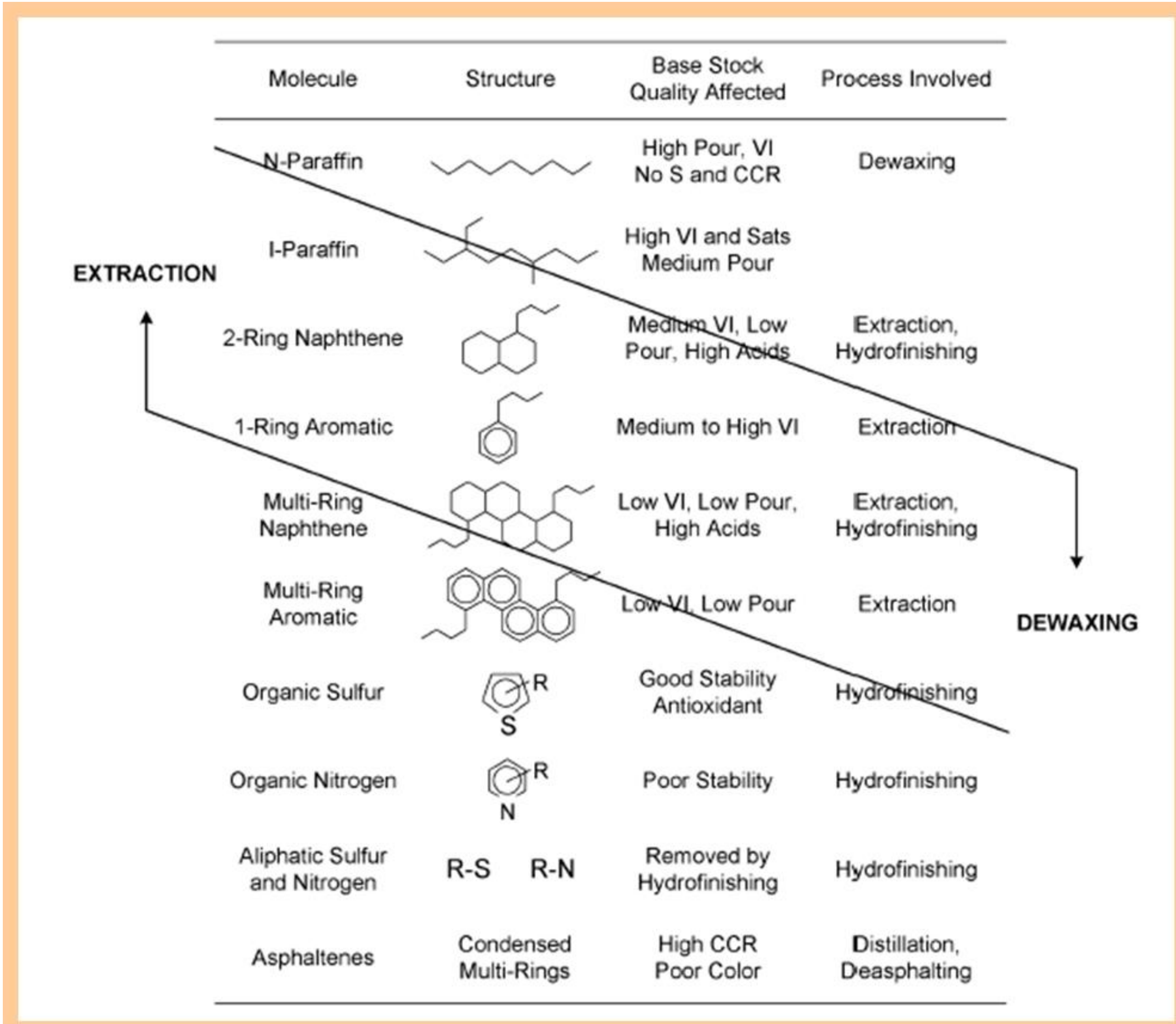
DMAPH, DMIPH: reduce sulfur content, improve color

DLOR: viscosity settinng

DLOB: quality setting

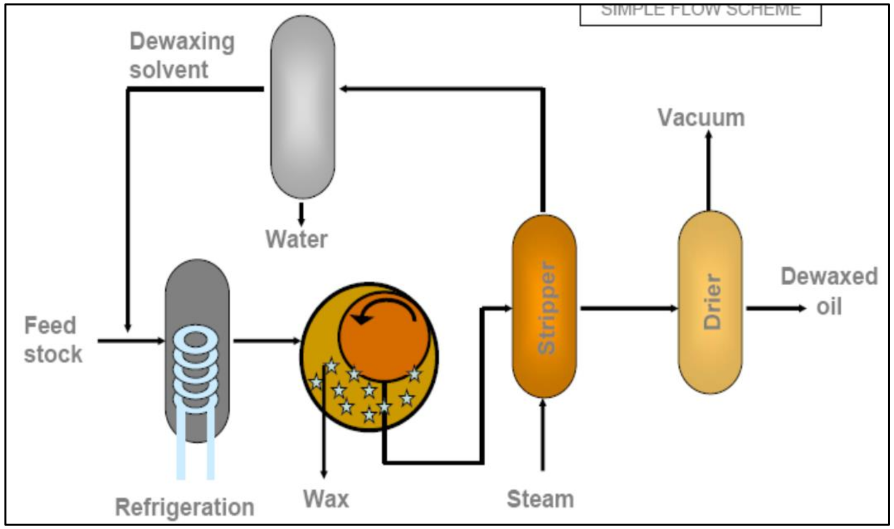
Clay treating: remove polar components, setting food quality

Molecules and processes



Molecule	Structure	Base Stock Quality Affected	Process Involved
N-Paraffin		High Pour, VI No S and CCR	Dewaxing
I-Paraffin		High VI and Sats Medium Pour	
2-Ring Naphthene		Medium VI, Low Pour, High Acids	Extraction, Hydrofinishing
1-Ring Aromatic		Medium to High VI	Extraction
Multi-Ring Naphthene		Low VI, Low Pour, High Acids	Extraction, Hydrofinishing
Multi-Ring Aromatic		Low VI, Low Pour	Extraction
Organic Sulfur	R S	Good Stability Antioxidant	Hydrofinishing
Organic Nitrogen	R N	Poor Stability	Hydrofinishing
Aliphatic Sulfur and Nitrogen	R-S R-N	Removed by Hydrofinishing	Hydrofinishing
Asphaltenes	Condensed Multi-Rings	High CCR Poor Color	Distillation, Deasphalting

Process solvent and ratios



Solvent Dewaxing

Solvent Deasphalting

Solvents: **Propane** to Heptane $\mathbf{C_3}$ - C_7

Typical solvent ratio (C_3 case): 1:3,4-3,6 t/t

Solvent Treating (Aromatic removal)

Solvents: Furfural, Phenol,

NMP (N-methyl pyrolidone)

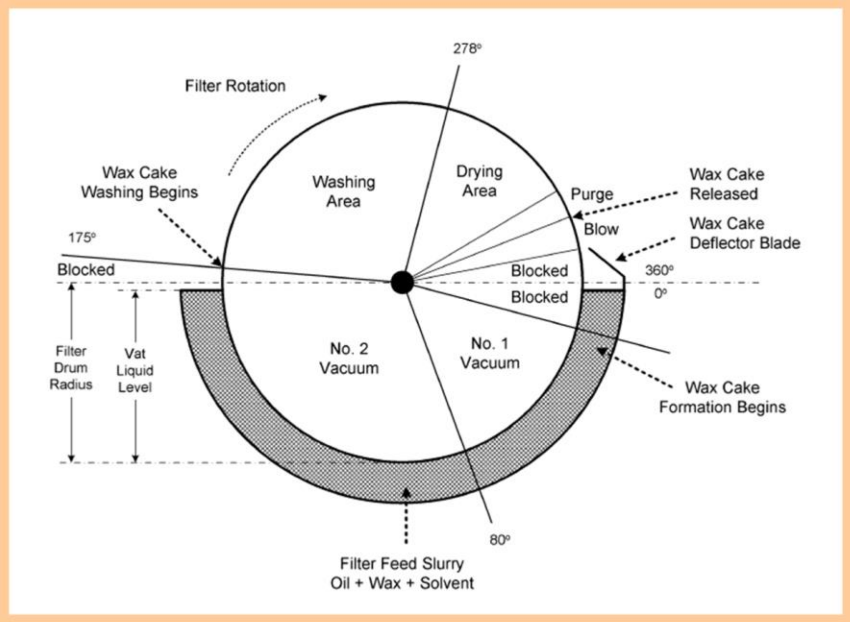
Typical solvent ratio (NMP case): 1:1,75-2,25 t/t

Solvent Dewaxing and Deoiling

Solvents: **MEK, Toluene,** Acetone

Typical solvent ratio (MEK-T): 1:3 - 1:5 t/t

Solvent Composition: MEK 40-45%, T: 55-60%



Wax Filtering

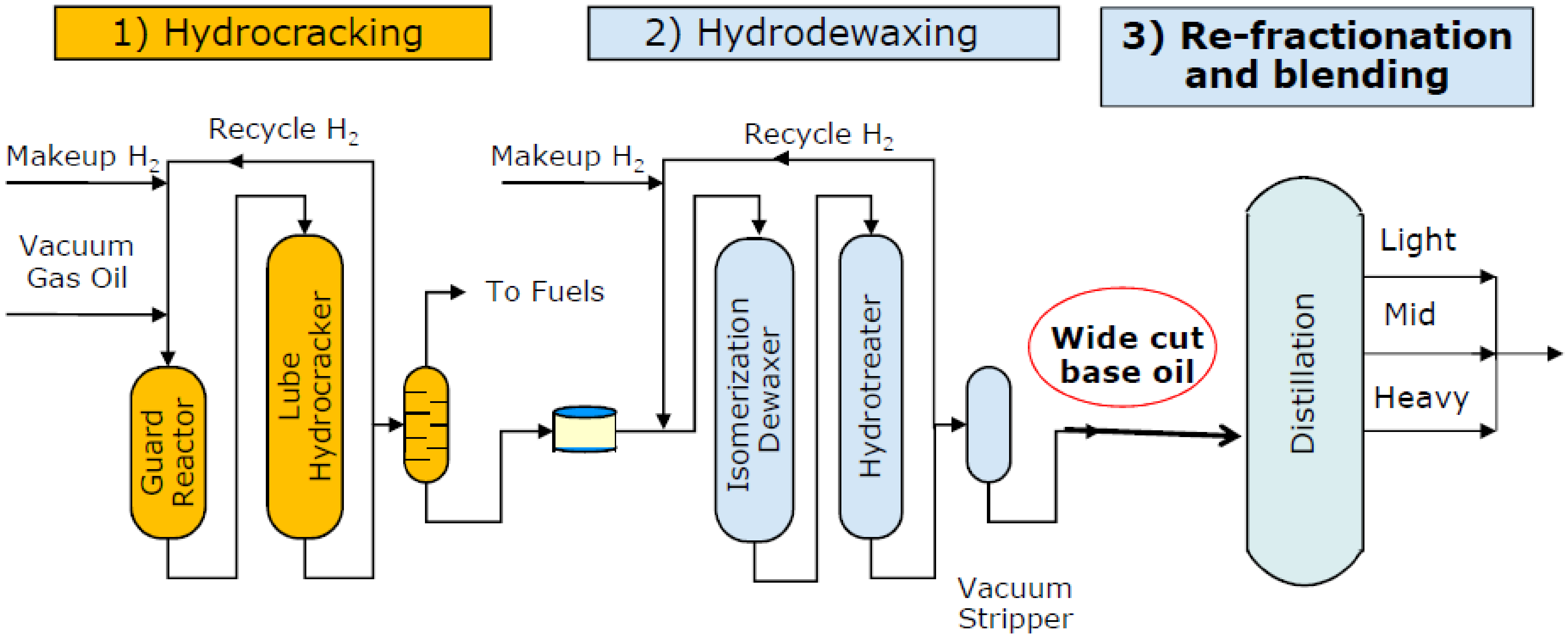
Process types and steps

- Solvent processes
  - Vacuum distillation
  - Solvent Deasphalting
  - Solvent Extraction
  - Solvent Dewaxing
  - Solvent Deoiling
  - Hydrotreating
  - Clay treating

- Catalytic processes
  - Vacuum distillation
  - Base Oil Hydrocracking
  - Cat. Dewaxing / Isodewaxing
  - Hydrotreating

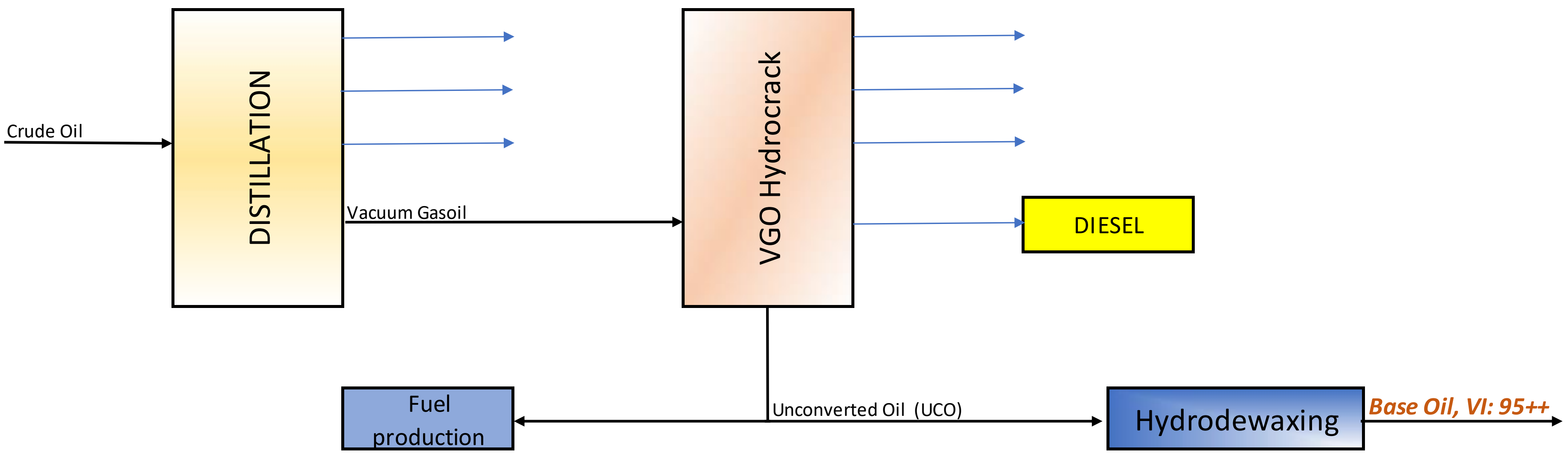
Base Oil Hydrocracking & Isodewaxing

- Catalytic Lube Hydrocracking & Catalytic Dewaxing



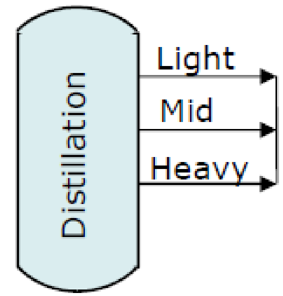
Group III production on HCU base

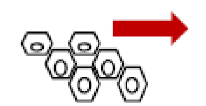
- Base case: VGO Hydrocracker unit (HCU) exists for Diesel production
- Unconverted Oil (HCU Residue) is applicable for Base Oil Production
- Only a Hydrodewaxing unit is needed, Lube Hydrocracker unit is not needed



Catalytic quality parameter controls

Property	Process where controlled
Viscosity	Crude distillation and back-end re-distillation after hydrocracking / hydrodewaxing
VI	Hydrocracking + VI increases as aromatics are removed
Saturates	Hydrocracking + Sats increase as aromatics are removed
Pour Point	Hydrodewaxing + Pour point decreases as wax is removed



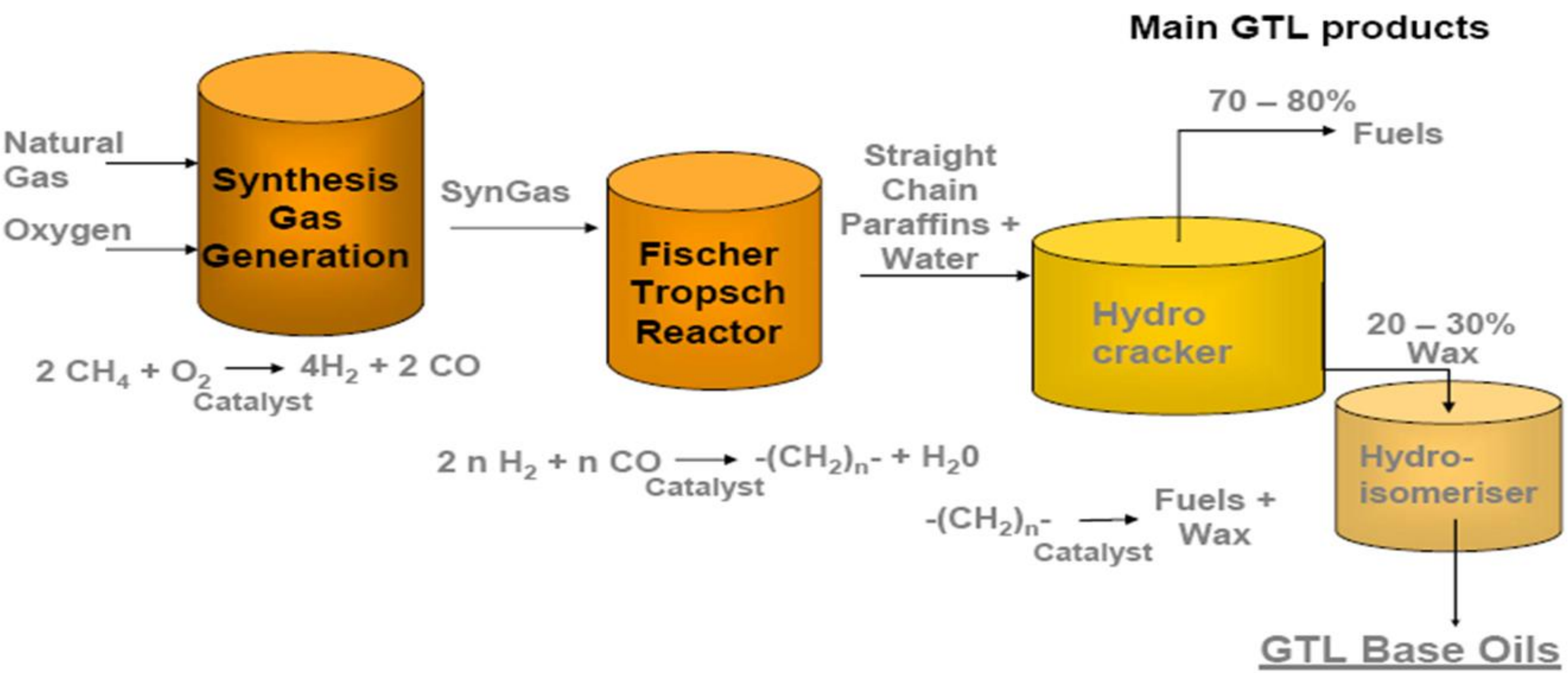


Aromatics

Wax

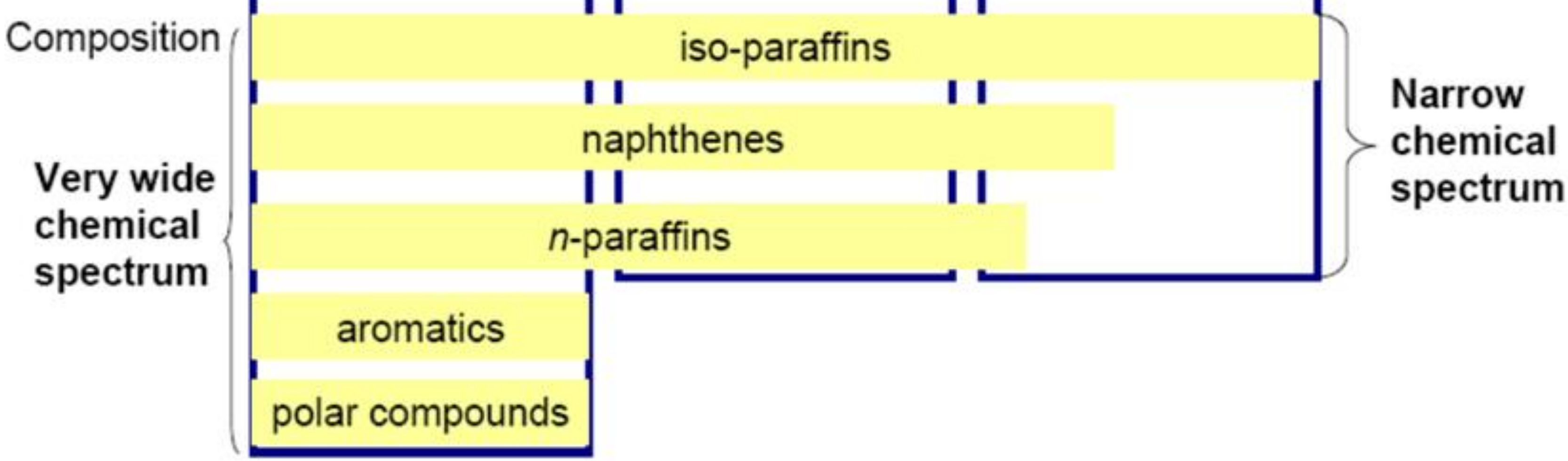
Group III$^+$ production on GTL process

- Fischer-Tropsch process base
- F-T HCs products are a white waxy crude for upgrading
- Group III$^+$ quality Base Oils can be produced next to the fuels



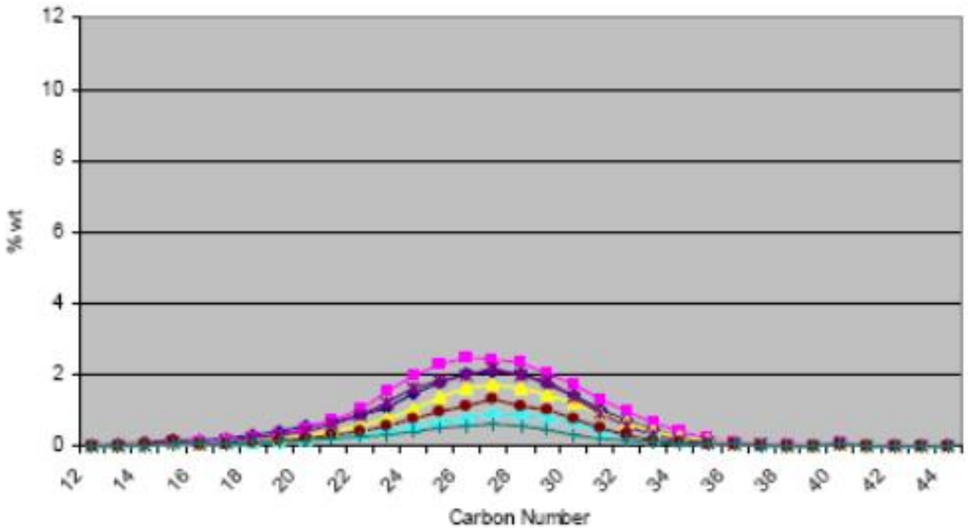
Typical API Group composition

Category	Group I	Group II	Group III
VI	80 ≤ VI < 120	80 ≤ VI < 120	VI ≥ 120
Saturates	< 90%	≥ 90%	≥ 90%
Sulphur	> 0.03%	≤ 0.03%	≤ 0.03%

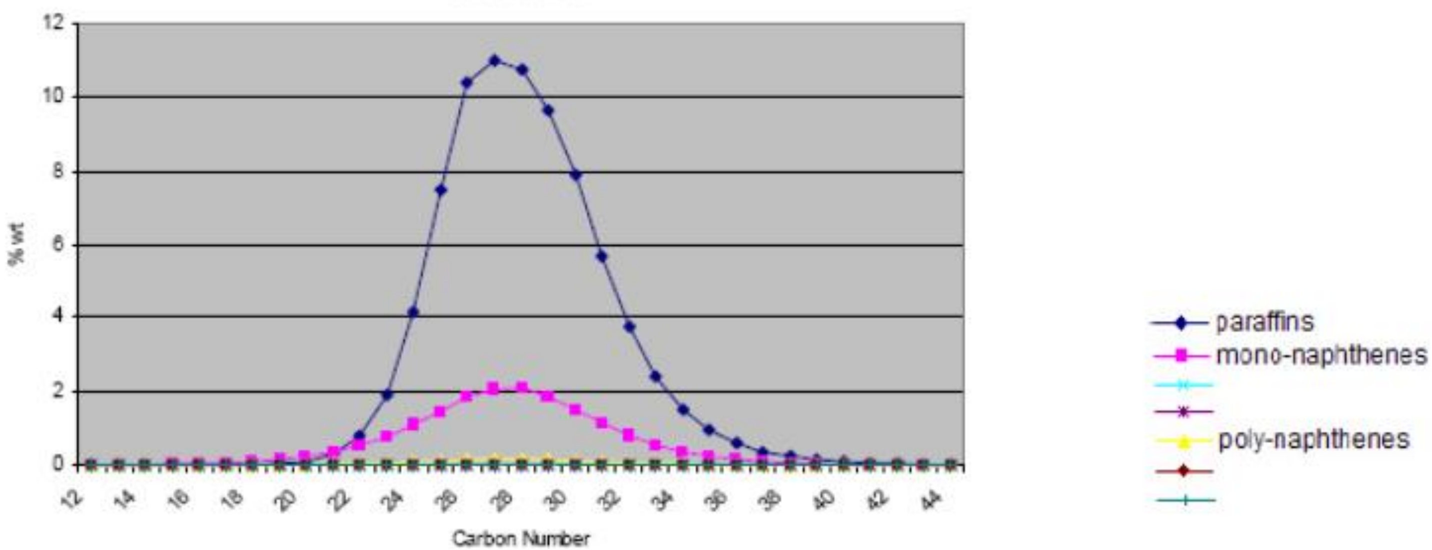


Composition differences

Group I



Group III



API Groups - What's better?

Same Labels, New Perceptions Regarding What's "Better"?

Naphthenics

Group I

Group II

Group III

Group III+

PAO

Fine oxidation stability (95 VI) — Naphthenics, Group I, Group II

Better oxidation stability (higher saturates, higher VI) — Group III, Group III+, PAO

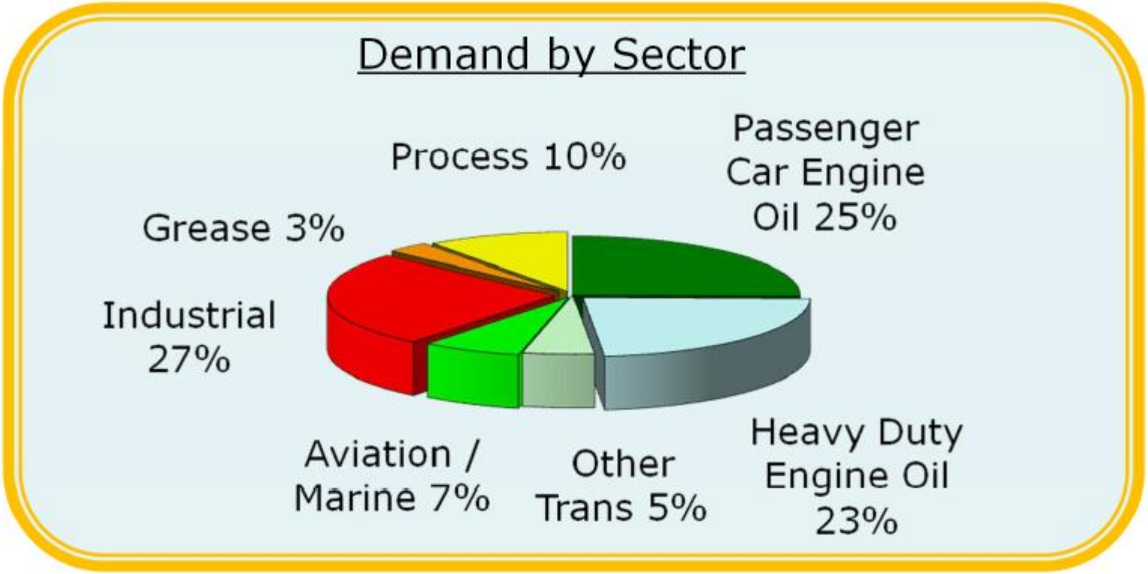
Better solvency

Higher viscosity grades — Naphthenics, Group I

Poor solvency (absence of aromatics, naphthenes) — Group III, Group III+, PAO

Lubricant market

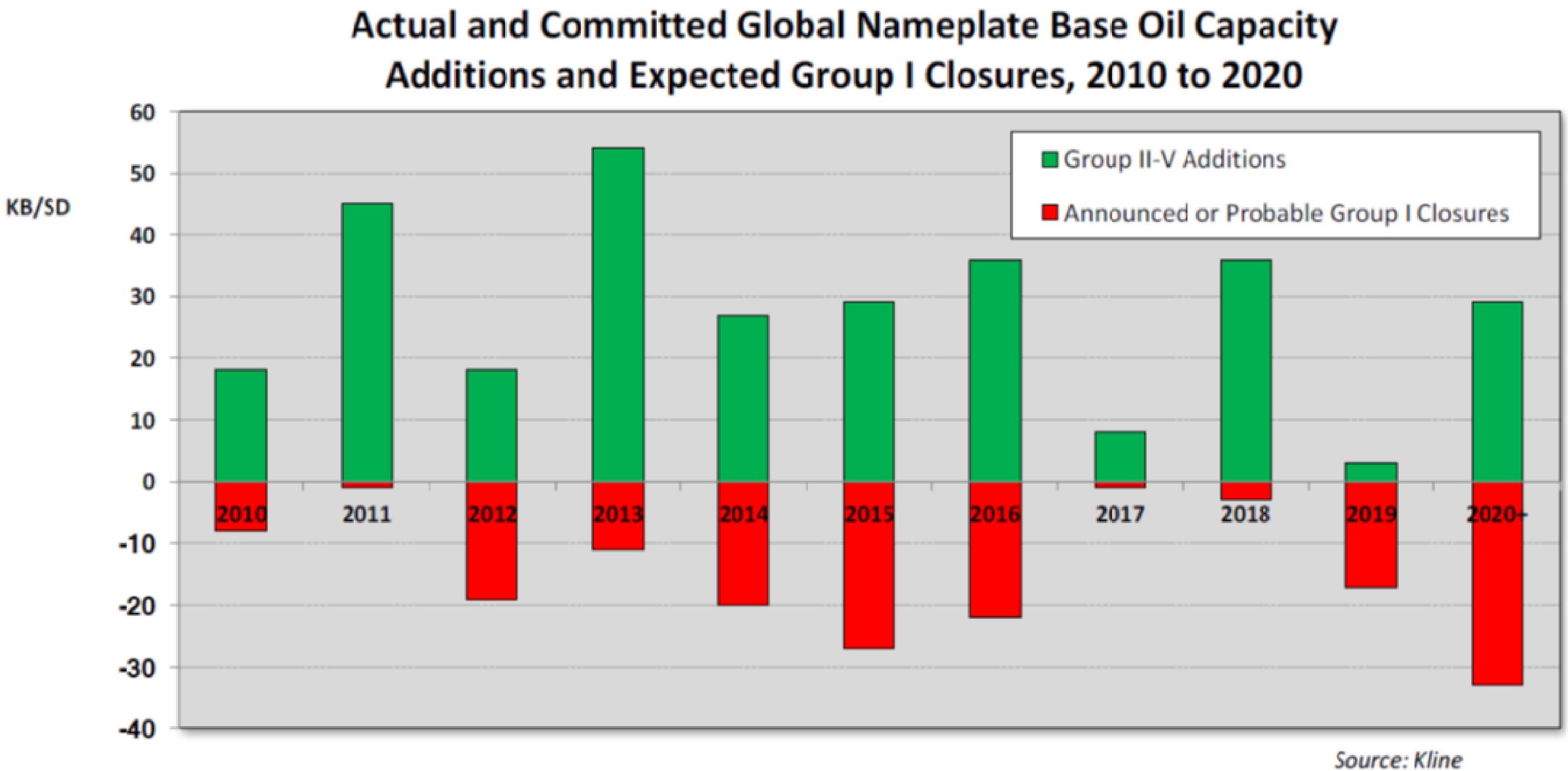
- **Transportation-related lubrication is largest market at around 60% of global applications**



- **Industrial / grease applications are ~ 30%**
- **Non-lubricating applications ("process oils") are ~ 10%**

Sources: My Energy Databases, Fuchs Lubricants, Kline & Company

Group I – Group II/III capacities



Nearly 150 KB/D of Group I capacity could be decommissioned during this decade, and another 100-150 KB/D is "At Risk" from low margins/refinery shutdowns by 2030

Base Oil – Changes in global production

CLOSED AND JEOPARTIZED REFINERY IN EUROPE

ESSAR — Stanlow shutdown in 2013

Group I base oil capacity: 260 ktpa
To produce base oil requires very specific, light, higher cost crudes. Base oil represents only two percent of the refinerys output but dictates choice of crudes for around 25 percent of total crude intake at Stanlow.

Shell, Pernis shutdown in 2016

Base oil capacity: 370 ktpa.
The causes of closure are continued decline of European demand and new Group II capacity. Without Pernis, it may be that more GTL stocks (from Quatar) will find their way into Shells European lubricant supply chain.

COLAS — Colas, Dunkerque shutdown in 2015

Capacity: 271 kt Group I + 25 kt Group III
It is a small specialty plant, not a refinery. They bought feed (atm residue) from other refinery.

Petroplus — Petroplus, Petit Couronne shutdown in 2013

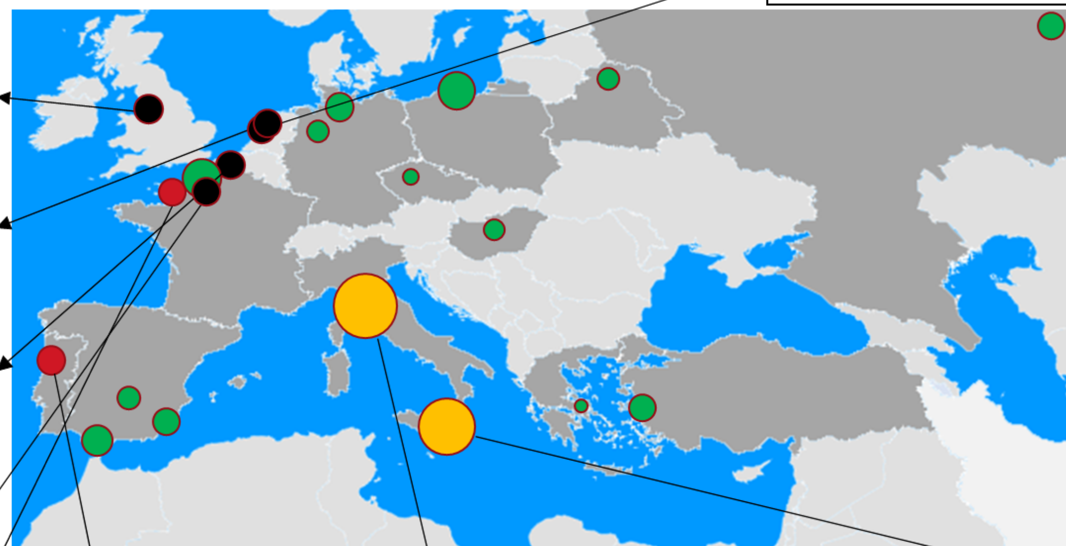
Capacity: 320 kt Group I
It is a small specialty plant, not a refinery. They bought feed (atm residue) from other refinery.

TOTAL — Gonfreville shutdown in 2021

Group I base oil capacity: 250 ktpa
Total has decided to permanently close a base oil plant at its refinery in Gonfreville, France,. The plant has not produced base oil since a fire damaged the refinery's crude unit in December 2019.

Kuwait Oil, Rotterdam shutdown in 2016

Base oil capacity: 235 ktpa.



galp — PORTO shutdown in 2021

Base oil capacity: 150 ktpa
Porto has the lowest conversion factor of the 10 refineries on the Iberian Peninsula . The structural changes in oil product demand patterns, driven by the regulatory context in Europe and the effects caused by the Covid-19 pandemic, have led to a significant impact on Galp's downstream industrial activities

eni — Livorno

Base oil capacity: 630 ktpa
The refinery is a low complex one, with a focus on gasoline and lubricants.

Eni confirmed its willingness "to carry out the appropriate assessments for the start of the conversion of the Livorno refinery into a biorefinery

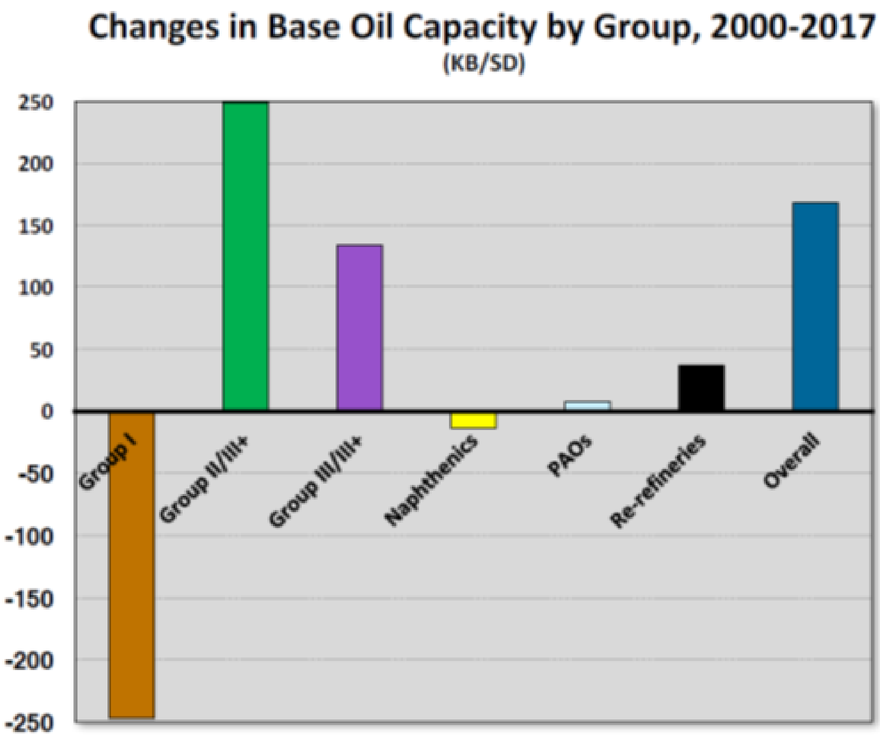
Sonatrach, Augusta

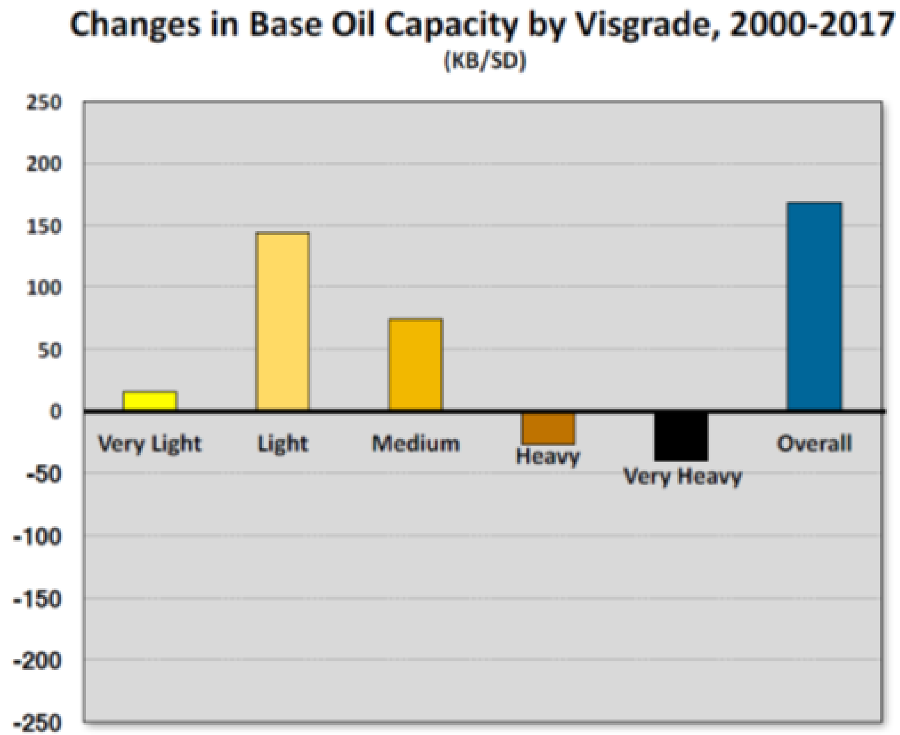
Base oil capacity: 730 ktpa
Augusta was designed for crude oil of medium and heavy grades and not for the light crude oil of the type produced by Algeria.

Sonatrach had made a commitment to ExxonMobil that the Augusta plant would supply the latter with a given volume of base lubricants for a period of ten years.

jeopartezed | operating | closed in 2021 | closed

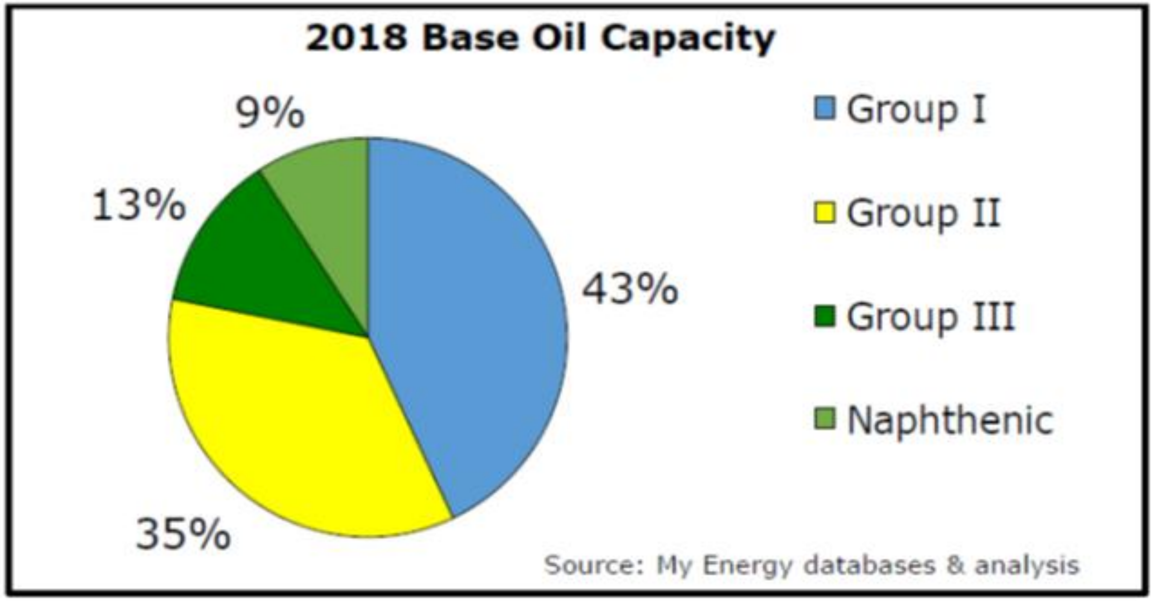
Base Oil – Changes in global production





Source: Kline

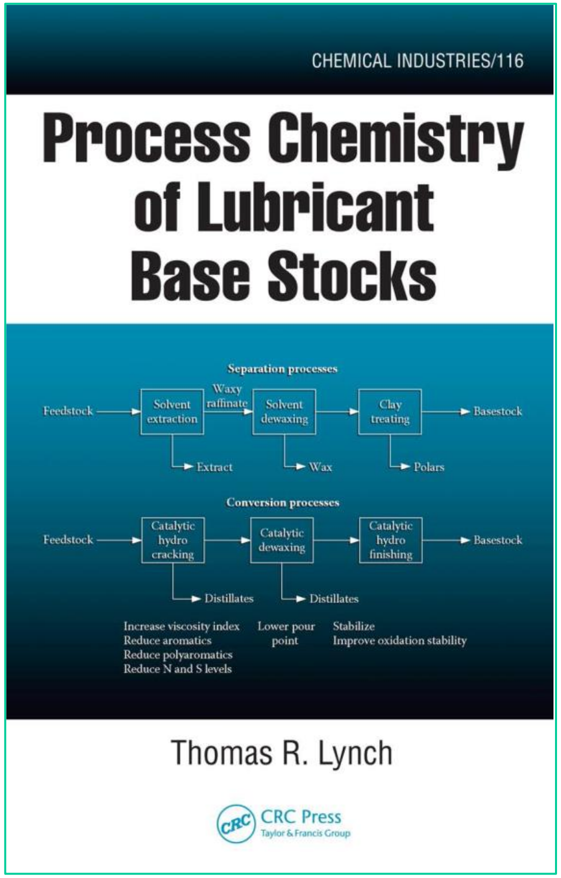
Base Oil Global Demands



Group I	23500 mT
Group II	19500 mT
Group III	7000 mT
Naphthenic	5000 mT

Total ~ 55 MMT
~ 80% avg. global capacity utilization
(supply ~ 44 MMT)

Thank you !



Thank You for Your Attention !