Infineum

Lubricant Base Stocks

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Sept. 9, 2026

What's in the bottle?

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- Viscosity Modifier
- Pour Point Depressant
- **Base Stocks**
- Performance Additives

Outline

1

What are base stocks?

Why are base stocks important?

Key properties of base stocks

2

Refining processes

Overview

Major base stock types

Solvent Extraction (SE)

Hydrocracking (HC)

Synthetics

3

API base oil groups

4

Base stocks in detail

Names and definitions

Measurements and typical targets

Recent trends

What are base stocks?

Lubricant base stocks

A lubricant component:

Roughly **80 - 99+%** of petroleum products

- Usually does not have all required properties
- Additives are used to enhance and customize properties

Common processes:

SOLVENT EXTRACTION

Separate "good" from "bad" molecules

HYDROCRACKING

Convert "bad" molecules into "good" molecules

SYNTHESIS

"Build" from chemical reactions

Mineral oil base stocks:

Refined from crude oil

- Petroleum = "Petra-oleum" = "Rock Oil"

Animal and vegetable oils also used

Base stock

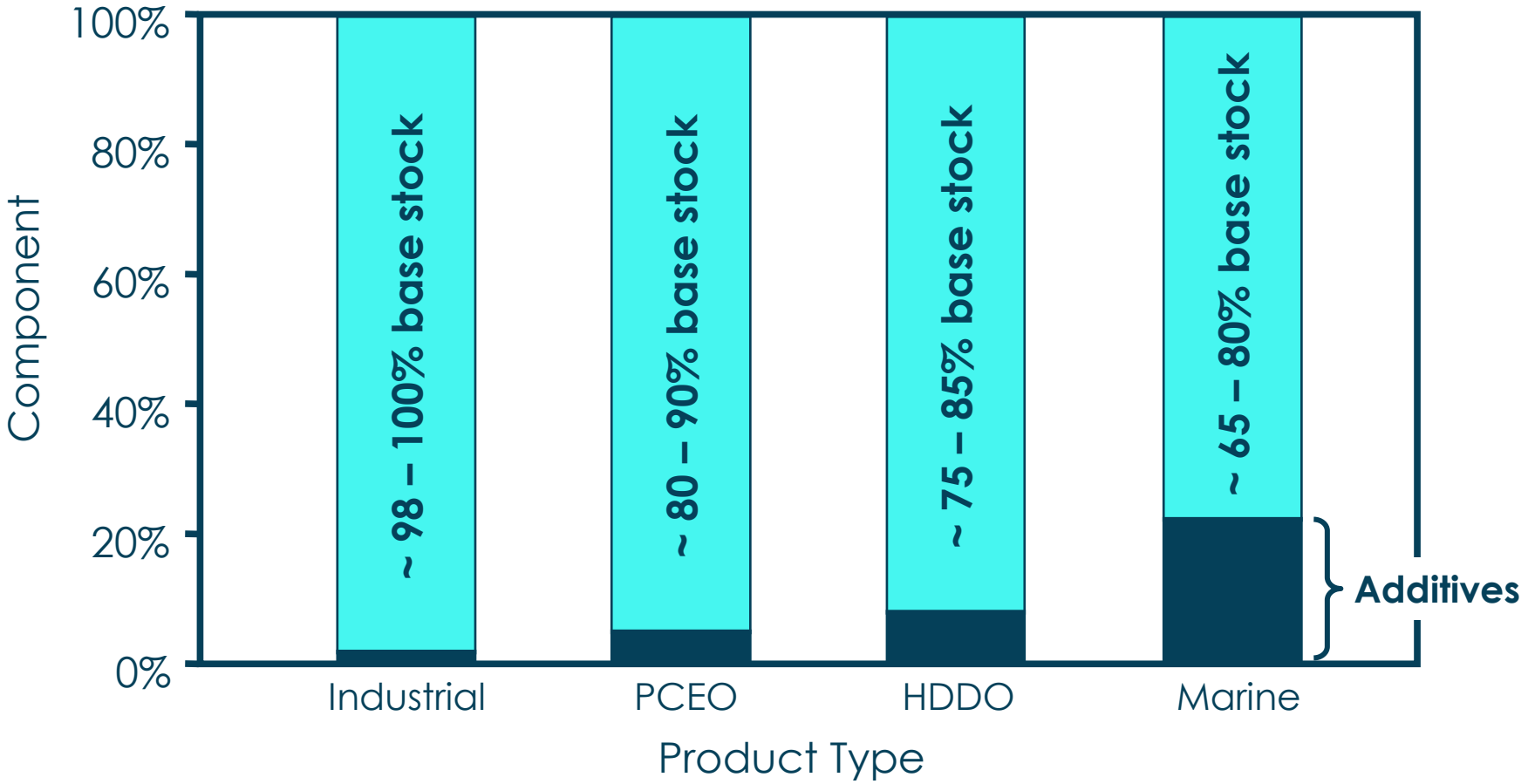
- API 1509, Appendix E, section E1.2.1
- ASTM D4175
- ASTM D6074

Bright stock

- Heaviest grade of base stock

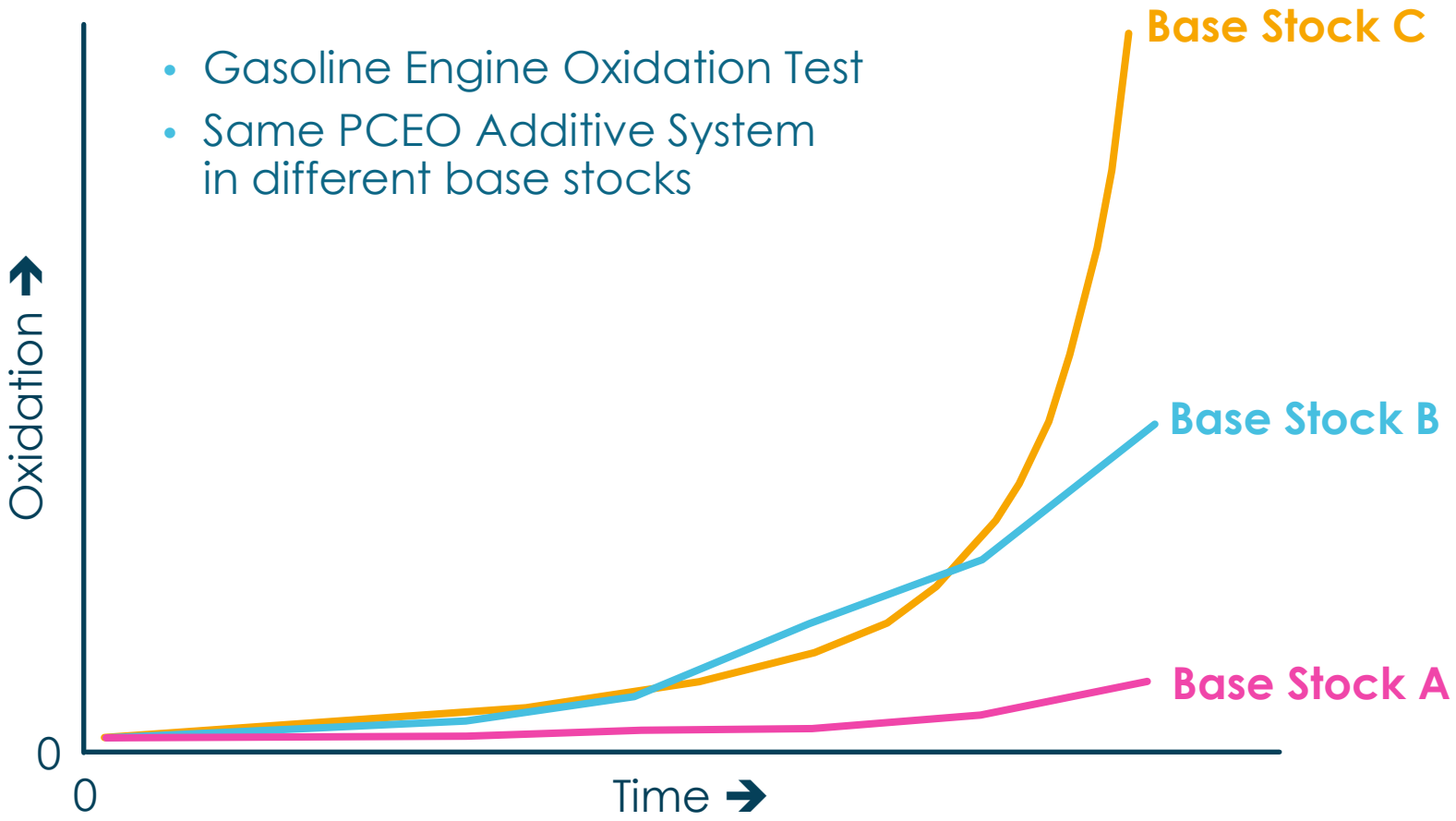
1 Why are base stocks important?

Base stocks are the major component in lubricants



2 Why are base stocks important?

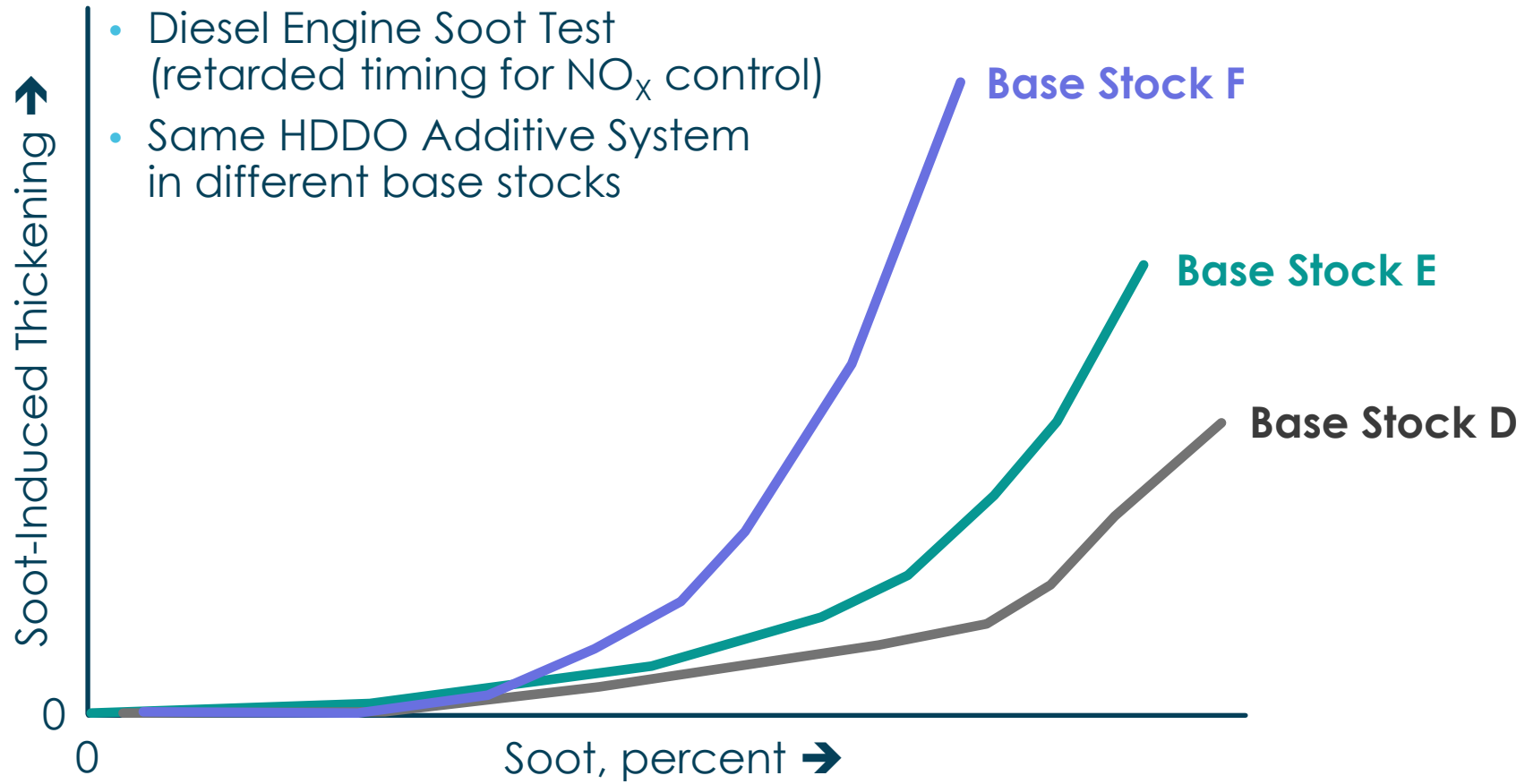
Base stocks have a major effect on performance (oxidation)



3 Why are base stocks important?

Infineum

Base stocks have a major effect on performance (soot-handling)



Lubricant properties affected by base stocks

Viscometrics

- SAE viscosity grade (e.g., SAE 5W-30)
- Pour point and low temperature fluidity
- Fuel economy
- Wear protection

Oxidation

- Viscosity increase
- Acid formation, that leads to corrosion
- Deposit control

Dispersancy and Solvency

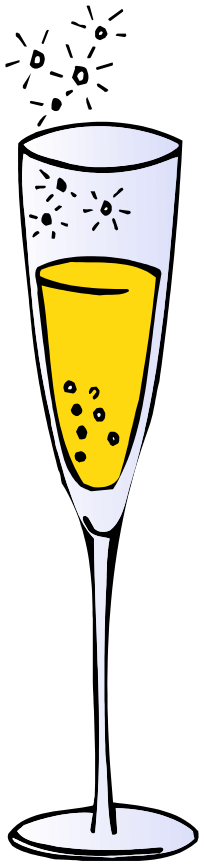
- Soot control (HDD) and sludge
- Viscosity increase and filter plugging
- Deposit control

Foaming and air entrainment

Volatility (evaporation)

- Oil Consumption and Flash Point

Foam



Air Entrainment

What are base stocks?

Base stocks are primarily hydrocarbons

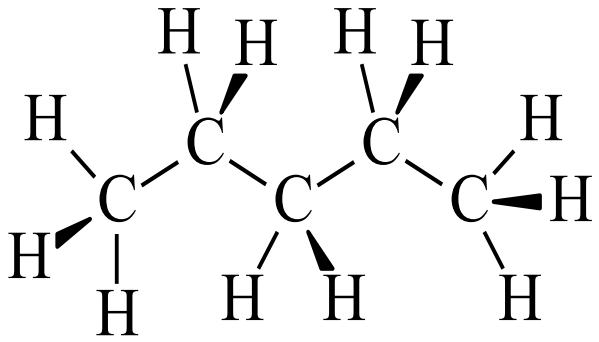
Hydrocarbon =

molecule containing Hydrogen and Carbon

Sometimes generalized to molecules with other elements

Equivalent chemical notations:

C_5H_{12} (pentane) =



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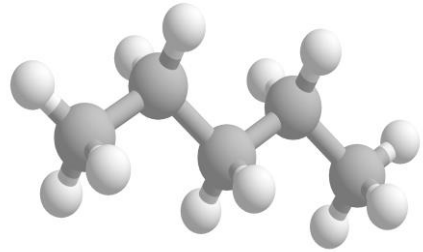

(three-dimensional)

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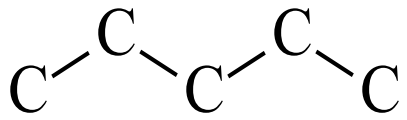

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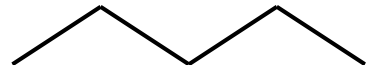


Chemical bonds and terminology

Carbon likes to have four bonds

- In three dimensions

- **Carbon can form chains**
  - Hydrogen fills in the remaining four spaces
    - All positions filled → relatively unreactive
    - Saturated

If there's a missing place, a double bond forms

- Prefer to fill the spaces → more reactive; *e.g.*, oxidation
  - Unsaturated = missing spaces

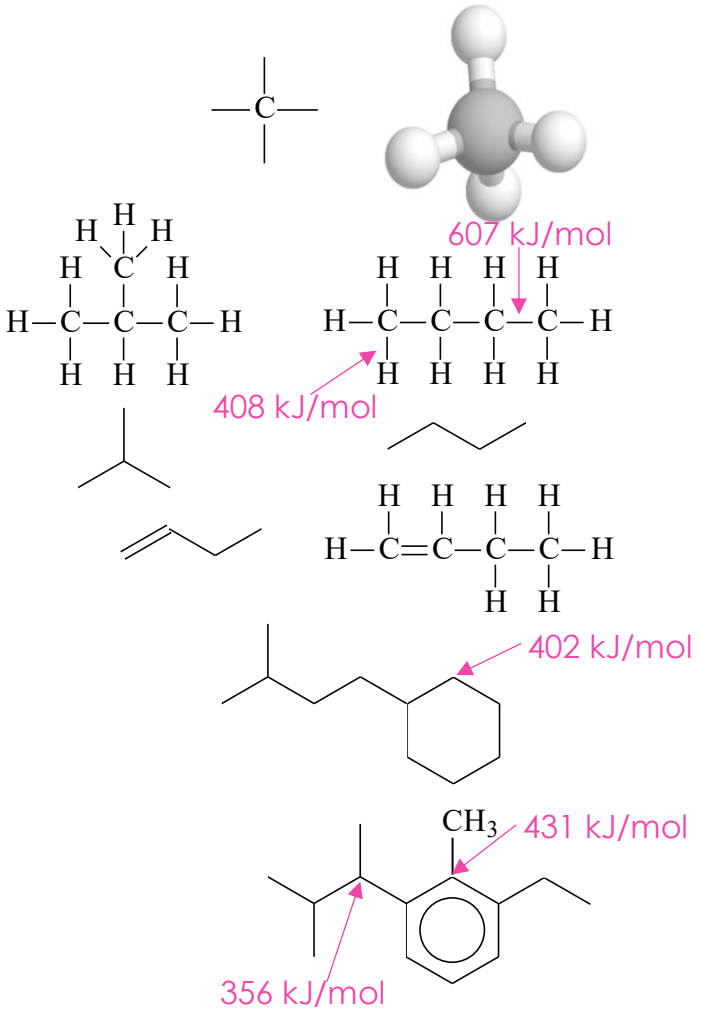
Ring structures (saturated)

- Six-membered rings are common, but others are possible
  - Naphthene (cyclo-alkanes)

Six-membered rings with three double bonds

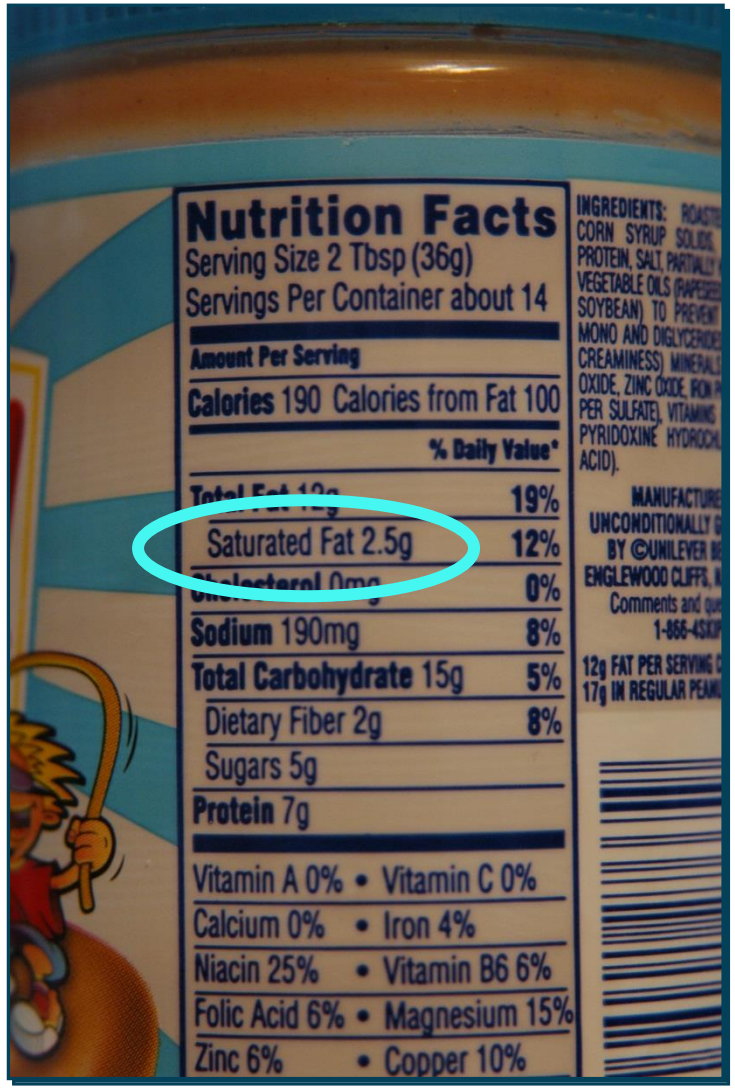
- Aromatic
- Ring weakens neighboring bonds

Examples:
Real base stock molecules are much larger

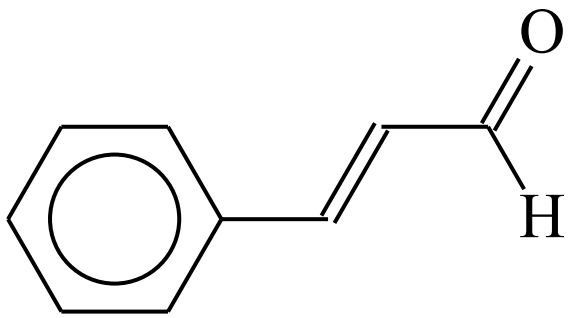


Lange's Handbook of Chemistry, 15th ed., Chapter 4, "Properties of Atoms, Molecules, and Bonds," Table 4.11

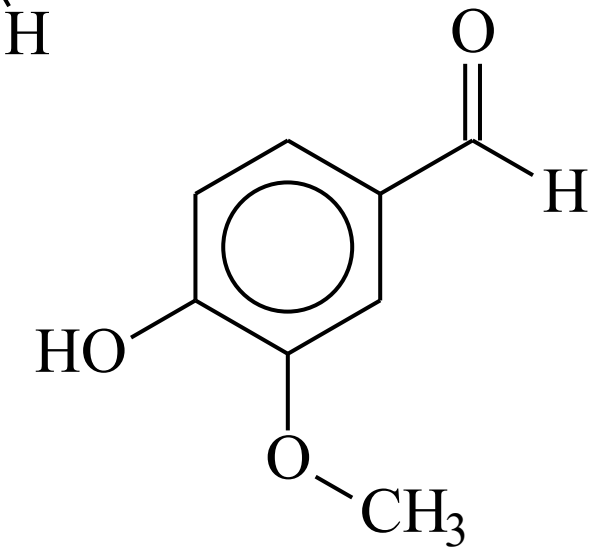
Everyday saturates



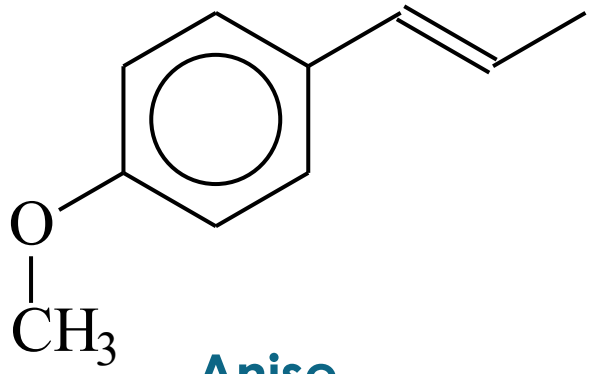
Everyday aromatics



Cinnamon

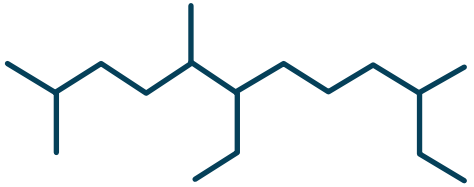
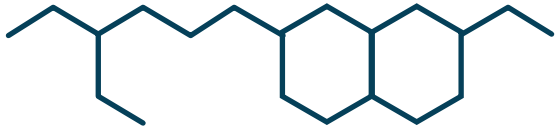


Vanilla

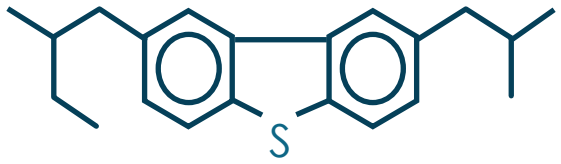
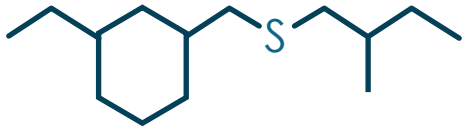
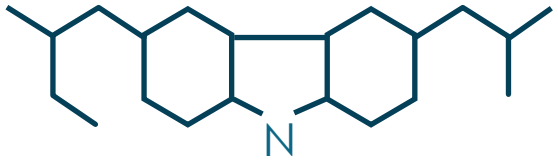
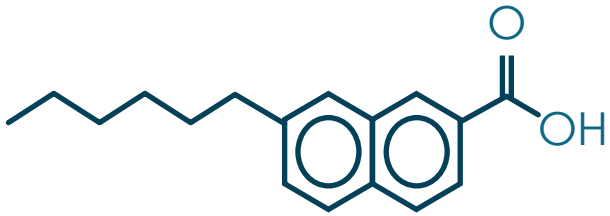


Anise

Base stock molecules – hydrocarbons

Type	Structure	Properties
• Saturates – **Paraffins** (no rings) • Straight chain		Very high VI (~175) Excellent oxidation Very high pour point
Best lube molecules • Branched chain		High VI (~100-150) Good oxidation Medium pour point
– **Naphthenes** (saturated rings)		Medium VI (~60-110) Poor oxidation Low pour point
• **Aromatics** (unsaturated rings)		Low VI (<60) Very poor oxidation Good solubility

Base stock molecules – polars

Type	Structure	Properties
• **Sulfur** – Dibenzothiophene		Anti-oxidant
– Dialkylsulfide		Corrosive
• **Nitrogen** – Alkylhydrocarbazole		Mild pro-oxidant
• **Oxygen** – β-naphthenoic acid		Usually not in base stock (formed during oxidation)

Key base stock properties

Viscosity **(D445)**

- Kinematic viscosity at 100°C, 40°C (mm^2/s)
- Sometimes "Neutral Number" (approx. 4.6 x mm^2/s at 40°C): S150N, S600N
- Low temperature: CCS (D5293), MRV (D4684), SBV (D5133), Pour Point (D97)

Chemical properties are also very important

- More difficult to measure and specify

Viscosity Index **(D2270)**

- Rate of change of viscosity with temperature
- Arbitrary scale defined by ASTM "table look-up"

Saturates **(D2007)**

- Measure of "stable" vs. "reactive" molecules
- Intended as an approximation of oxidative stability

Sulfur **(D4294)**

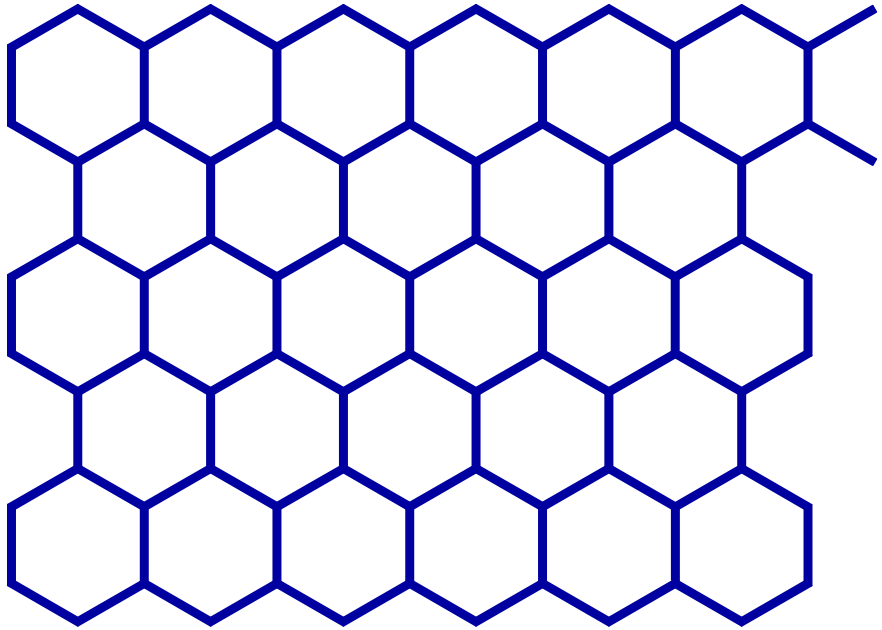
- Corrosive and poison to exhaust catalysts

Properties used to define "Groups"

Volatility **(D5800)**

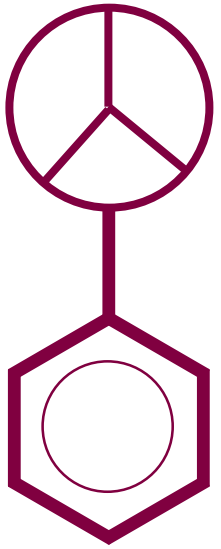
- Evaporation

Quiz – good or bad?



dimethyl chicken wire

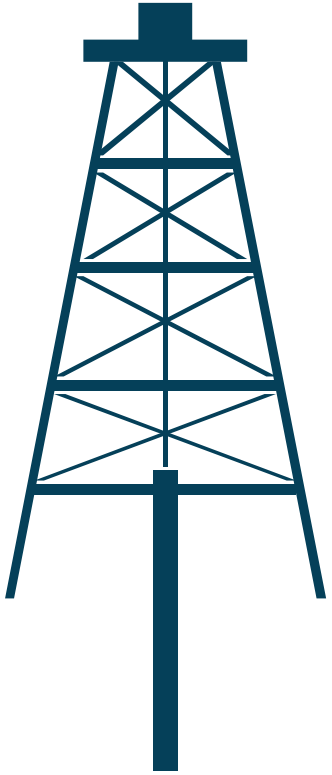
dimethyl bathroom tiles

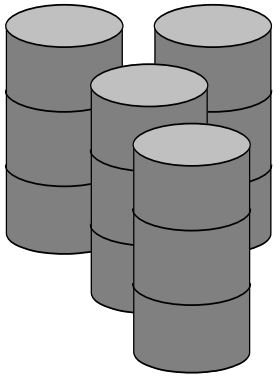


Mercedes Benz-ene

Base stock refining

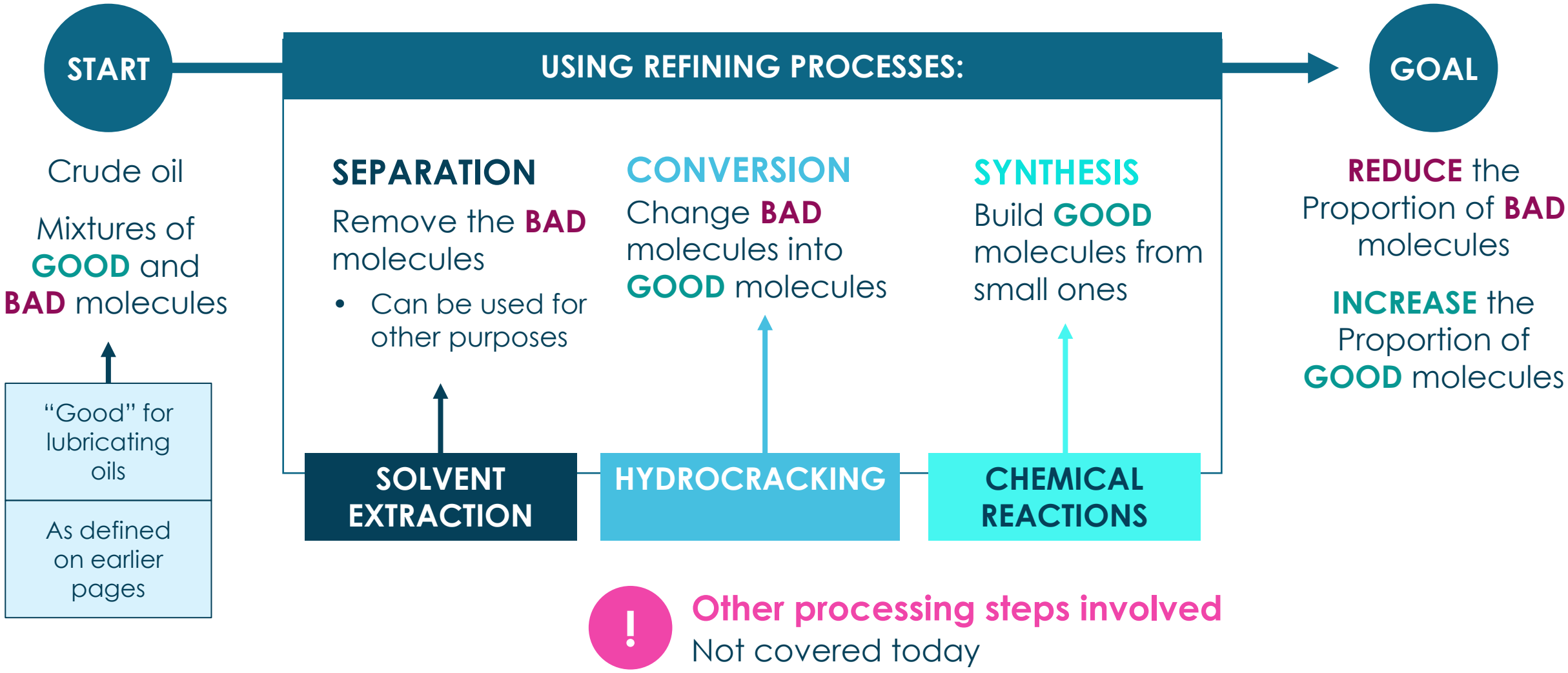
Refinery overview





Crude oil → Processing → Refined petroleum products

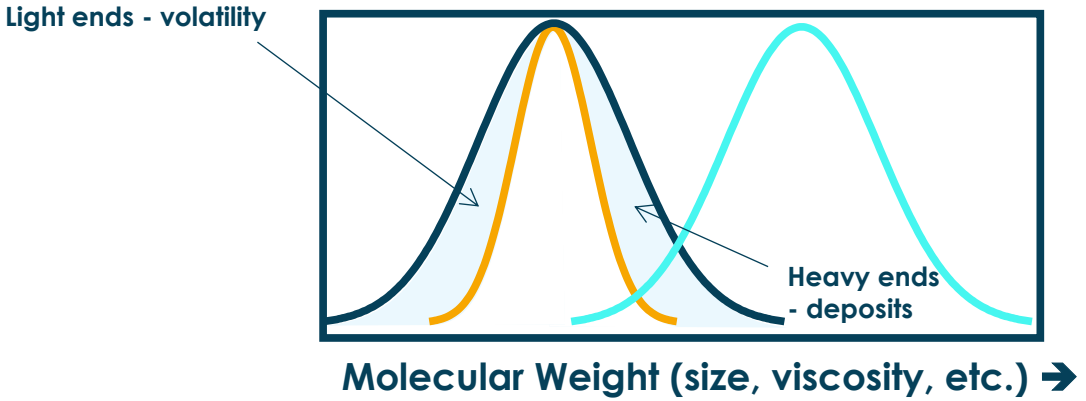
Refining in a nutshell

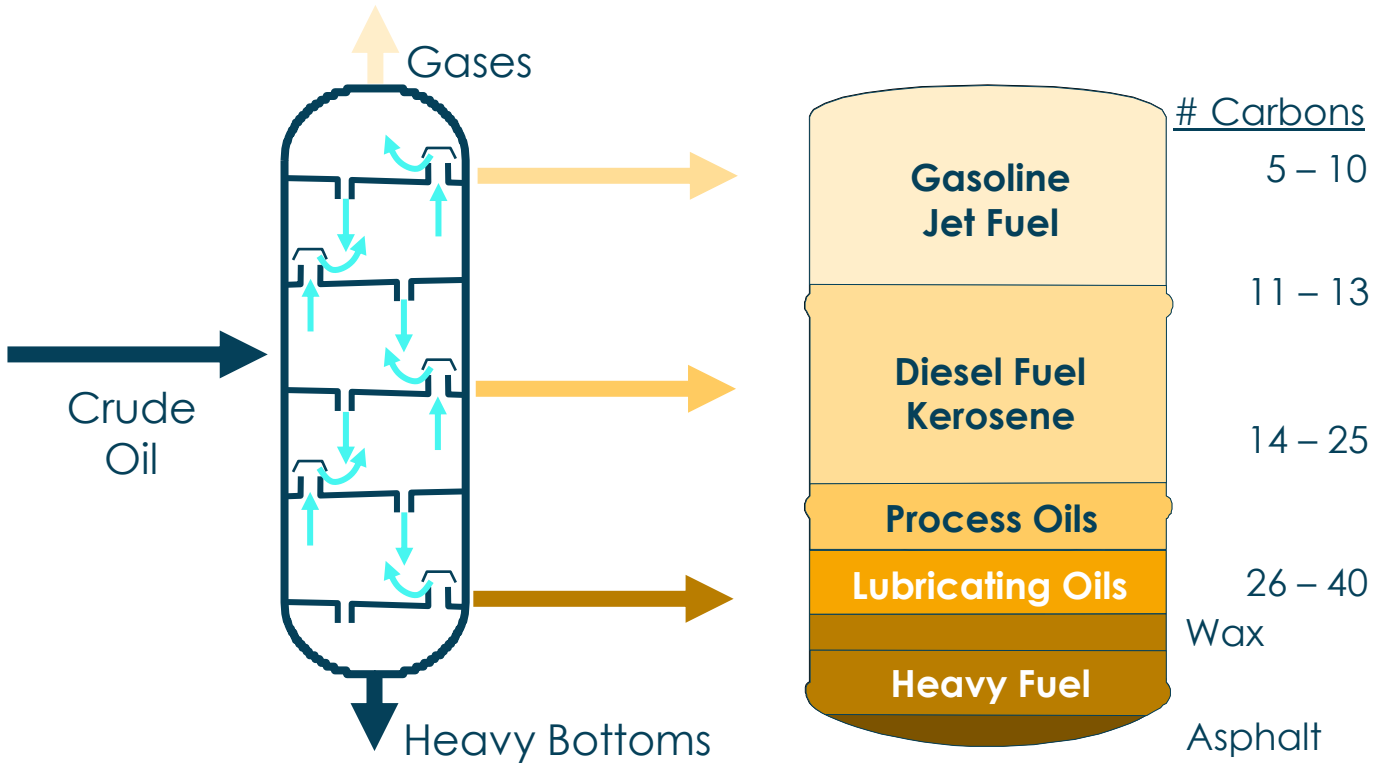


Base stock refining – first steps

Distillation

- Separates **lighter** from **heavier** fractions
- Selects viscosity 'cut' →
- Controls **volatility** (evaporation) →





Major base stock refinery processes

SOLVENT EXTRACTION

- Separation technology
- Polar solvent removes aromatics leaving good saturated molecules
- Removes sulfur, which is predominantly in aromatic molecules

Generally, not definitely: (Group I)

HYDROCRACKING

- Conversion technology
- Breaks chemical bonds and adds hydrogen
- Increases saturates by adding hydrogen
- Removes sulfur, converting to volatile H_2S
- Group II *vs* III is a function of feedstock and hydrocracker severity

(Group II & III)

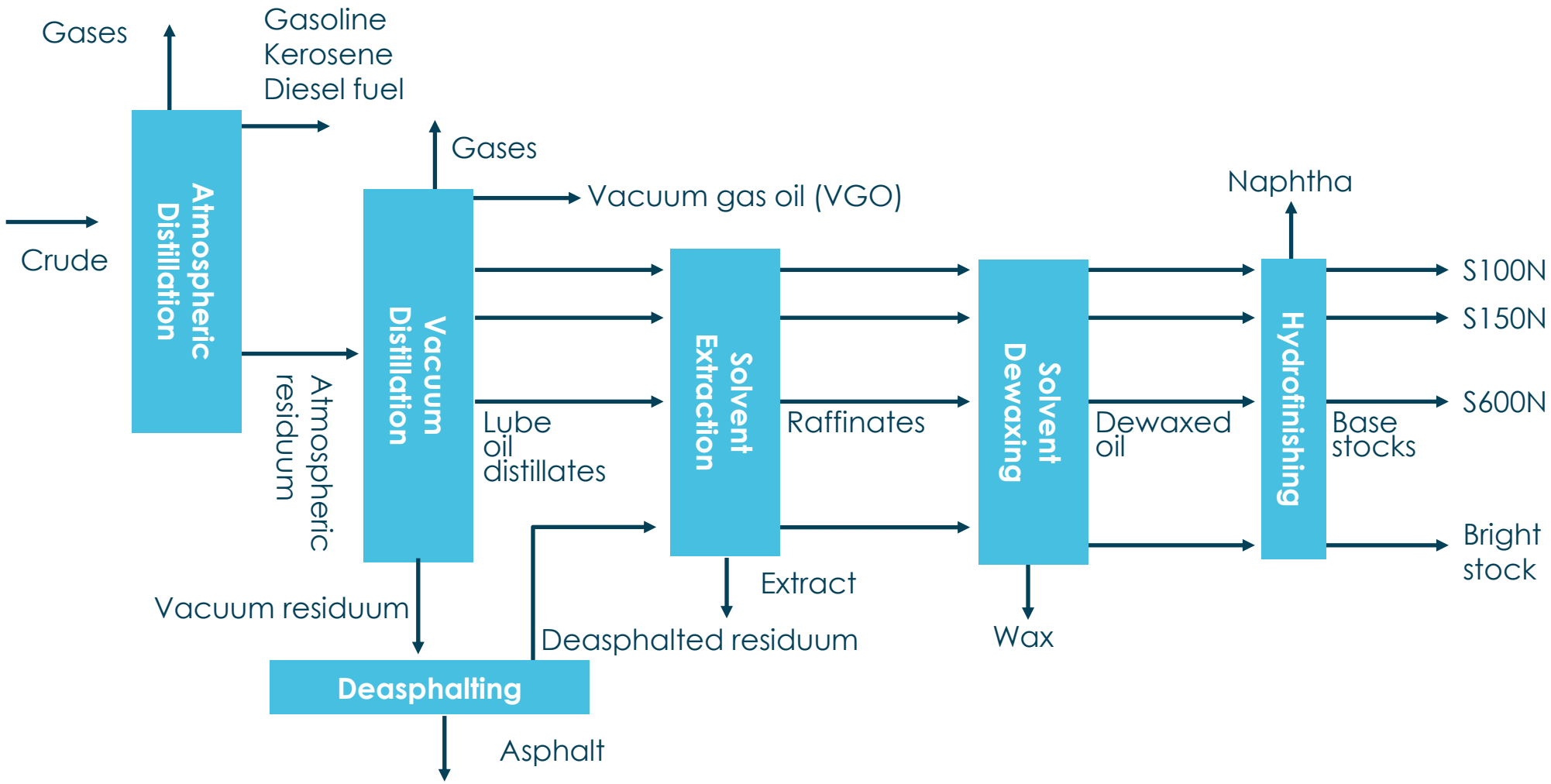
SYNTHESIS

- Synthetic technology
- PAO – PolyAlphaOlefin – combine small double-bond molecules
- GTL – gas to liquid – combine methane (natural gas) into large hydrocarbons
- Esters – build up specific molecules using various starting molecules

(Group III, IV, & V)

Solvent extraction

Solvent extraction refinery process



Solvent extraction

Separation based on solubility

"Good" molecules are *less* polar

- Straight and branched chain paraffins
- Naphthenes

More "like oil"

"Bad" molecules are *more* polar

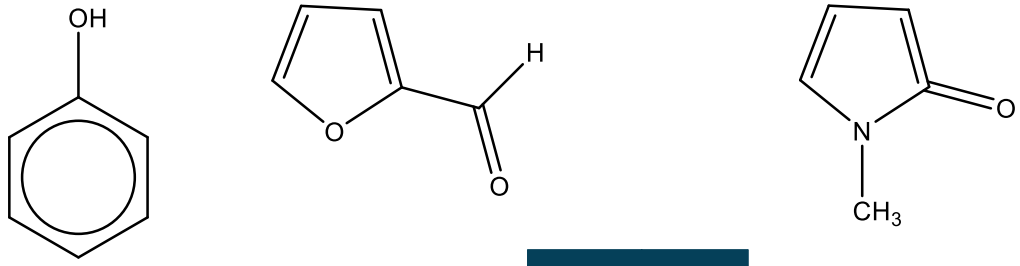
- Aromatics

More "like water"

! Must choose crudes with significant "good" molecules

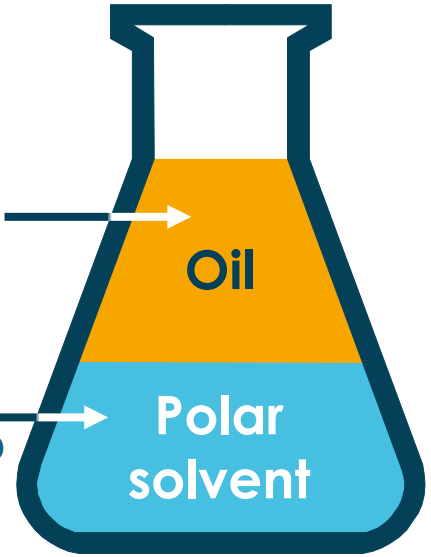
Use a polar solvent

Phenol	Furfural	N-methyl pyrrolidone (NMP)



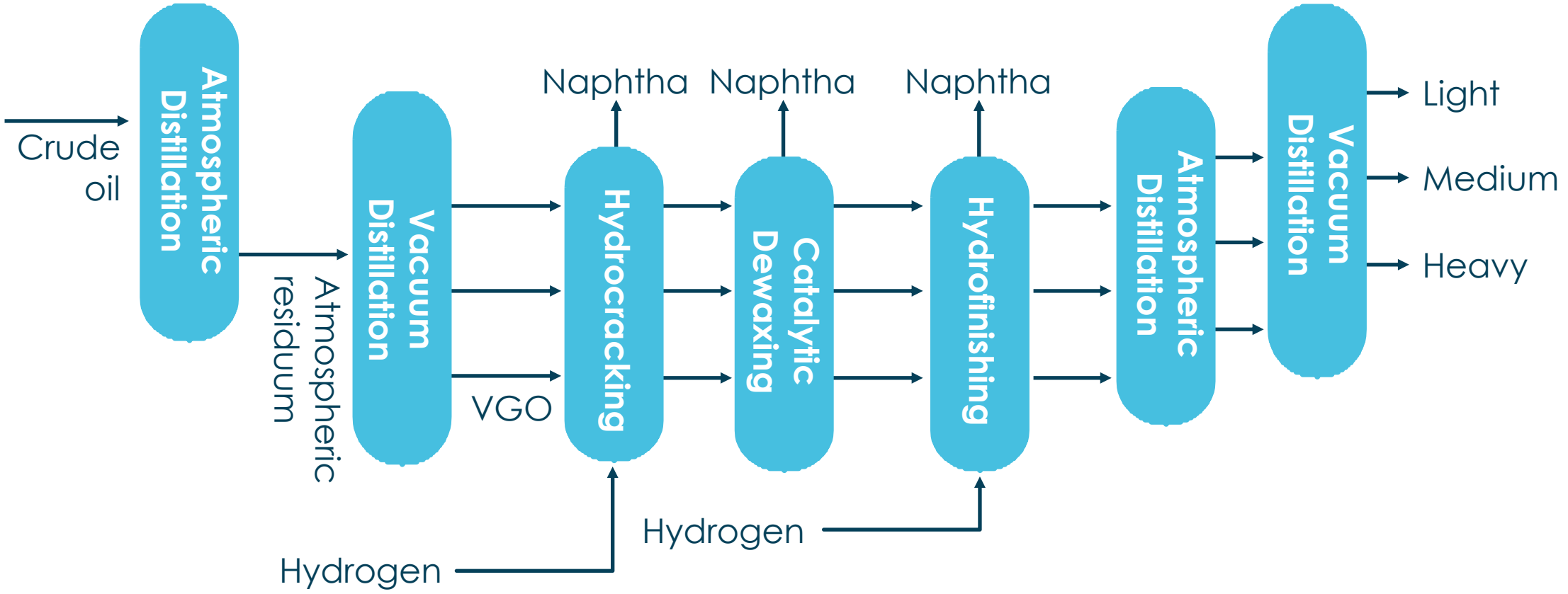
"Good" non-polar molecules stay in oil

"Bad" polar molecules end up in polar solvent



Hydrocracking

Hydrocracking refinery process

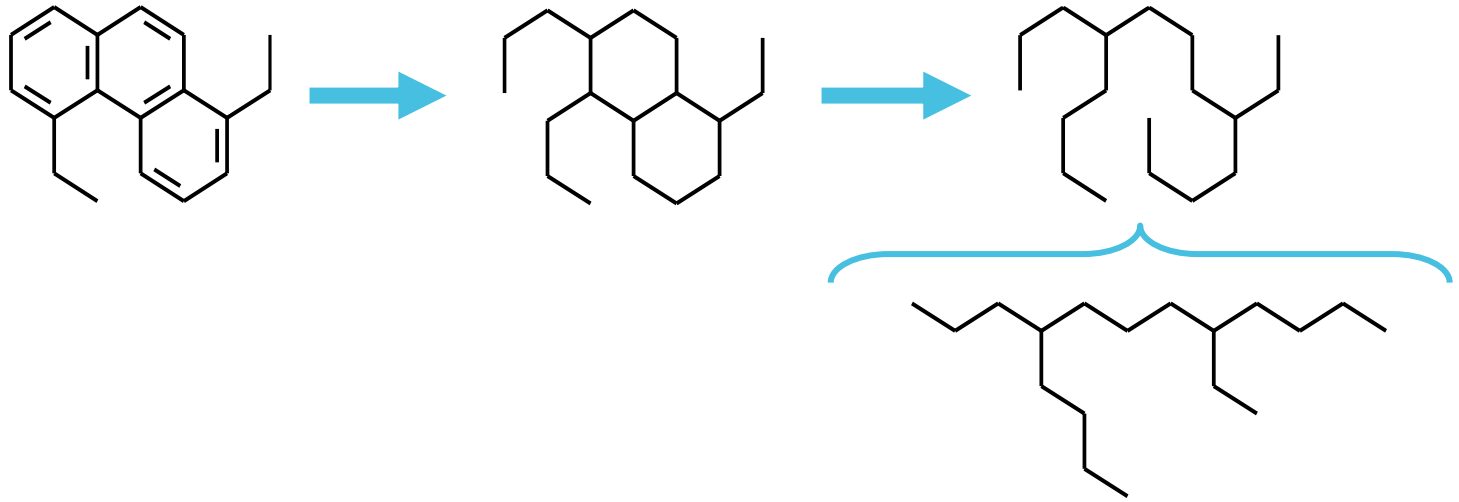


Hydrocracking

Conversion of "bad" molecules into "good" molecules

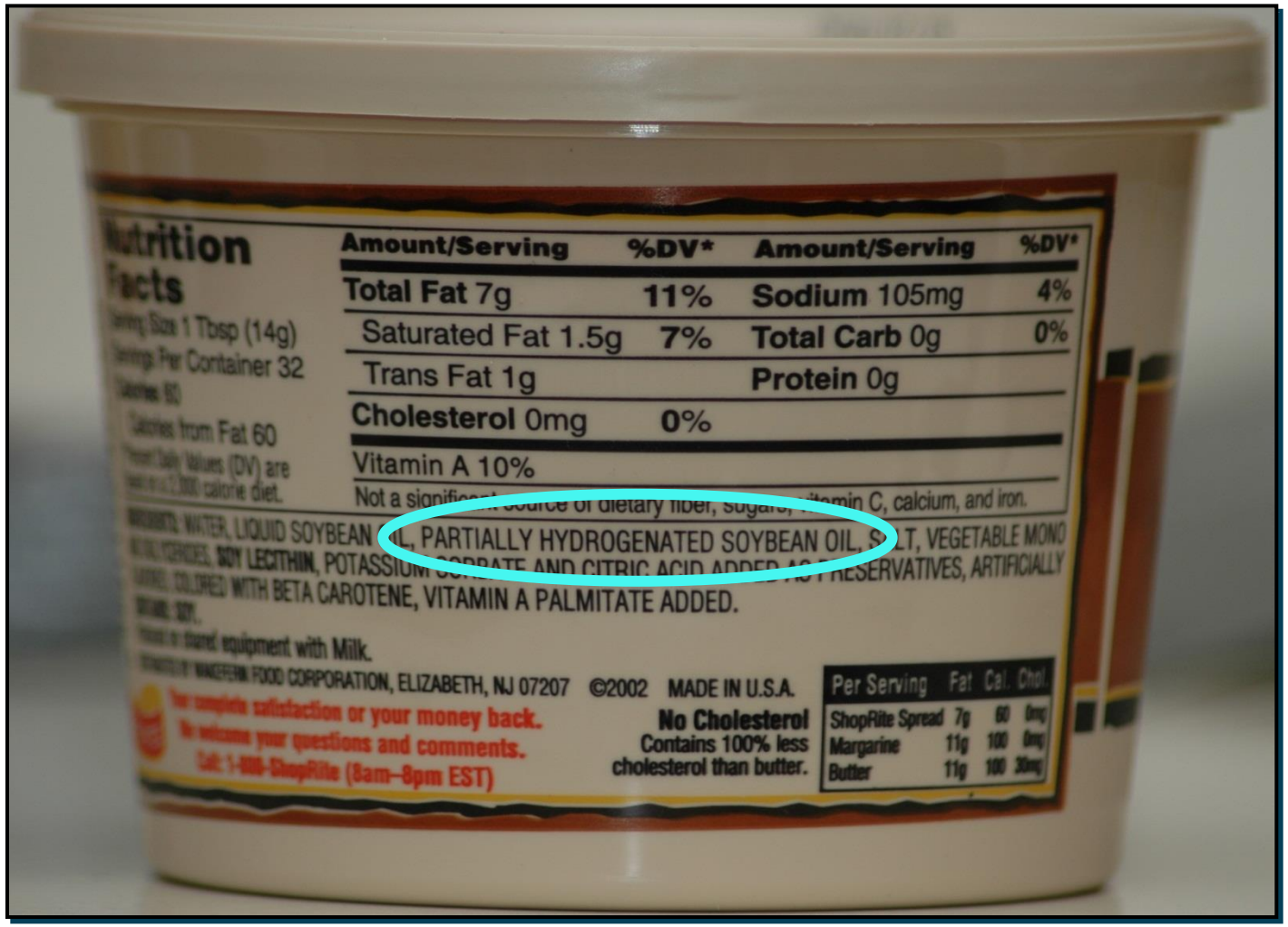
- "Cracking" means breaking apart
- "Hydro" means adding hydrogen
- "Hydrocracking" is breaking bonds and adding hydrogen
  - Hydrocracking usually implies high severity
  - Hydrofinishing usually implies low severity
  - Hydrotreatment can mean either

Hypothetical example



For illustration only – Not real base stock molecules
Base stocks have ~ 30 – 60 carbon atoms
~ 350 – 600 MW

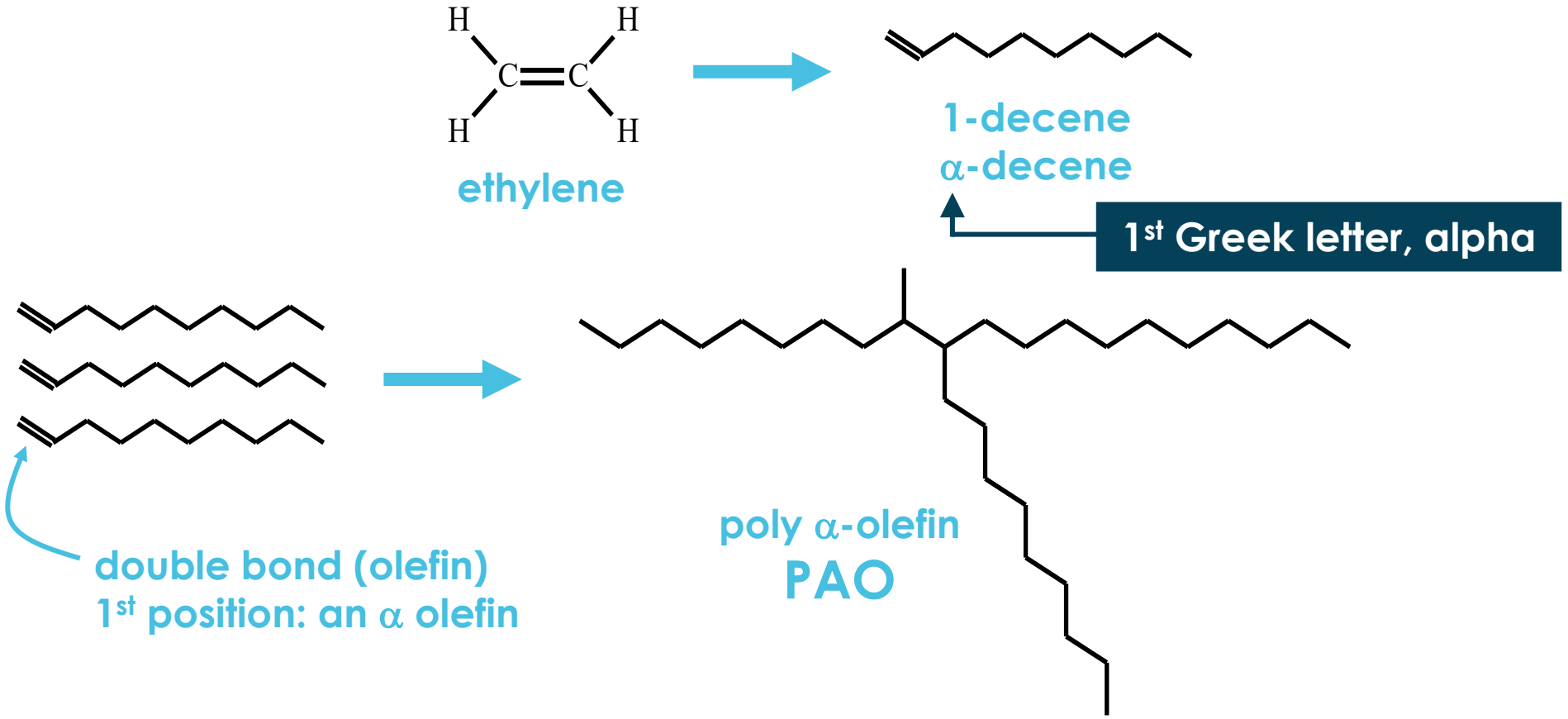
Everyday hydrotreatment



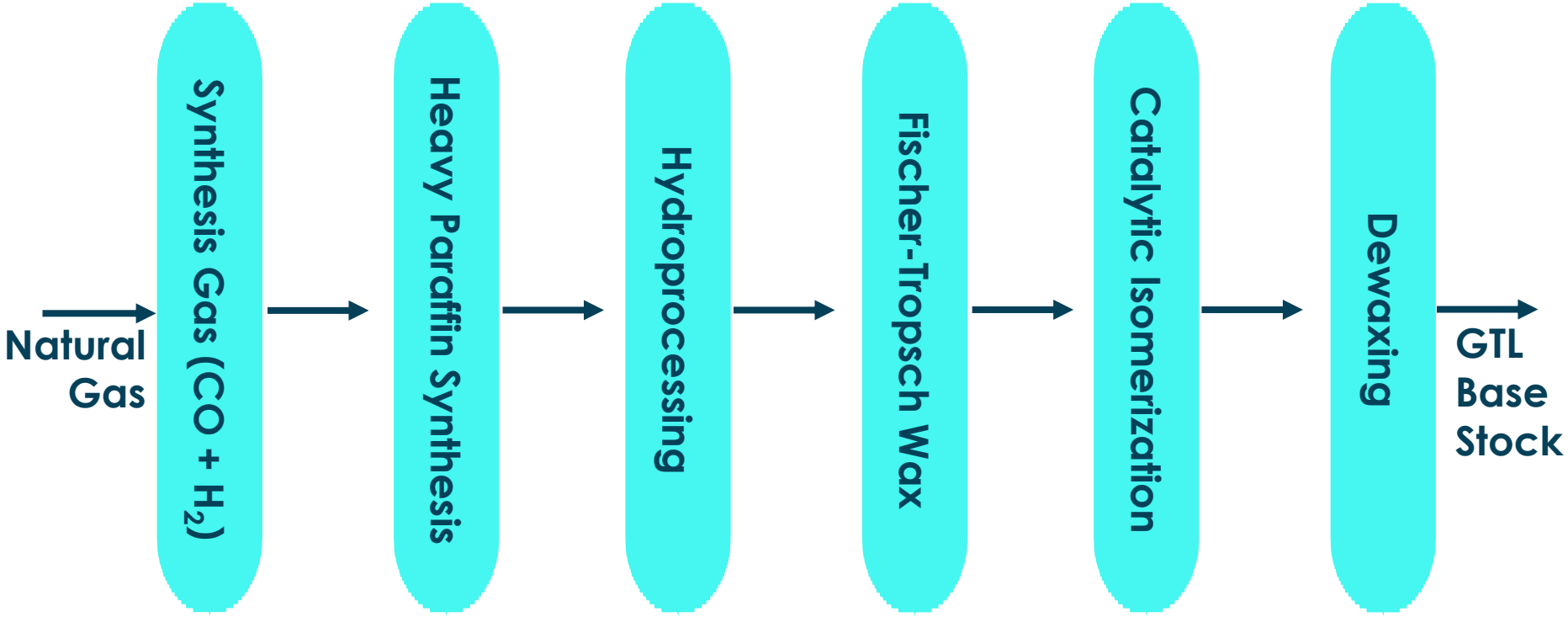
Synthetics and others

Synthetic process – PAO

- **Select small molecules** from other refinery streams
- **Build up good molecules** from the small ones



Gas-to-liquids (GTL)



Source: RPS Energy, Lubes 'n' Greases, May 2014

Re-refining

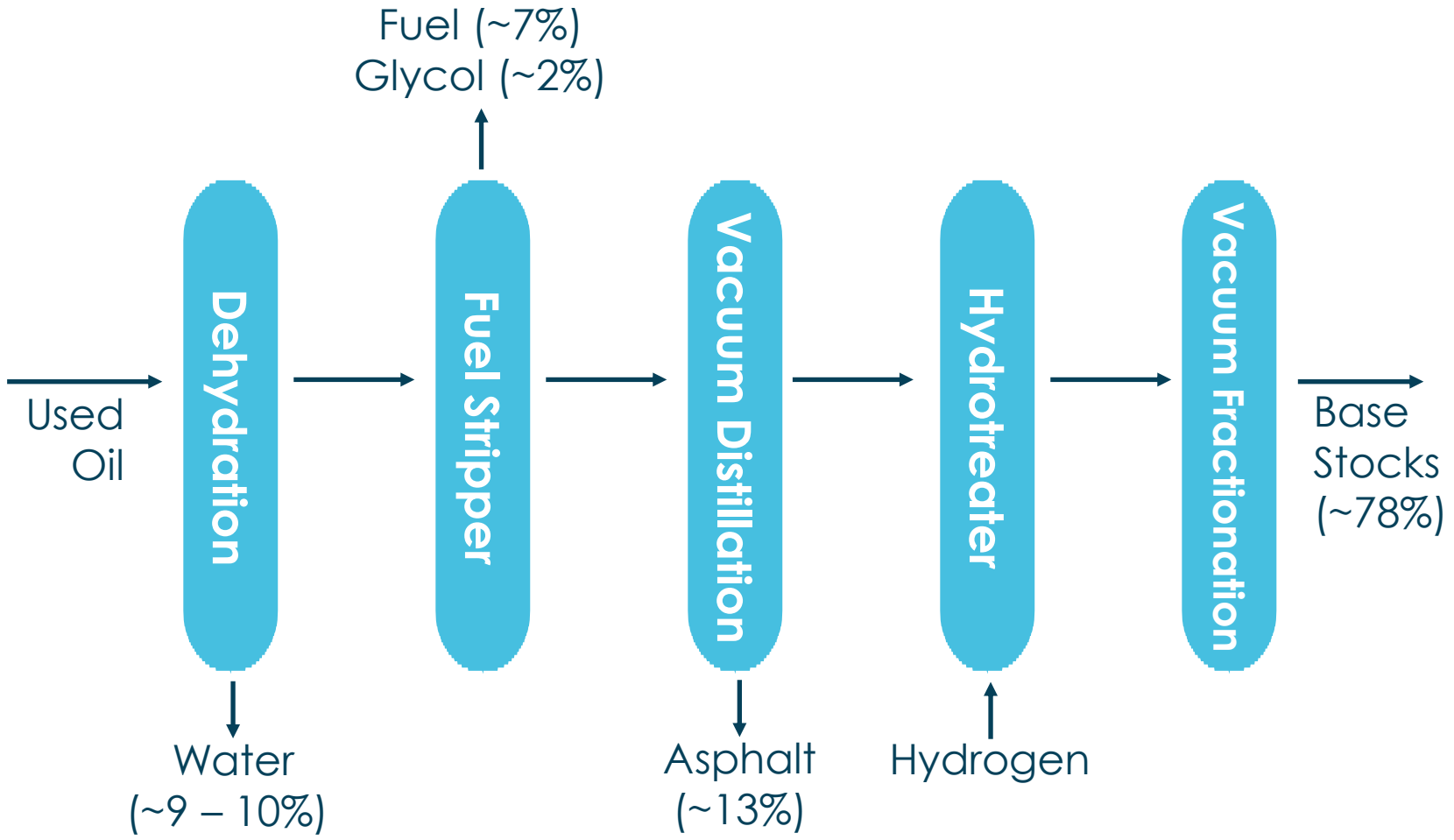
- Starting material is used oil
  - Instead of crude

Mixture of GOOD and BAD molecules

- Very similar to conventional processes
  - Solvent extraction
  - Hydrocracking
- Requires some extra steps
  - Remove water, sludge, dirt, fuel, contaminants
  - Remove additive components
- Quality depends on
  - Starting material
  - Processes
  - Desired targets

Just like conventional base stocks!

Re-refining process



Information courtesy of Safety-Kleen

Other base stock types (reference)

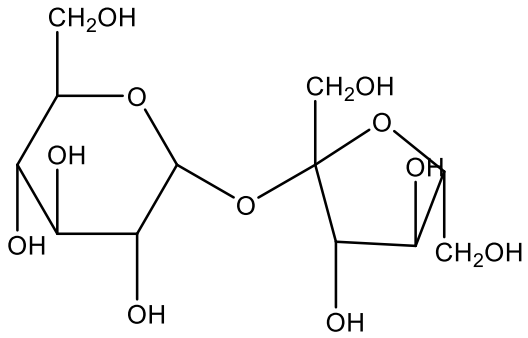
- **Esters**
  - Diesters
  - Polyol esters
  - Phosphate esters
- **PolyAlkylene Glycol** (PAG)
- **Alkylated naphthene** (AN)
- **Polyphenyl ether**
- **Silicones**
- **Bio-based**
  - Natural oils
  - Chemically-functionalized vegetable oils
  - Biotechnology renewable oils (*e.g.*, from plant sugars *via* algae or yeast)
- **Many others**

Reference:
"Synthetics, Mineral Oils, and Bio-Based Lubricants, Chemistry and Technology,"
L. R. Rudnick (ed.), CRC Taylor and Francis, 2006

Bio-base stocks

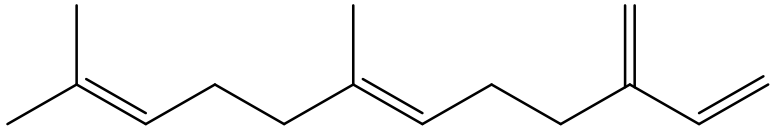
Raw material

- Sugar



Initial process

- Sugar + yeast ➔ farnesene



Synthesis of intermediate

- Farnesene + linear PAO ➔ Intermediate

Synthesis of base stock

- Intermediate + hydrogenation ➔ base stock

Properties (assay of two samples)

- Viscosity Index 140 – 145
- Saturates 93 – 96 %
- Sulphur <0.005%

References:
"New Ideas for Novel Base Stocks" Lubes'nGreases, February 16, 2018

US Patent US20140221258, "Base Oils and Methods for Making the Same" September 1, 2018

API base oil classification

Base oil classification

American Petroleum Institute (API)

Trade association of oil companies

Wanted a way to **classify base oils:**

Base oil is a mixture of (one or more) **base stocks** (ASTM D6074)

Intended for Base Oil Interchange Guidelines (BOIG)

To approve an additive package previously approved in another base oil

- Using read-across
- More detail in the specifications and passenger car sections

Embodied in API 1509

"Engine Oil Licensing and Certification System," **Annex E**, "API Base Oil Interchangeability Guidelines for Passenger Car Motor Oils and Diesel Engine Oils"

Now used for **marketing**, **lobbying**, and other **commercial activities**

API base oil classification

Group	Viscosity Index	Saturates		Sulfur	Other properties
I	80 ≤ x < 120	< 90%	and / or	> 0.03%	
II	80 ≤ x < 120	≥ 90%	and	≤ 0.03%	
III	≥ 120	≥ 90%	and	≤ 0.03%	
IV					PAO (Poly Alfa Olefins)
V					Everything else

Companies started using their own (unofficial) marketing phrases

- "Group II Plus" and "Group III Plus"
- Now used generally to mean "towards the high end of the group"

Note:
The word "Synthetic" is not part of the API Classification

- "Synthetic" is a marketing term, not a technical term
- "Group III" can legally be labeled 'synthetic'

Base stock names

Base stock names – API group I

Base stock names are brand names

- These are some typical naming conventions:

Solvent xxx Neutral (SxxxN, or SNxxx, or xxxSN, *etc.*)

- Solvent from "Solvent Extracted"
- xxx = viscosity, usually Saybolt Universal Seconds (SUS) at 100°F
  - Approximately 4.6 times mm^2/s at 40°C
- Neutral from "Neutralization after Acid Washing"
  - First base stock refining technique

HVI

- Redwood Number 1 Seconds at 140°F (European)

Descriptions

- Light, Medium, Heavy

Bright Stock

- Heaviest grade of base stock (~ S2500N)
- xxx Bright Stock = SUS viscosity at 210°F
  - Approximately 4.6 times mm^2/s at 100°C
- "Bright" because heavy aromatics often fluorescent

Base stock names – API groups II, III, and IV

Base stock names are brand names

- Specific to each producing company
- These are some typical naming conventions:

HC xxx

- HydroCracked with viscosity "xxx"
  - Viscosity often mm^2/s at 100°C
  - Viscosity sometimes equivalent "Neutral" number

MVI, HVI, VHVI, XHVI

– Medium Viscosity Index	Naphthenic	API Group V
– High Viscosity IndexParaffinic	API Group I	
– Very High Viscosity Index	Hydrocracked	API Group II
– eXtra High Viscosity Index	Hydrocracked	API Group III

PAO

- Usually some number related to viscosity
- Often mm^2/s at 100°C

Base stocks in detail

Base stock grade equivalents

Grade	SUS* at 100°F	Redwood# at 140°F	mm²/s at 100°C	mm²/s at 40°C
S 75N	75	-	3.1	13
S100N	105	-	4.1	20
S150N	155	-	5.1	30
S325N	330	-	8.5	65
S600N	590	160	12.1	115
150 Bright Stock	2500	650	31.5	5000

150 SUS at 210°F

*SUS = Saybolt Universal Seconds
#Approximate

Base stock recent trends

Transition from API Group I to Group II continuing:

- Demand for higher quality (oxidation, dispersancy, *etc*.)
- Specifications with sulfur restrictions
- Demand for lower volatility in lower viscosity grades

API Group I base stocks still have uses:

- Higher viscosity: marine, railroad, gear oils
- Lower viscosity: transformer oils, process oils, spray oils

Demand for API Group III (and Group III plus) will increase:

- Growth of SAE 0W-xx and 5W-xx grades

- **Supply-Demand imbalance** in many regions
- **PAO capacity** expected to increase
- **Green base stocks** are niche for now
  - Re-refined (derived from used oil re-cycling)
  - Bio-lubricants (derived from sugarcane, algae, *etc*.)

Base stock summary

1

Base stocks are the main component in lubricants

Have a significant effect on performance

2

Base stocks are complex mixtures of molecules

Derived from crude oil by refinery processes

3

Chemical composition determines performance

Saturates and sulfur usually most important, but not the whole story

4

Physical properties are also important

Viscosity, viscosity index, pour point, volatility

5

Performance testing of products still required

Compositional effects not well enough known

Additives are a major factor in finished products

API BOIG's are used to read-across testing

6

Base stock research continuing

Develop better analytical test methods

Improve performance predictions

Demand for higher quality expected to continue

Thank you

Formulating tomorrow together

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