Performance you can rely on.

Lubricant base stocks

InfineumInsight.com/Learn

Infineum

Outline

- What are base stocks?
  - Why are base stock important?
  - Key properties of base stocks
- Refining processes
  - Overview
  - Major base stock types
    - Solvent Extraction (SE)
    - Hydrocracking (HC)
    - Synthetics
    - Others
- API base oil groups
- Names and definitions
- Measurements and typical targets
- Recent trends

Lubricant base stocks

- A lubricant component
  - Roughly 80-99+% of petroleum products
    - Usually doesn't have all required properties
    - Additives are used to enhance and customize properties
- Mineral oil base stocks
  - Refined from crude oil
    - Petroleum = "Petra-oleum" = "Rock Oil"
  - Common processes
    - Solvent extraction
      - Separate "good" from "bad" molecules
    - Hydrocracking
      - Convert "bad" molecules into "good" molecules
    - Synthesis
      - "Built" from chemical reactions
- Animal and vegetable oils also used

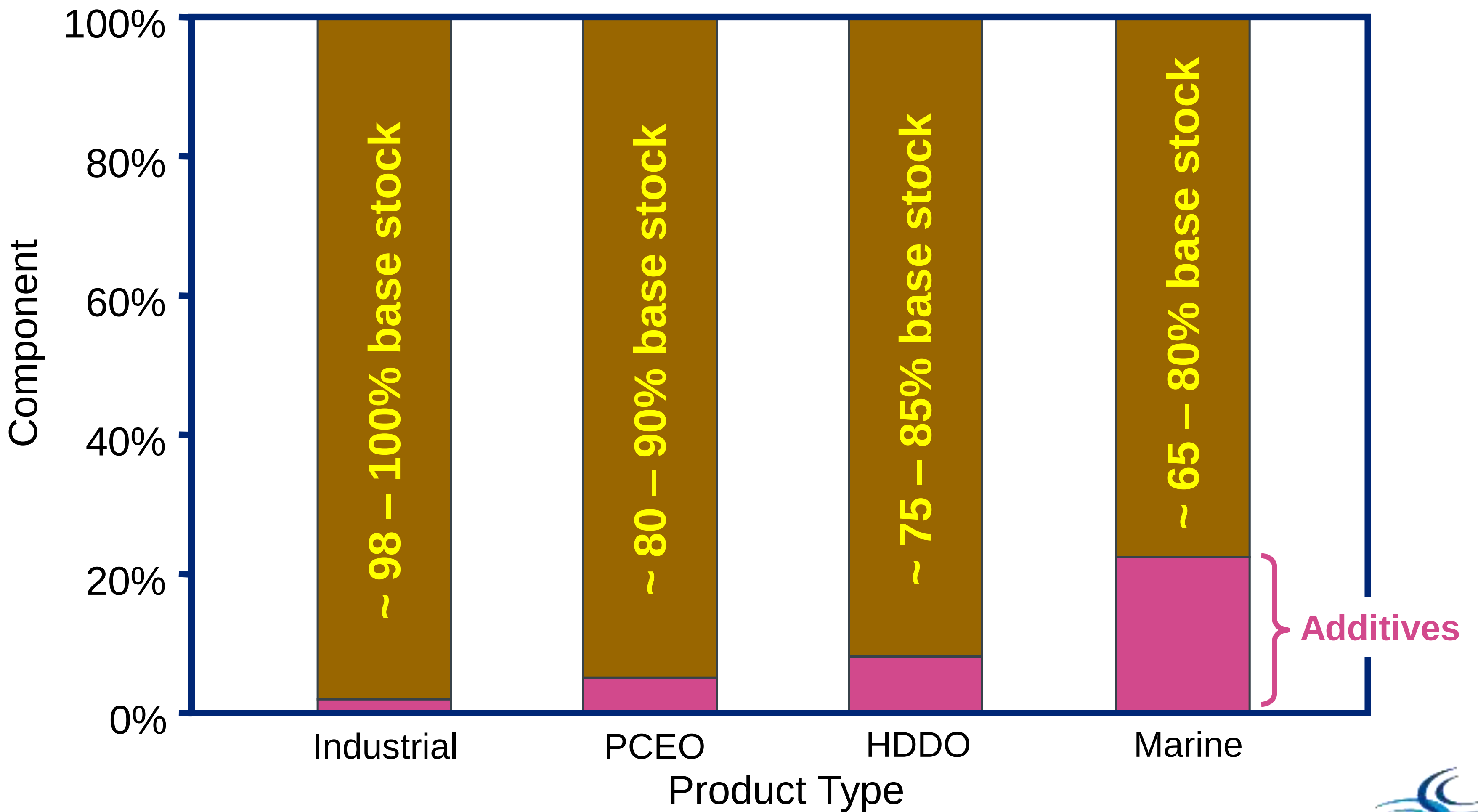
Found in minerals, not made of minerals

Most of the starting materials come from crude oil

Infineum

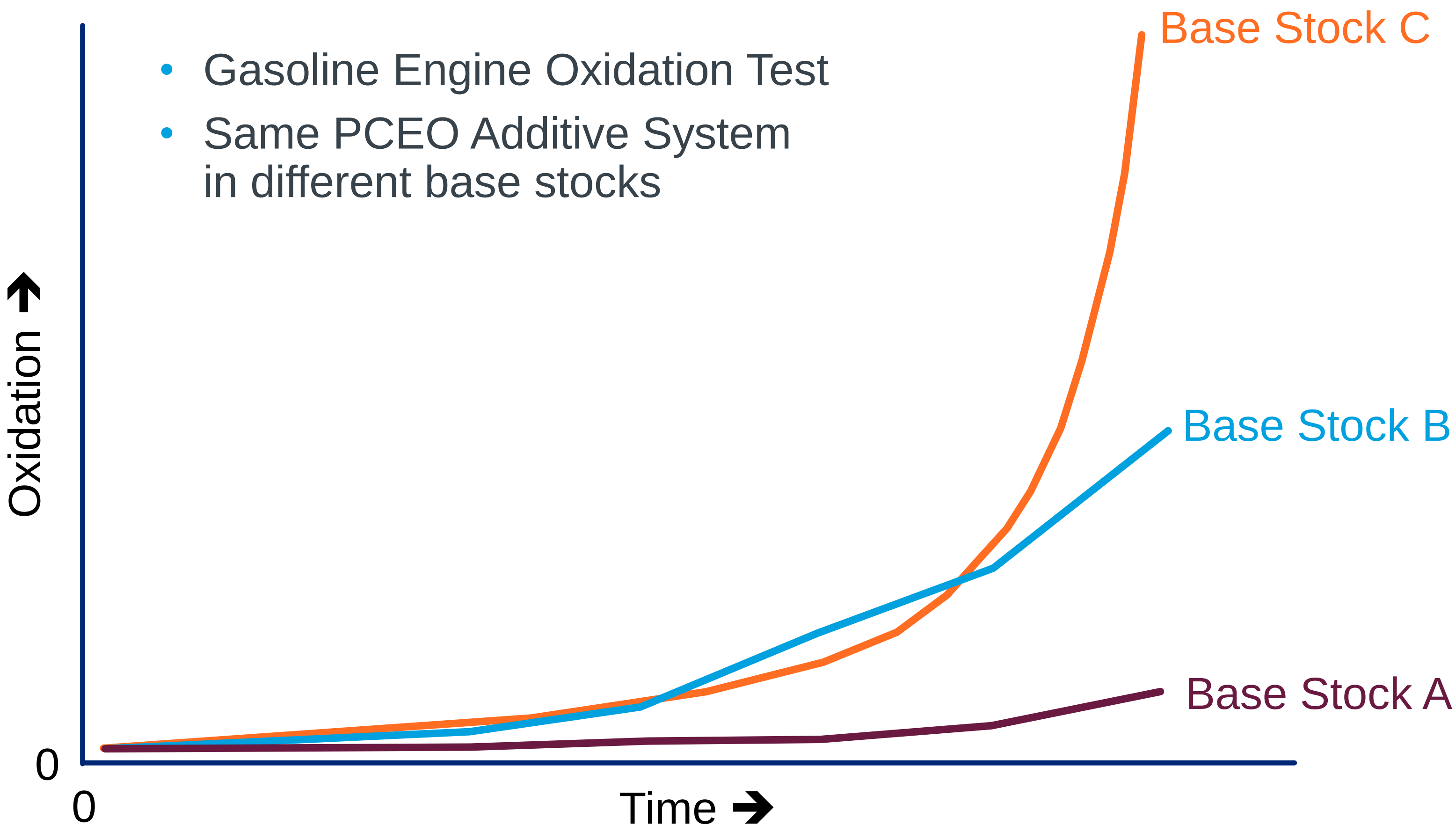
Why are base stocks important?

1. They are the major component in lubricants



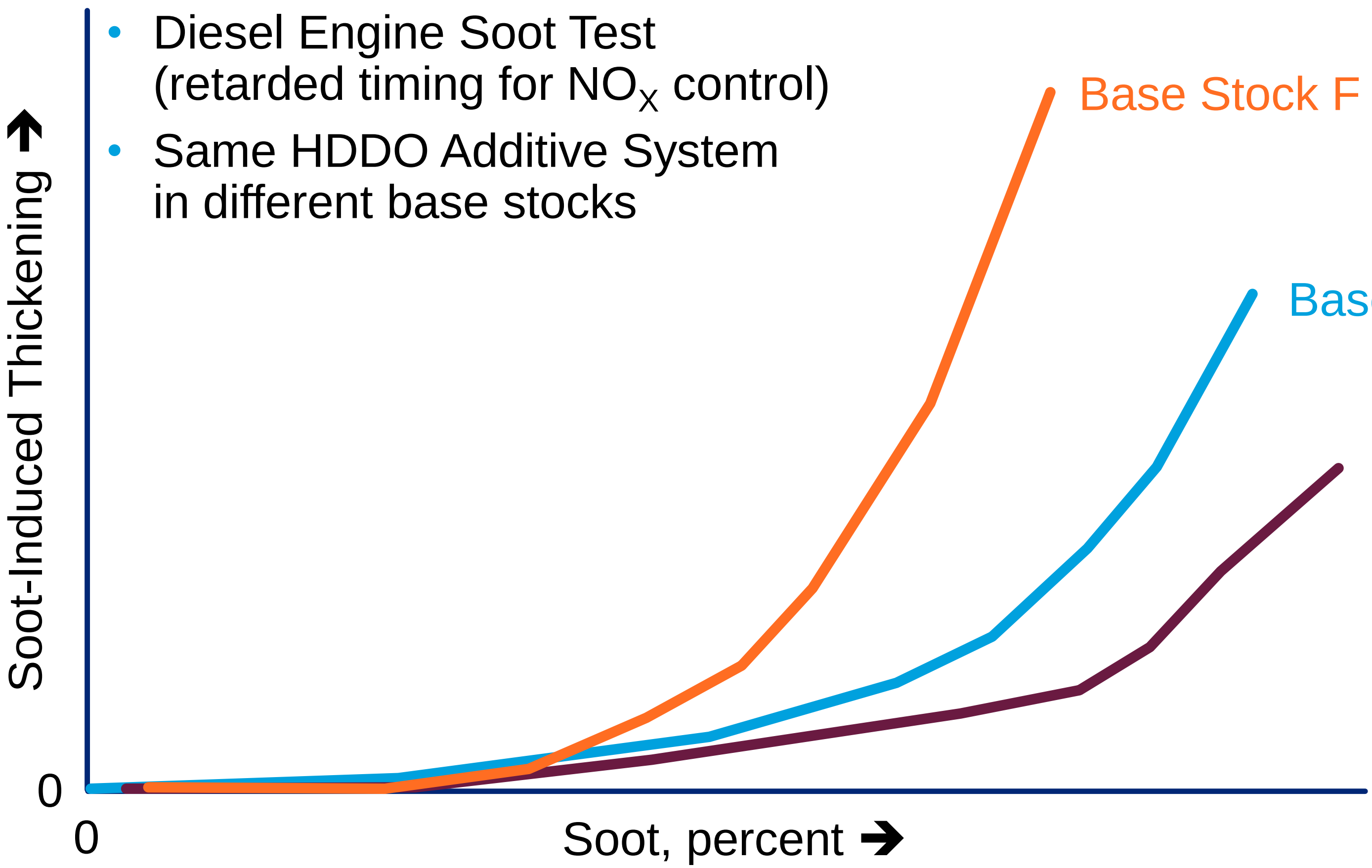
Why are base stocks important?

2. They have a major effect on performance (oxidation)



Why are base stocks important?

3. They have a major effect on performance (soot-handling)



Lubricant properties affected by base stocks

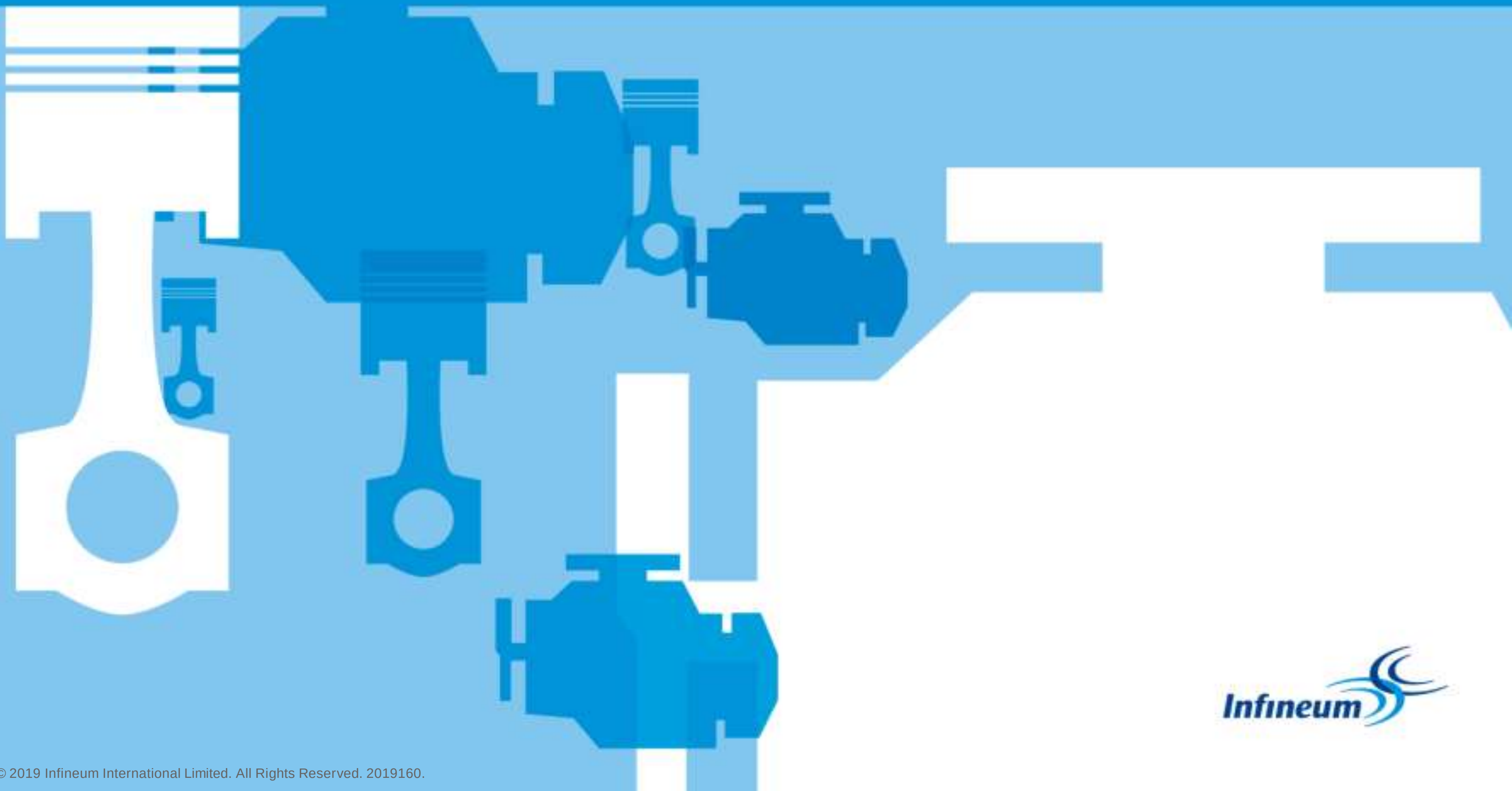
- Viscometrics
  - SAE viscosity grade (*e.g.*, SAE 5W-30)
  - Viscosity Index
  - Pour point and low temperature fluidity
  - Fuel economy
  - Wear protection
- Oxidation
  - Viscosity increase
  - Acid formation, that leads to corrosion
  - Deposit control
- Dispersancy and solvency
  - Soot control (HDD)
  - Viscosity increase and filter plugging
  - Sludge
  - Deposit control
- Foaming and air entrainment
- Volatility (evaporation)
  - Oil Consumption and Flash Point

Key base stock properties

- Viscosity (D445)
  - Sometimes kinematic viscosity at 100°C: HC 4, HC 6, HC 12
  - Sometimes “Neutral Number”: S150N, S600N
  - ISO Grade for Industrial Oils – related to kinematic viscosity (mm^2/s) at 40°C
  - Low temperature: CCS (D5293), MRV (D4684), SBV (D5133), Pour Point (D97)
- 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 – Not perfect
- Sulfur (D4294)
  - Corrosive and poison to exhaust catalysts
- Volatility (D5800)
  - Evaporation
- Chemical properties are also very important
  - More difficult to measure and specify

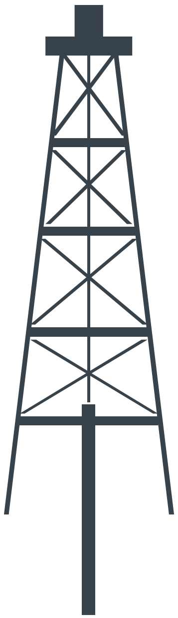
Infineum

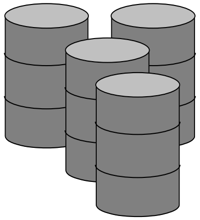
Base stock refining



Infineum

Refinery overview





Crude oil → Refinery processes → Petroleum products

Refining in a nutshell

- Start
  - Crude oil
  - Mixtures of **GOOD** and **BAD** molecules
- Goal
  - **REDUCE** the Proportion of **BAD** molecules
  - **INCREASE** the Proportion of **GOOD** molecules
- Using Refining processes:
  - Separation
    - Remove the **BAD** molecules
      - Throw them away?
      - Use them for something else!
  - Conversion
    - Change **BAD** molecules into **GOOD** molecules
  - Synthesis
    - Build **GOOD** molecules from small ones
- Other processing steps involved
  - Not covered today

"Good" for lubricating oils

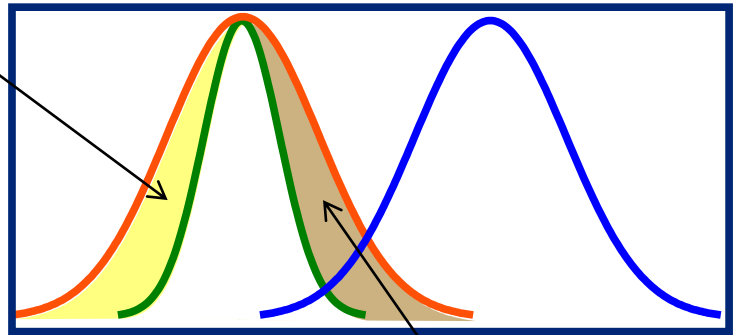
Solvent Extraction

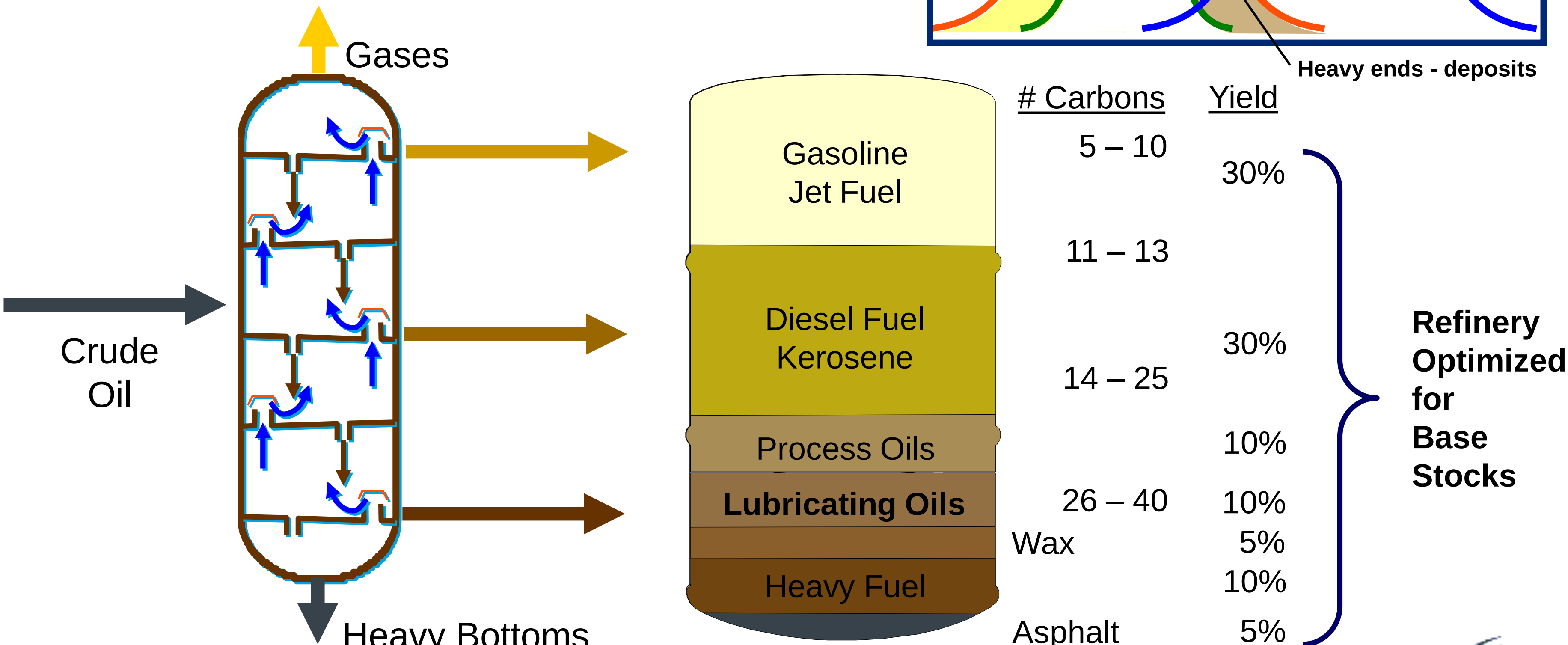
Hydrocracking

Synthetics

Major base stock refinery processes – 1

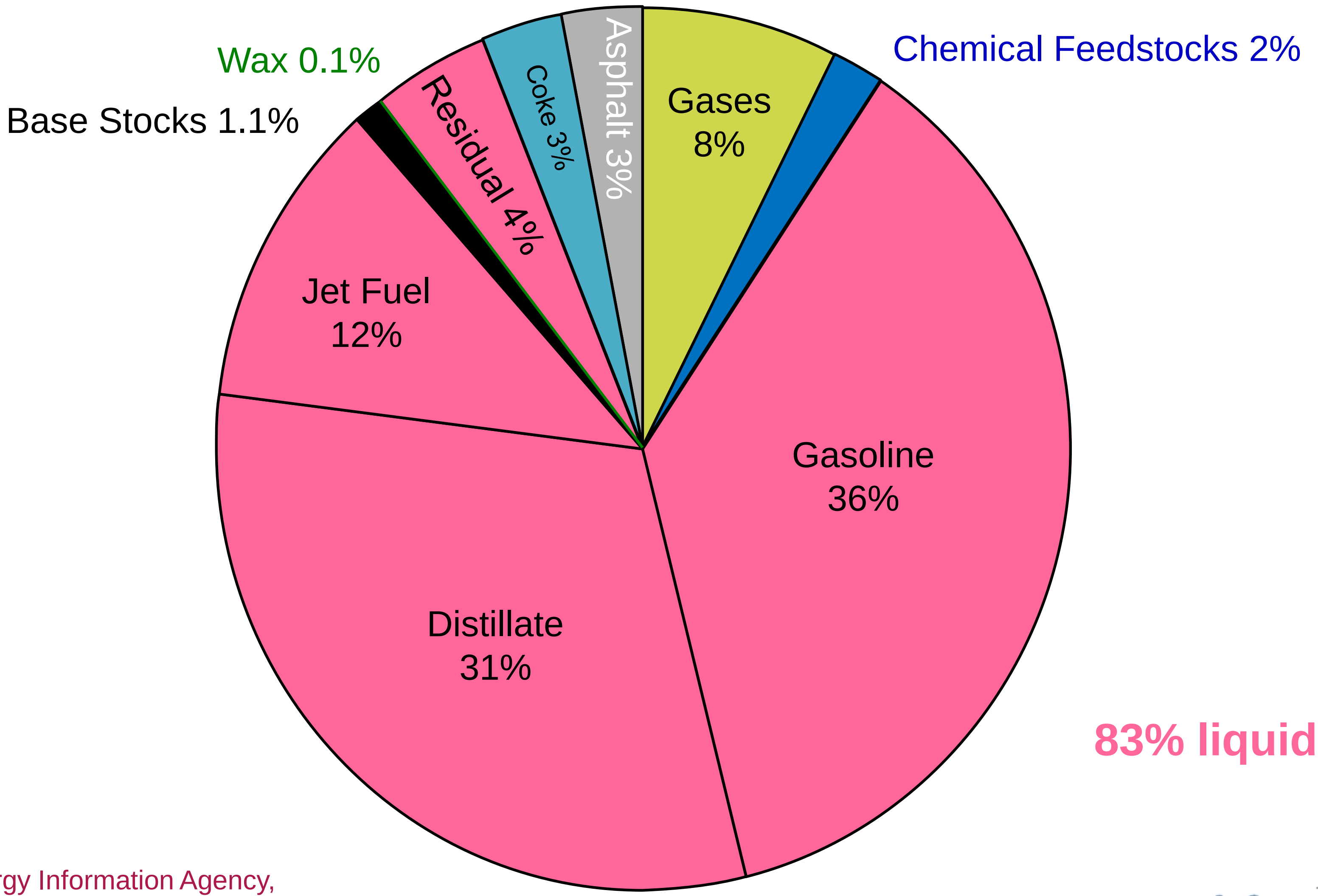
- Distillation
  - Separates lighter from heavier fractions
  - Selects viscosity 'cut' →
  - Controls volatility (evaporation) →





Infineum

U.S. refinery yields



83% liquid fuels

Energy Information Agency,
U.S. Department of Energy

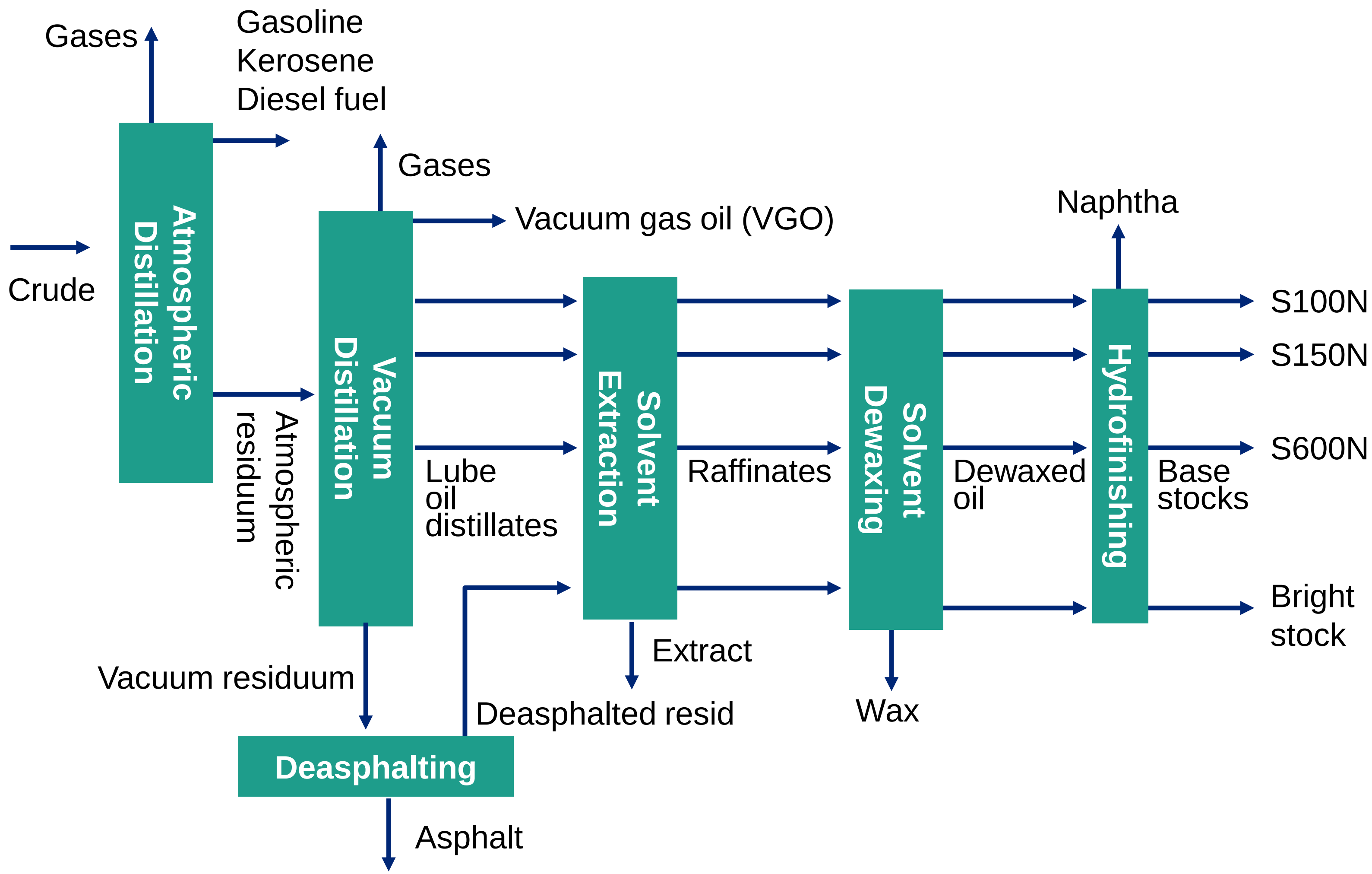
Major base stock refinery processes – 2

- Solvent Extraction (Group I)
  - Separation technology
  - Polar solvent removes aromatics leaving good saturated molecules
  - Removes sulfur, which is predominantly in aromatic molecules
- Hydrocracking (Group II & III)
  - 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
- Synthesis (Group III, IV, & V)
  - GTL – Gas to Liquid – combine methane (natural gas) into large hydrocarbons
  - PAO – PolyAlphaOlefin – combine small double-bond molecules
  - Esters – Build up specific molecules using various starting molecules

Infineum

Solvent Extraction

Solvent extraction refinery process



Solvent extraction

- Separation based on solubility
  - "Good" molecules are less polar
    - Straight and branched chain paraffins
    - Naphthenes
  - "Bad" molecules are more polar
    - Aromatics
- Use a polar solvent
  - "Bad" polar molecules end up in polar solvent
  - "Good" non-polar molecules stay in oil
- Must chose crudes with significant "good" molecules

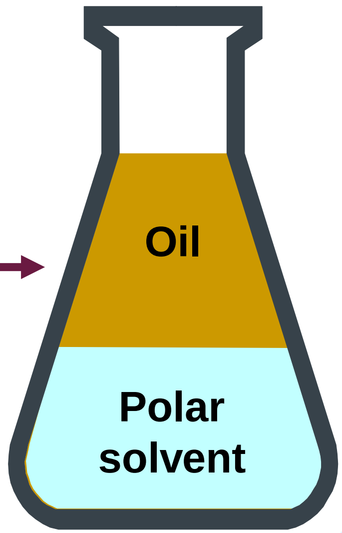
More "like oil"

More "like water"

Phenol
Furfural
N-methyl pyrrolidone

Less polar 'good' molecules end up here

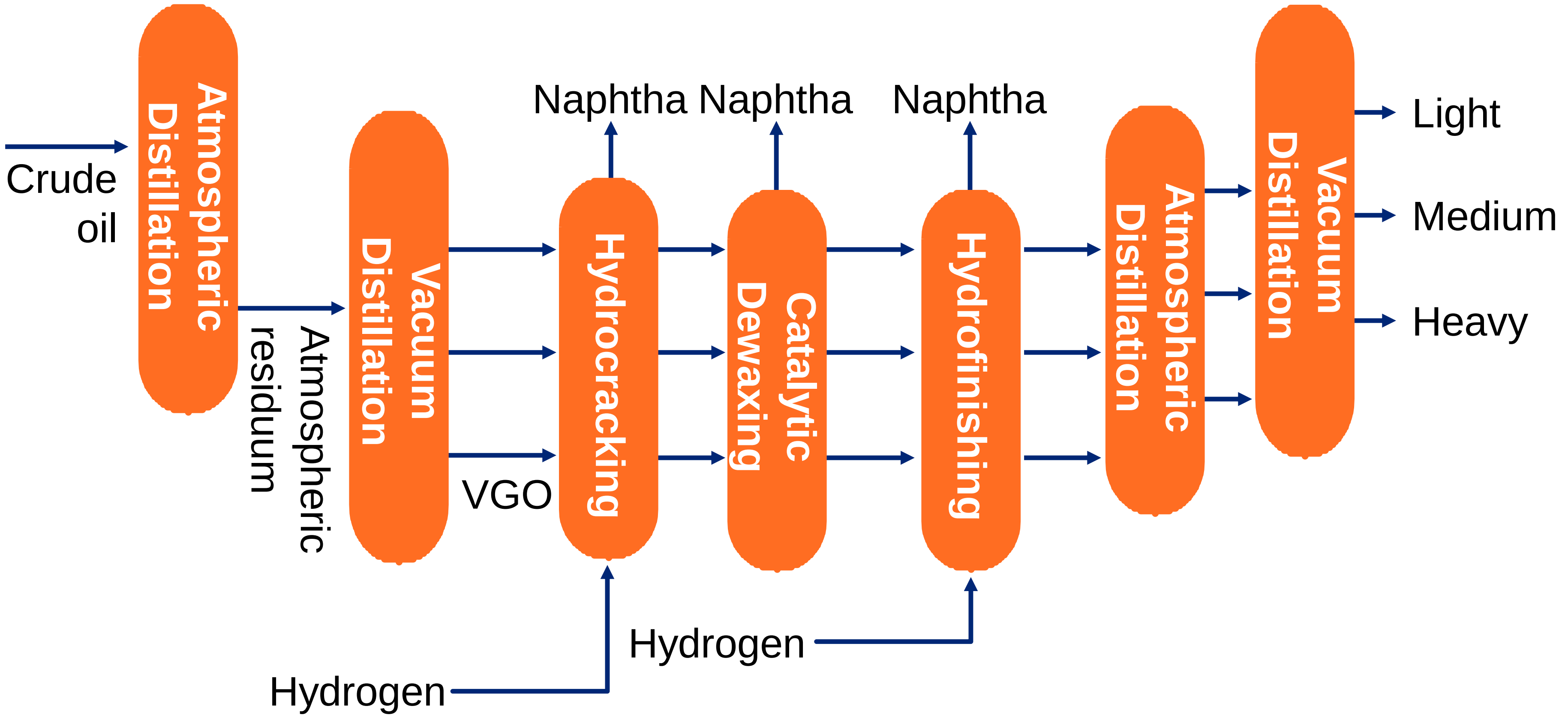
More polar 'bad' molecules end up here



Performance you can rely on.

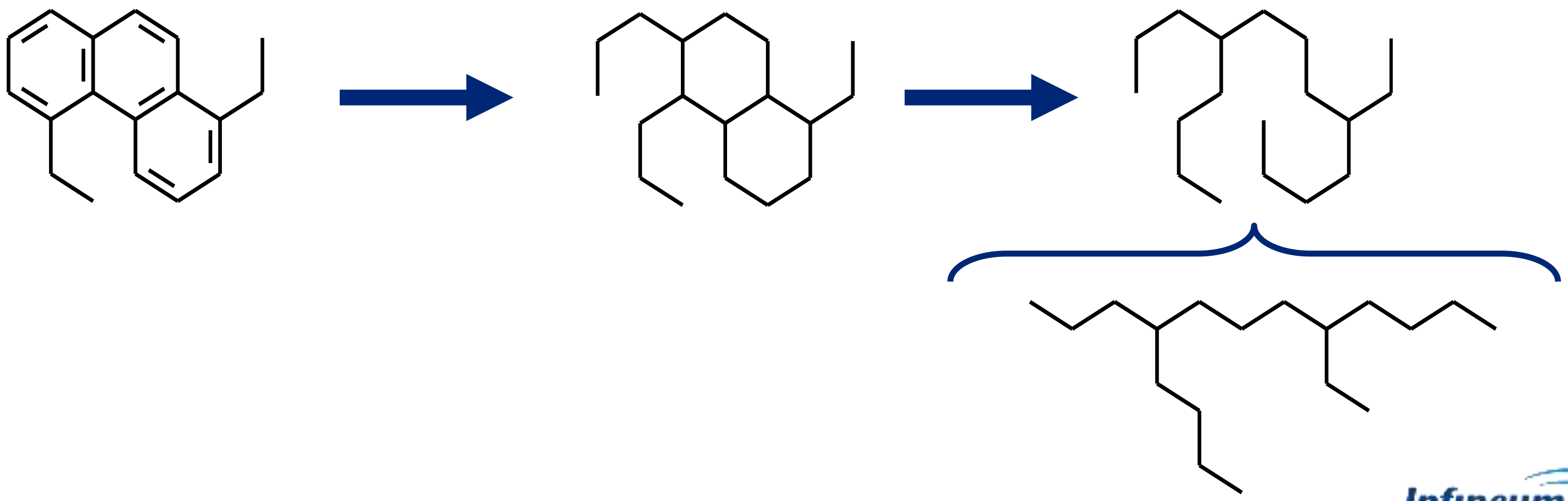
Hydrocracking

Hydrocracking refinery process



Hydrocracking

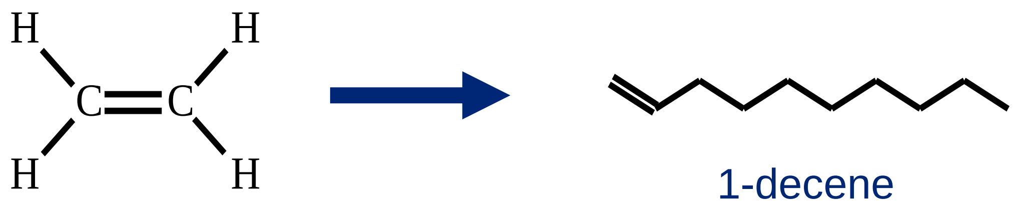
- Conversion of “bad” molecules into “good” molecules
  - “Cracking” means breaking apart
  - “Hydro” means adding hydrogen
  - “Hydrocracking” is breaking bonds and adding hydrogen
    - Hydrocracking usually implies high severity
    - Hydrofinishing usually implies low severity
    - Hydrotreatment can mean either



Synthetics

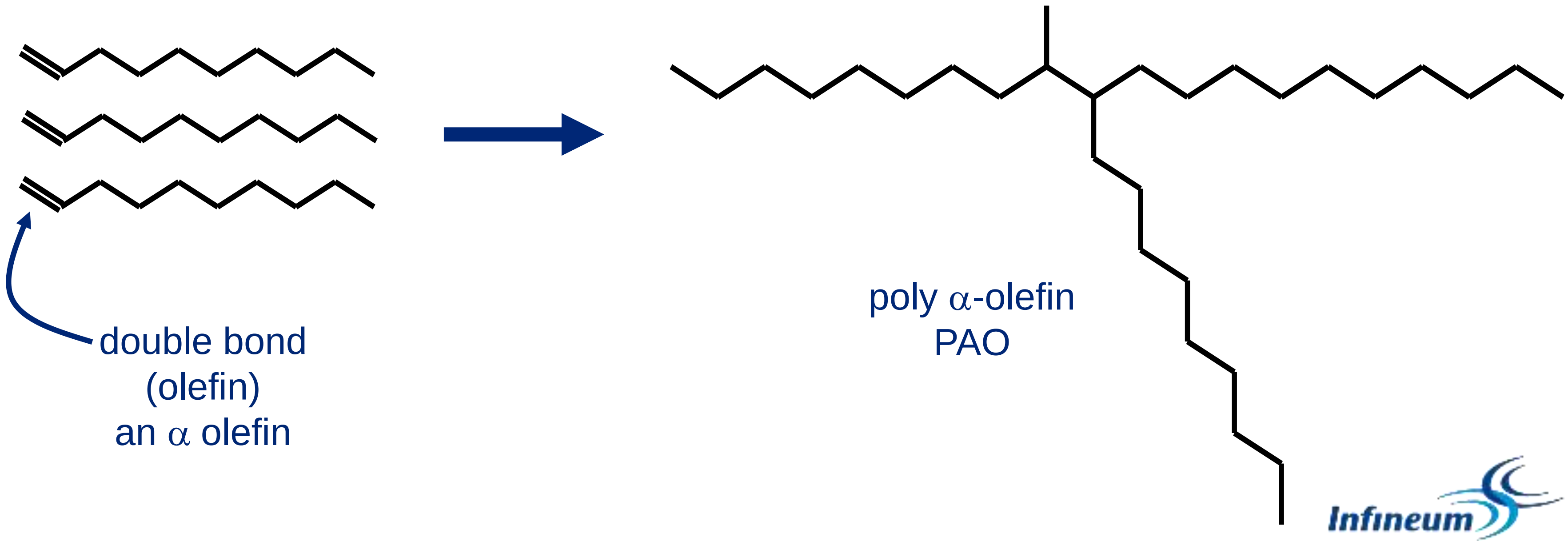
Synthetic process – PAO

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



ethylene

1-decene
α-decene



Infineum

Synthetic process – GTL*

- GTL = Gas-to-Liquids
  - Process of turning natural gas into liquid hydrocarbons
  - Primary focus is liquid fuel production, but base stocks can also be made
- Steam-Methane Reforming (SMR) to make "syngas" ← Also other ways to make syngas

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$CO + H_2O \rightarrow CO_2 + H_2$$
$$CH_4 + CO_2 \rightarrow 2CO + 2H_2$$

Net Reaction:

$$CH_4 + H_2O \rightarrow 2CO + 3H_2$$

"Syngas"

- Followed by Fischer-Tropsch synthesis

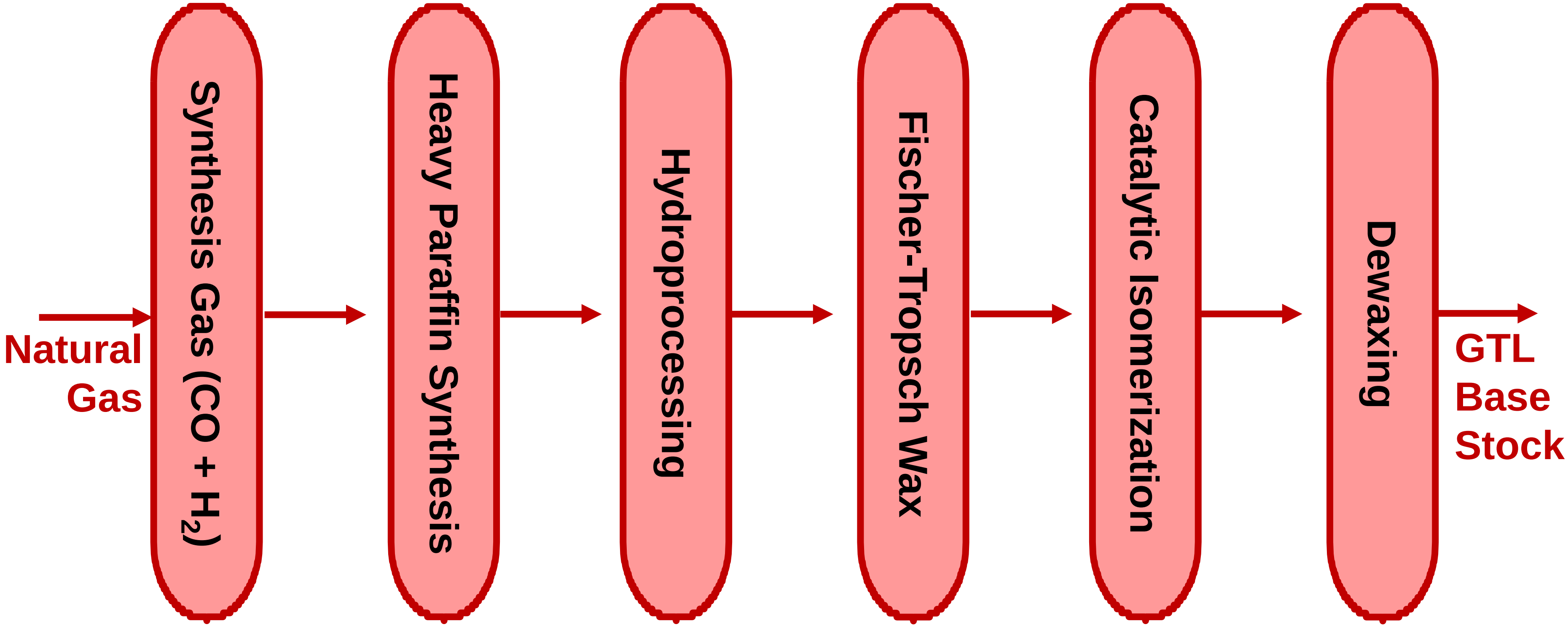
$$nCO + (2n+1)H_2 \rightarrow C_nH_{(2n+2)} + nH_2O$$

- GTL base stocks have:
  - Very high saturates and Viscosity Index
  - Essentially no sulfur, nitrogen, aromatics, or olefins
- GTL's meet the chemical and physical definition of API Group III
- A few GTL plants started supplying
  - A large fuels plant could become largest source of base stock

*"Chemistry and Technology of Lubricants," 3ed., Mortier, Fox, and Orszulik (Eds.), Springer, 2010

Infineum

Gas-to-liquids



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

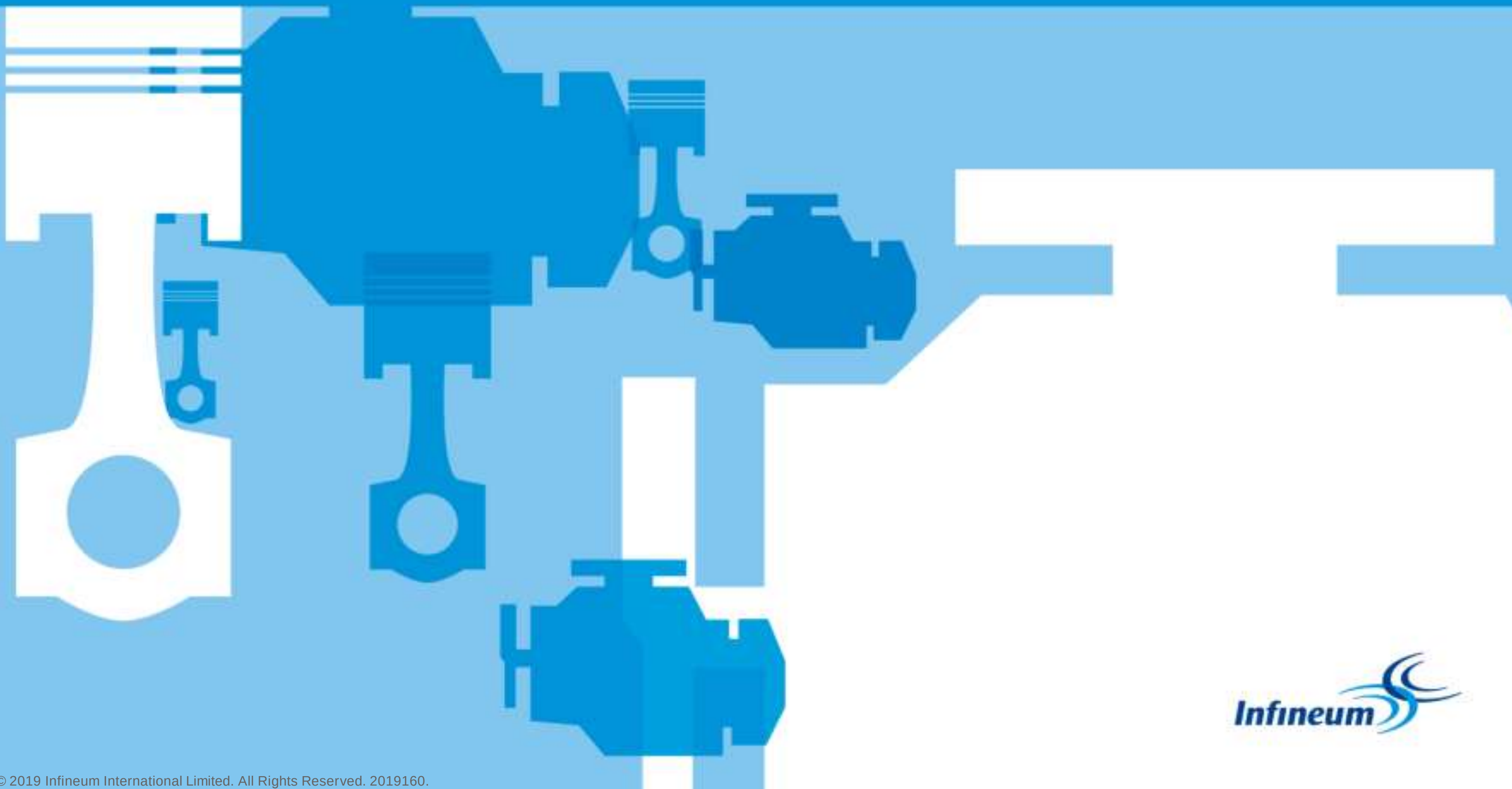
Other base stock types (reference)

- 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)
- Many others

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

Infineum

API base oil classification



Infineum

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

API base oil classification

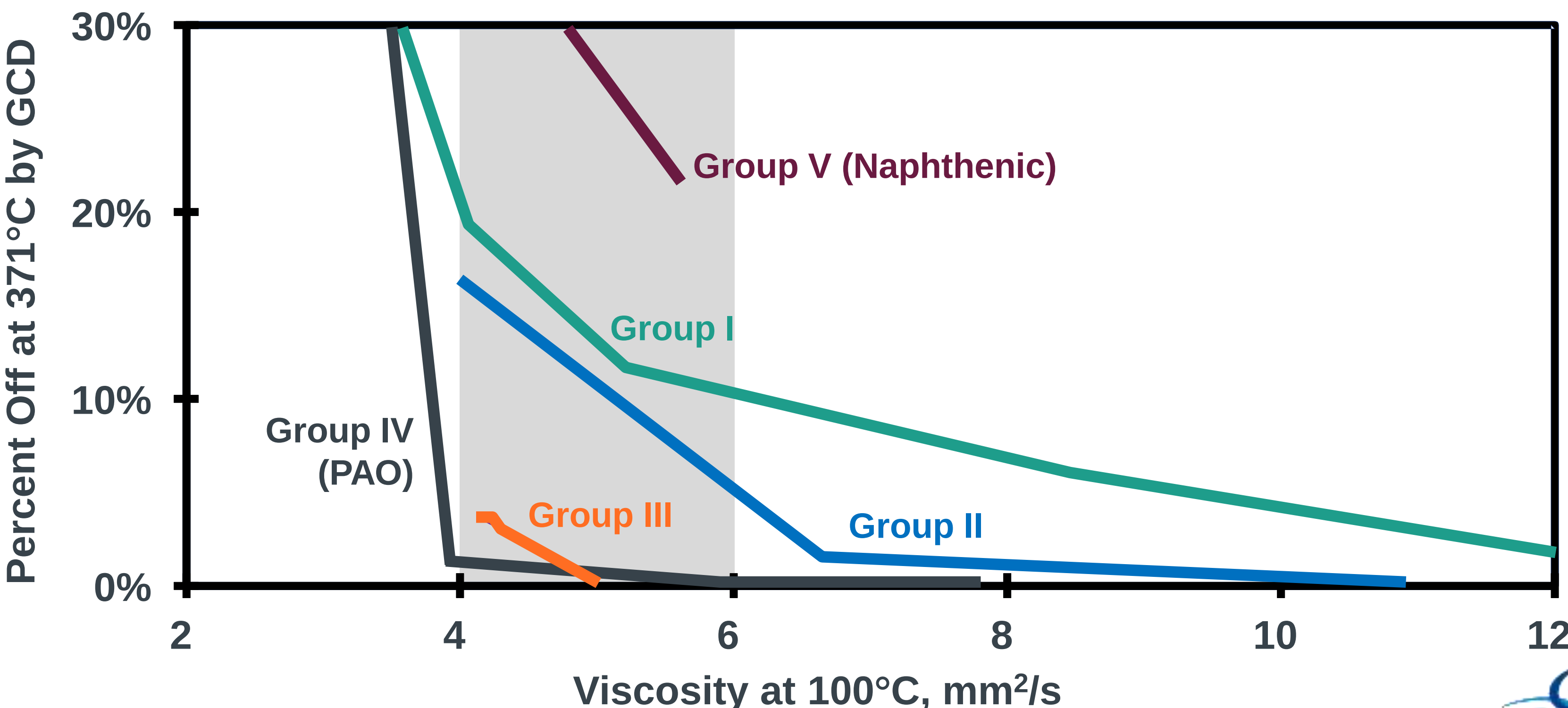
Group	Vis. Index	Saturates		Sulfur	Other Properties
I	80≤ x <120	<90%	and / or	>0.03%	
II	80≤ x <120	≥90%	and	≤0.03%	
III	≥120	≥90%	and	≤0.03%	
IV					PAO (Poly Alpha Olefins)
V					Everything Else

- 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’

Infineum

Volatility

- Volatility depends on viscosity and molecular structure
  - Advantages for Group III and Group IV at low viscosity



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
    - Saybolt Universal Seconds 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

S150N
~32 mm^2/s at 40°C
~5 mm^2/s at 100°C

HVI 150
~11 mm^2/s at 100°C

150 Bright Stock
HVI 650
~32 mm^2/s at 100°C

Base stock names – API Groups II, III, IV, & V

- Base stock names are brand names
  - Specific to each producing company
  - These are typical naming conventions:
- HC xxx
  - HydroCracked xxx
    - xxx viscosity usually mm^2/s at 100°C
      - HC4
    - Sometimes equivalent "Neutral Number"
      - HC100
- MVI, HVI, VHVI and XHVI

– Medium Viscosity Index	Naphthenic	(Group V)
– High Viscosity Index	Paraffinic	(Group I)
– Very High Viscosity Index	Hydrocracked	(Group II)
– eXtra High Viscosity Index	Hydrocracked	(Group III)

- PAO x = usually some number related to mm^2/s at 100°C

– PAO 4	Usually 4 mm^2/s at 100°C
– PAO 45	Could be 4.5 or 45 mm^2/s at 100°C
– PAO 954	Could be 4 or 54 or 95.4 mm^2/s at 100°C

S150N
~5 mm^2/s at 100°C

HVI 150
~11 mm^2/s at 100°C

150 Bright Stock
~32 mm^2/s at 100°C

PAO 150
~150 mm^2/s at 100°C

Infineum

Base stock grade equivalents

Grade	SUS* at 100°F	Redwood# at 140°F	mm^2/s at 100°C	mm^2/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 typical properties

Typical lube base stock properties (solvent neutrals – API Group I)*

	Light (S100N)	Medium (S150N)	Heavy (S600N)	Bright Stock (S2500N)
Viscosity at 100°C, mm^2/s	4	5	12	32
Viscosity at 40C, mm^2/s	20	30	110	490
Viscosity Index	95	95	95	95
Pour Point, °C	-18	-18	-9	-18
Volatility, GCD % off at 371°C	20	15	0	0
Volatility, NOACK	24	18	2	1
Flash Point, °C	200	210	250	280
Saturates, mass percent	75	75	70	60
Sulfur, mass percent	0.3	0.3	0.4	0.7

*Nominal, and not representative of any particular manufacturer

Typical lube base stock properties (hydrocracked – API Group II)*

	Light (100N)	Medium (200N)	Heavy (600N)
Viscosity at 100°C, mm^2/s	4	6	12
Viscosity at 40C, mm^2/s	20	40	110
Viscosity Index	100	100	100
Pour Point, °C	-18	-18	-18
Volatility, GCD % off at 371°C	16	2	0
Volatility, NOACK	23	11	2
Flash Point, °C	200	220	250
Saturates, mass percent	95	95	95
Sulfur, mass percent	0.01	0.01	0.01

*Nominal, and not representative of any particular manufacturer

Typical lube base stock properties (hydrocracked – API Group III)*

	Light (100N)	Medium (150N)	Heavy (250N)
Viscosity at 100°C, mm^2/s	4	6	8
Viscosity at 40C, mm^2/s	17	33	50
Viscosity Index	130	130	130
Pour Point, °C	-18	-18	-12
Volatility, GCD % off at 371°C			
Volatility, NOACK	13	6	4
Flash Point, °C	240	250	260
Saturates, mass percent	97	97	97
Sulfur, mass percent	0	0	0

*Nominal, and not representative of any particular manufacturer

Infineum

Typical lube base stock properties (GTL – API Group III)*

	Very Light (GTL 3)	Light (GTL 4)	Medium (GTL 6)	Heavy (GTL 8)
Viscosity at 100°C, mm²/s	3	4	6	8
Viscosity at 40C, mm²/s	11	17	32	46
Viscosity Index	120	130	135	145
Pour Point, °C	-42	-33		-24
Volatility, GCD % off at 371°C		3	0.6	0
Volatility, NOACK	34	9	3	1
Flash Point, °C	200	230	240	270
Saturates, mass percent	98	97	97	96
Sulfur, mass percent	0	0	0	0

*Nominal, and not representative of any particular manufacturer

Infineum

Typical lube base stock properties (PAO – API Group IV)*

	Light (PAO 4)	Medium (PAO 6)	Heavy (PAO 10)	Very Heavy (PAO 100)
Viscosity at 100°C, mm^2/s	4	6	10	100
Viscosity at 40C, mm^2/s	18	30	65	1300
Viscosity Index	130	135	130	160
Pour Point, °C	-63	-63	-51	-30
Volatility, GCD % off at 371°C	1	0	0	0
Volatility, NOACK	12	2	1	1
Flash Point, °C	200	240	270	290
Saturates, mass percent	96	96	96	94
Sulfur, mass percent	0	0	0	0

*Nominal, and not representative of any particular manufacturer

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*.)

Infineum

Base stock summary

- Base stocks are the main component in lubricants
  - Have a significant effect on performance
- Base stocks are complex mixtures of molecules
  - Derived from crude oil by refinery processes
- Chemical composition determines performance
  - Saturates and sulfur usually most important, but not the whole story
- Physical properties are also important
  - Viscosity, Viscosity Index, pour point, volatility
- 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
- Base stock research continuing
  - Develop better analytical test methods
  - Improve performance predictions
  - Demand for higher quality expected to continue