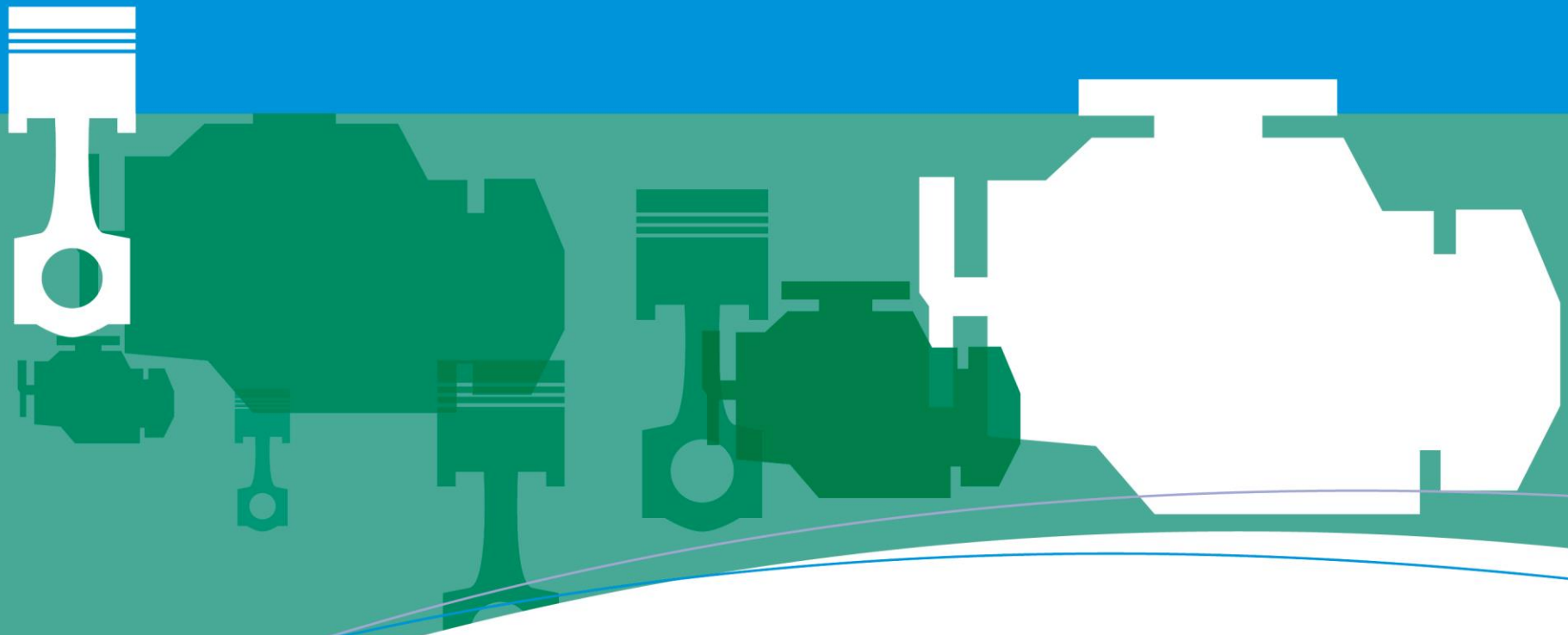
Performance you can rely on.

Lubricant Base Stocks



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Introduction

Base stocks are the main component in lubricants

Base stocks exhibit certain properties that impact how the lubricant performs in the engine

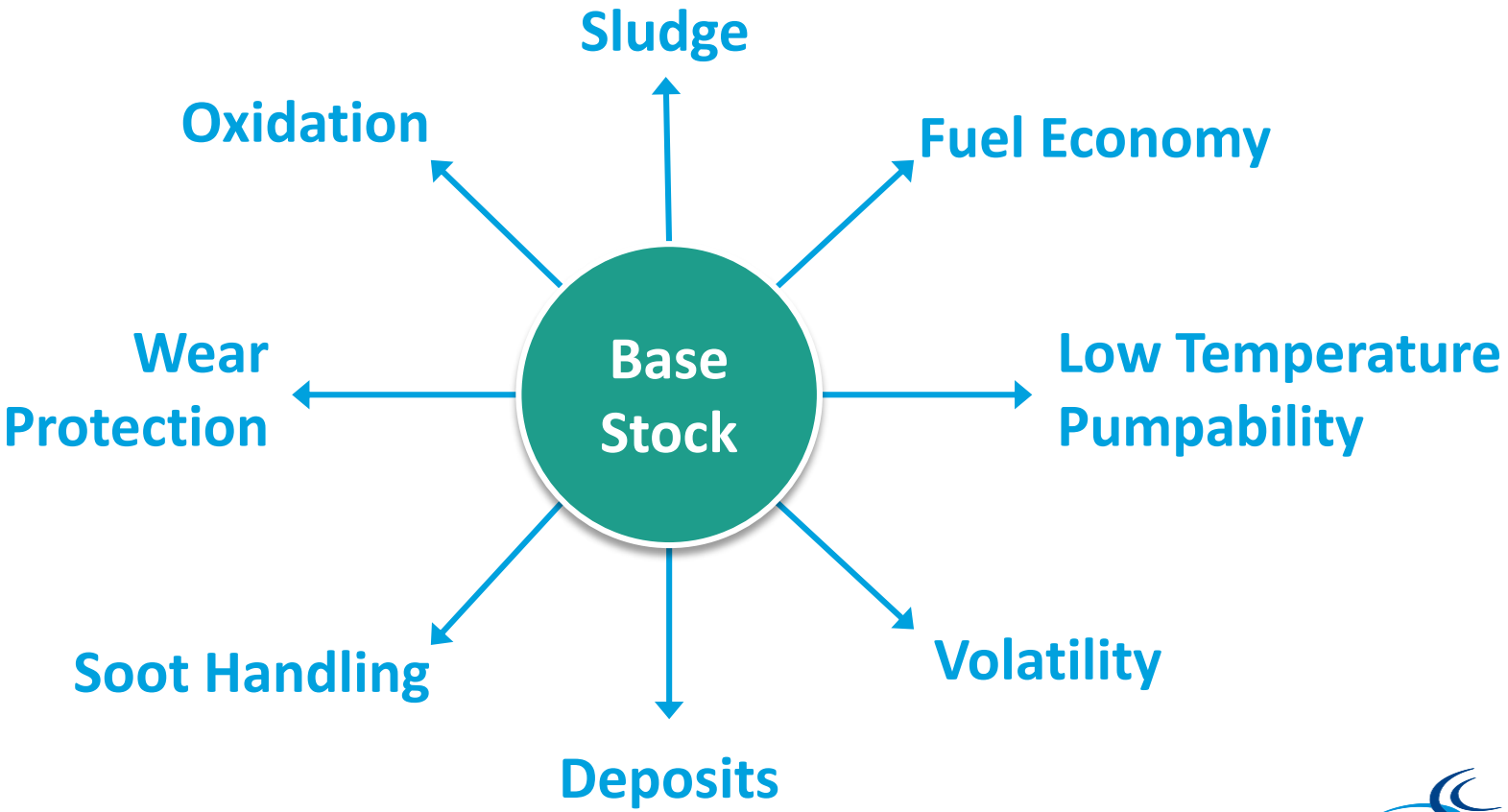
- Base stocks are not all the same and these properties can vary enormously from base stock to base stock
- Important when designing lubricant formulations but not always easy to understand and interpret

Additives are used to enhance the performance of the base stock and to impart additional beneficial properties onto the lubricant

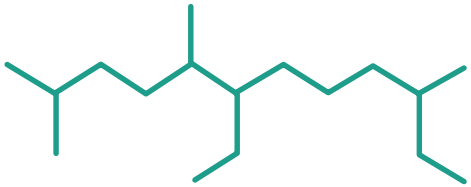
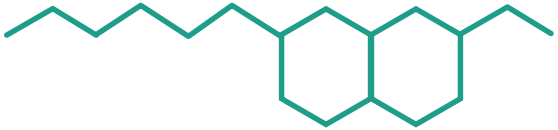
Why are Base Stocks Important?

Base stocks can have a major effect on **performance**

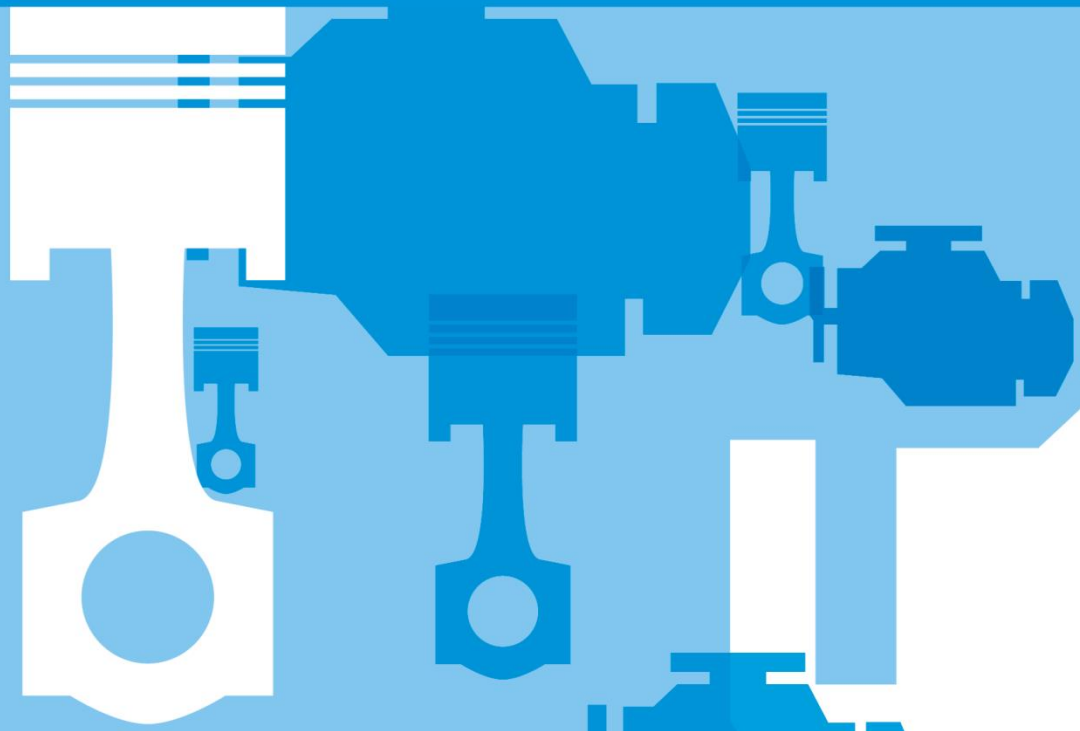
Some of these effects can be overcome by **additive selection**



Basic Chemistry of Base Stocks

	Type	Example Structure
Saturates	Paraffinic Straight Chain	
	Paraffinic Branched Chain	
	Naphthenic	
Unsaturates	Olefin	
	Aromatic	
Polar Constituents	Sulphur Containing	
	Nitrogen Containing	

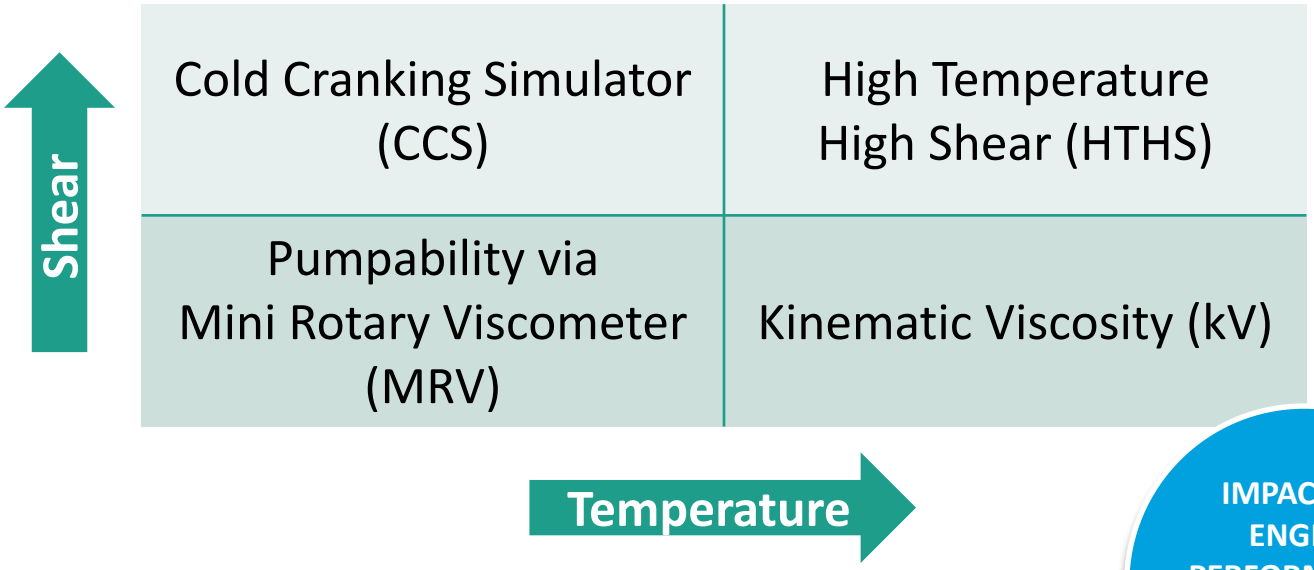
Properties of Base Stocks



Viscosity

Dependent upon **distillation conditions**

Different measures depending on **temperature** and **amount of shear**



IMPACT ON ENGINE PERFORMANCE:

Fuel economy and wear

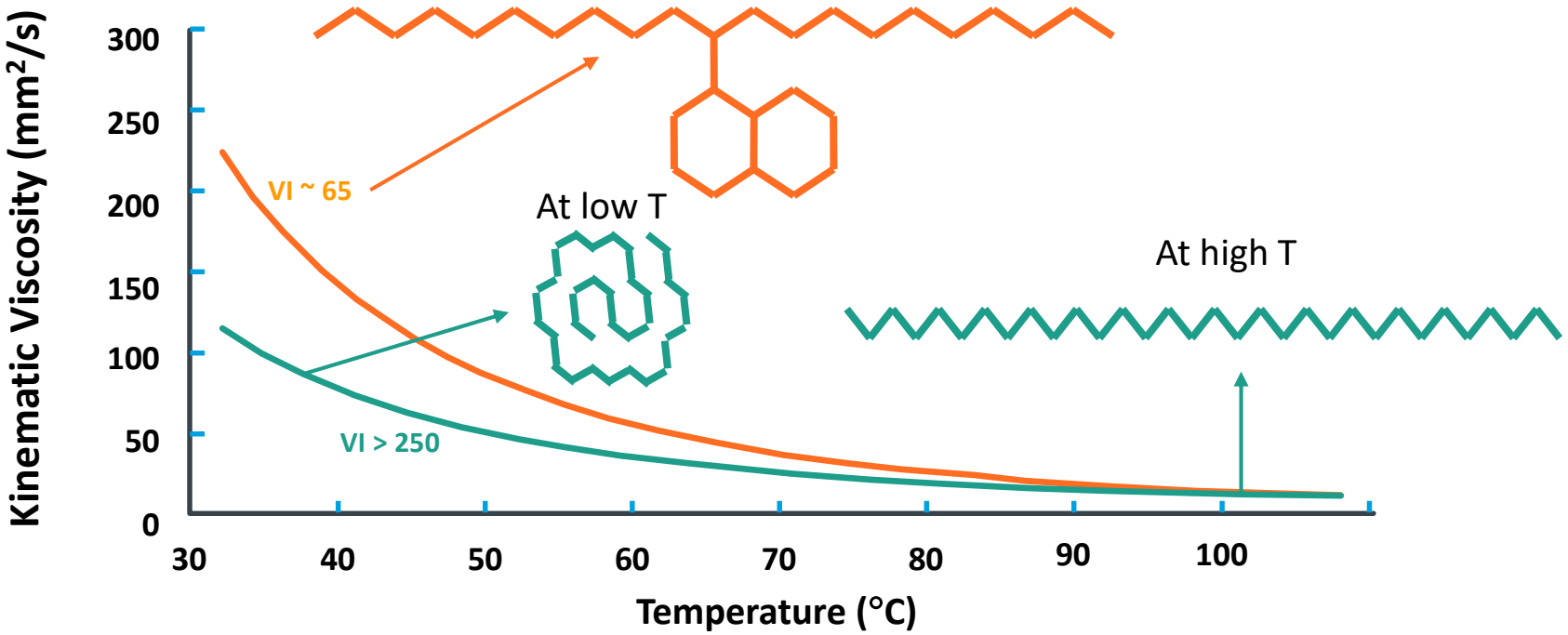
Viscosity Index (VI)

Base stocks become thinner with increasing temperature

The higher the VI **the less the base stock thins**

Flexible molecules have high VI

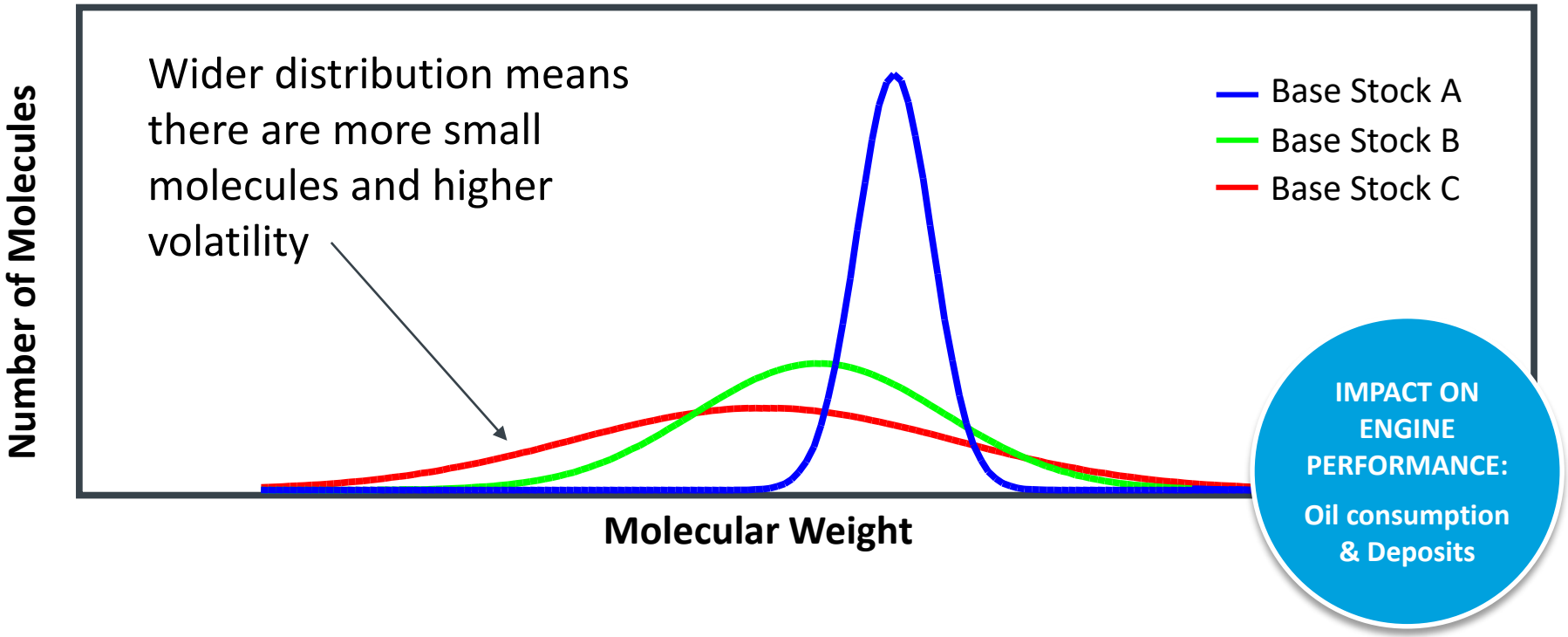
- Change configuration with temperature



NOACK Volatility

Measures **evaporation loss**

Dependent on small molecule content of the base stock ("light ends")



Pour Point

Defined as **temperature at which base stock becomes semi-solid and loses its flow characteristics**

- Related to melting point
- Effect is seen in low temperature crystallisation

Depends on level of rings and branching relative to straight chain paraffins; base stocks with high levels of rings and branching tend to have lower pour points

IMPACT ON ENGINE PERFORMANCE:

Low temperature pumpability

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Saturates

Dependent on processing conditions

Level of saturates impacts:

- Susceptibility of the base stock to undergo oxidation
- Solvency and additive compatibility

Sulphur and Nitrogen Content

Dependent upon **processing conditions**

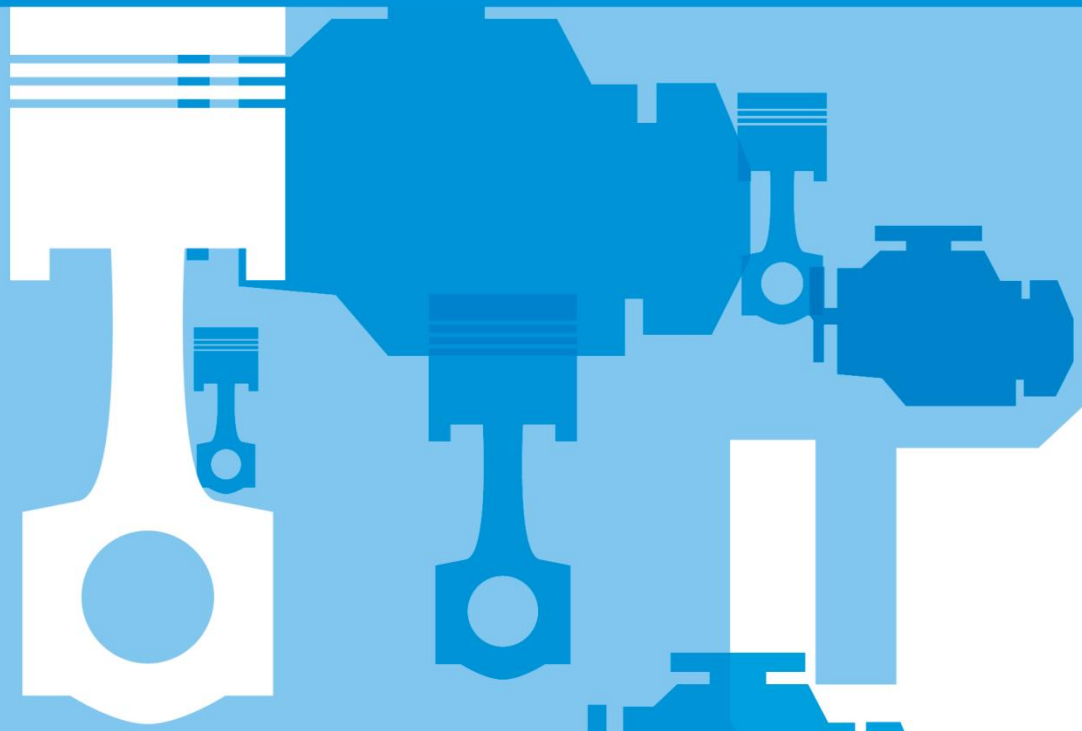
Sulphur is a natural **antioxidant**

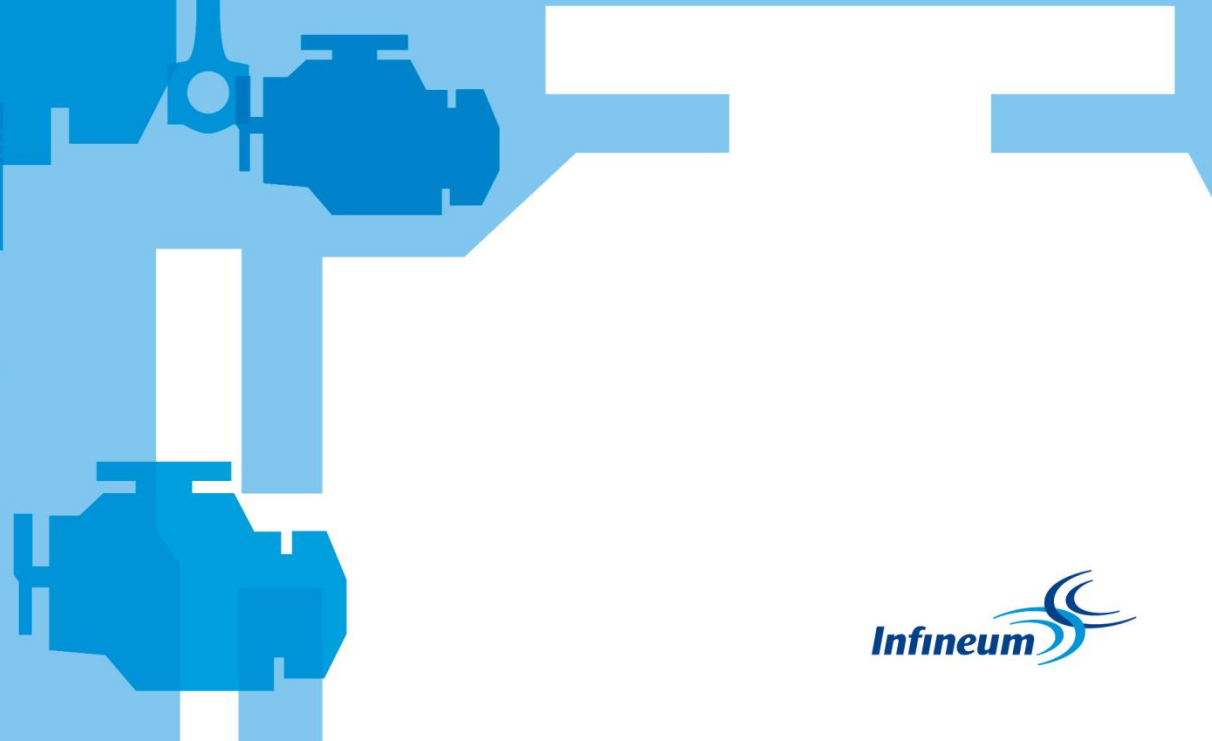
Nitrogen is a natural **pro-oxidant**

IMPACT ON ENGINE PERFORMANCE:

Oxidation and viscosity increase

Base Stock Classification





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API Base Stock Classification

Base stocks are classified according to their properties, and the saturate and sulphur content

Group	Viscosity Index	Saturates		Sulphur	Other
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

Group II+ and Group III+ Base Stocks

Each of the **API base stock groups** cover a broad range of properties

Different base stocks within the same group can have **very different properties**

The terms Group II+ and Group III+ describe base stocks with a viscosity index that is higher in the range for their group

- This is a marketing term with no formal definition

Generally

For Group II+ base stocks: VI > 110

For Group III+ base stocks: VI > 130

Comparison of Base Stock Groups

Group	Saturates	Sulphur Content	Volatility	Oxidative Stability	Cost
I	Low	High	High	Variable	Low
II	High	Low	Medium	Medium	Medium
III*	High	Low	Low	High	Medium
IV	Very High	Very Low	Very Low	Very High	High
V**	Very High	Very Low	Very Low	Variable	High

* Includes GTL

** Polyol ester used to improve polarity

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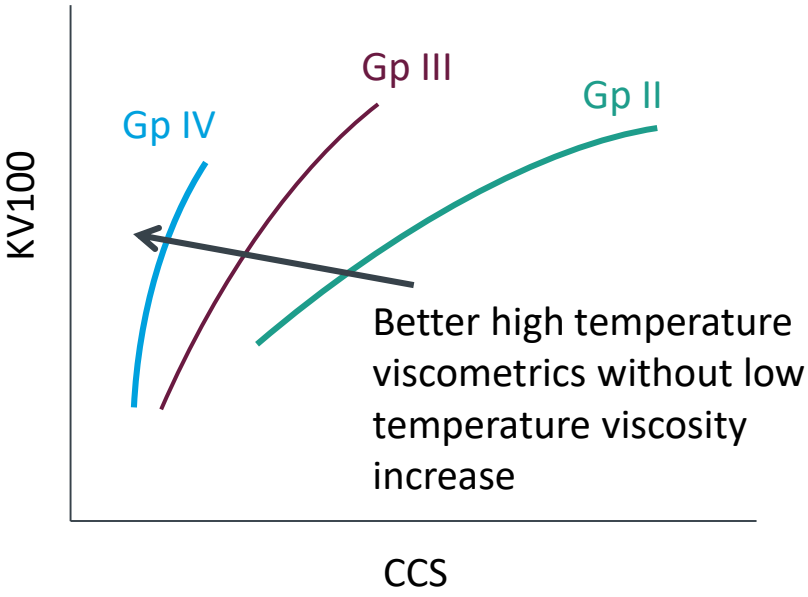
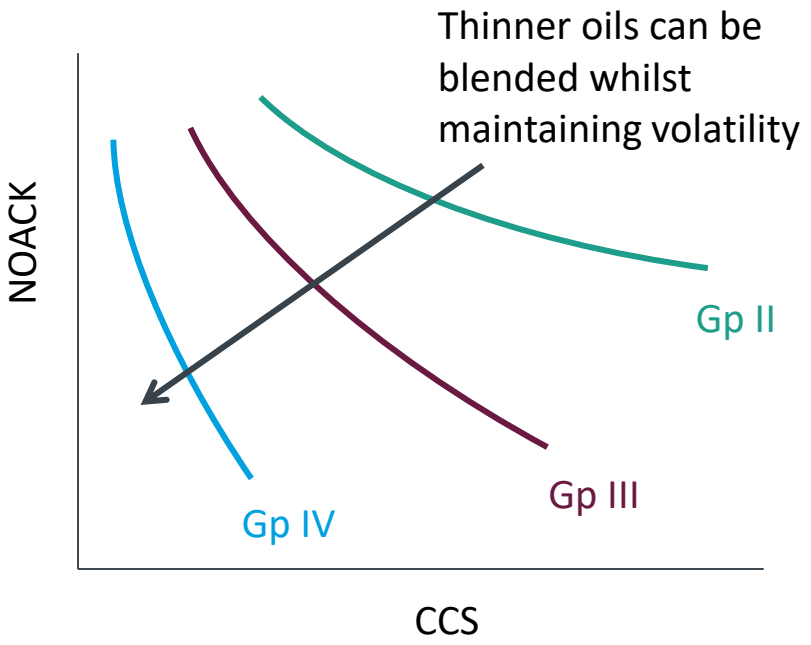
Base Stock Selection

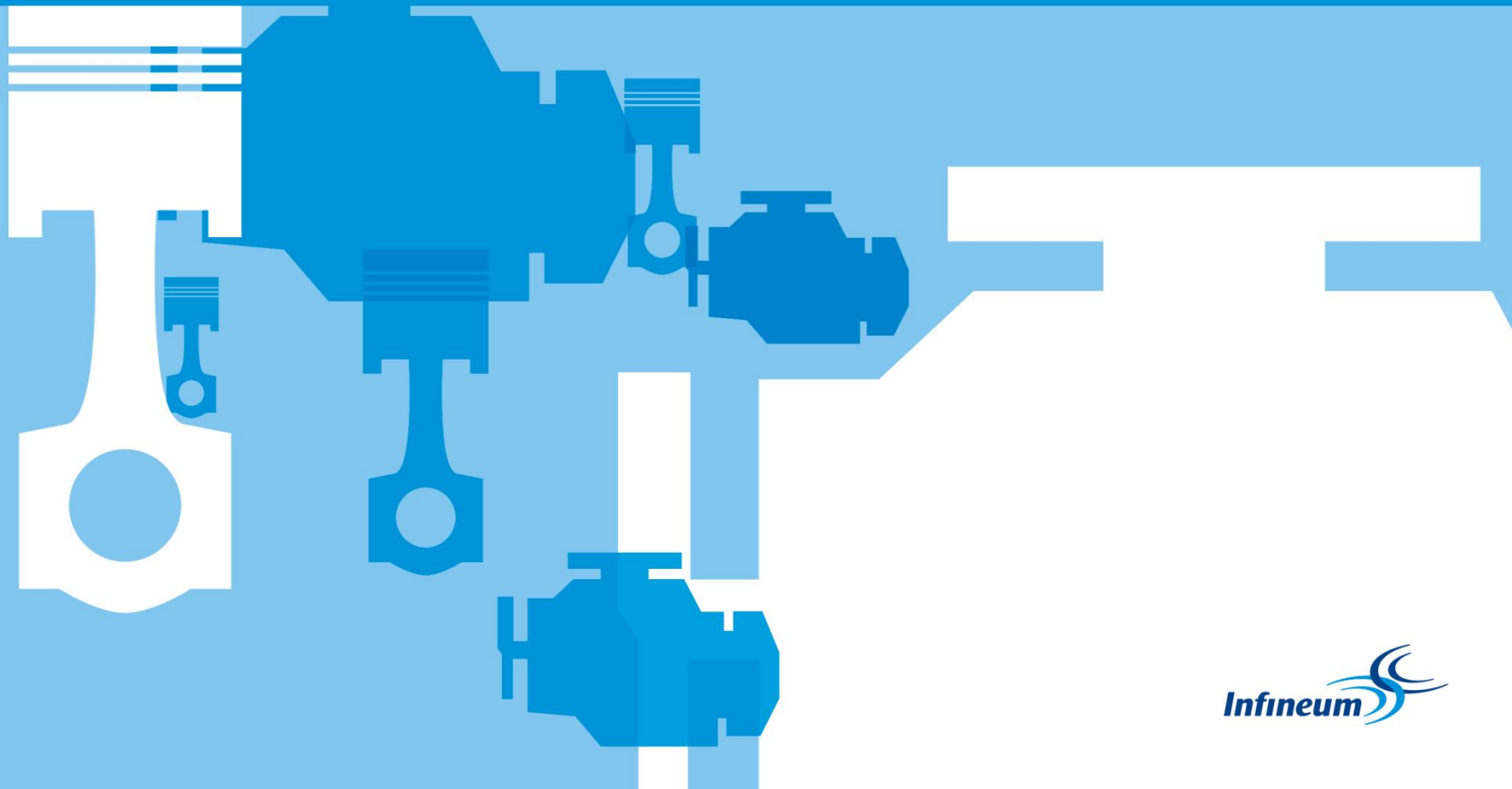
When selecting a base stock for a formulation the properties and cost of the base stock need to be considered



Base stocks will be selected in order to meet **viscometric and volatility requirements**



Refinery Processes



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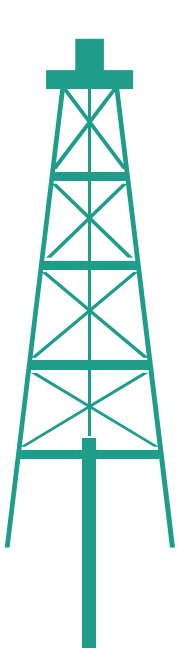
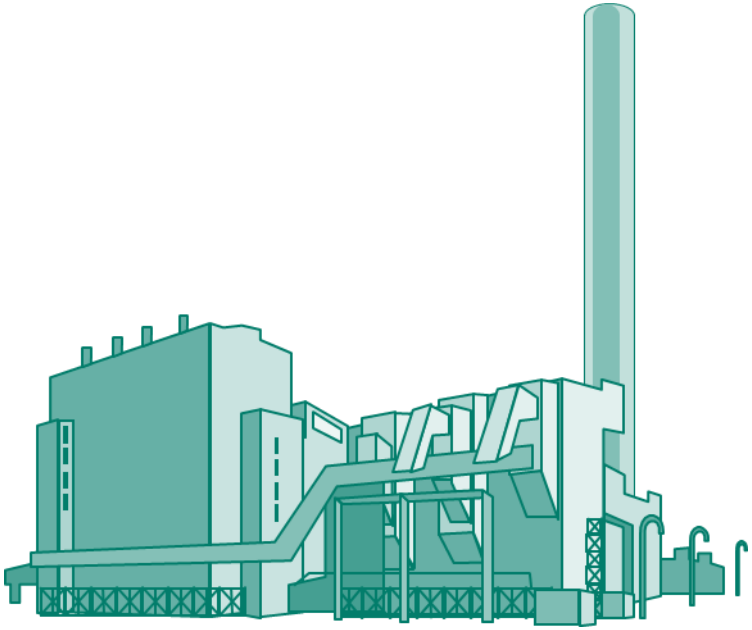
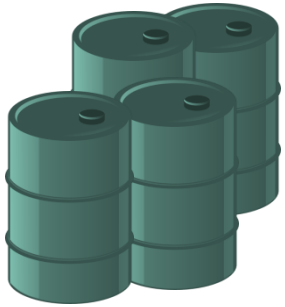
Refinery Overview



Crude oil



Refinery processes



Petroleum products

Crude Selection

Each crude source has a different composition

- Hydrocarbons
- Sulphur compounds
- Nitrogen compounds
- Others

Availability of various crudes

Determined by economics

- Supply vs. demand
- Fuel economics may be overriding

Political considerations may be important

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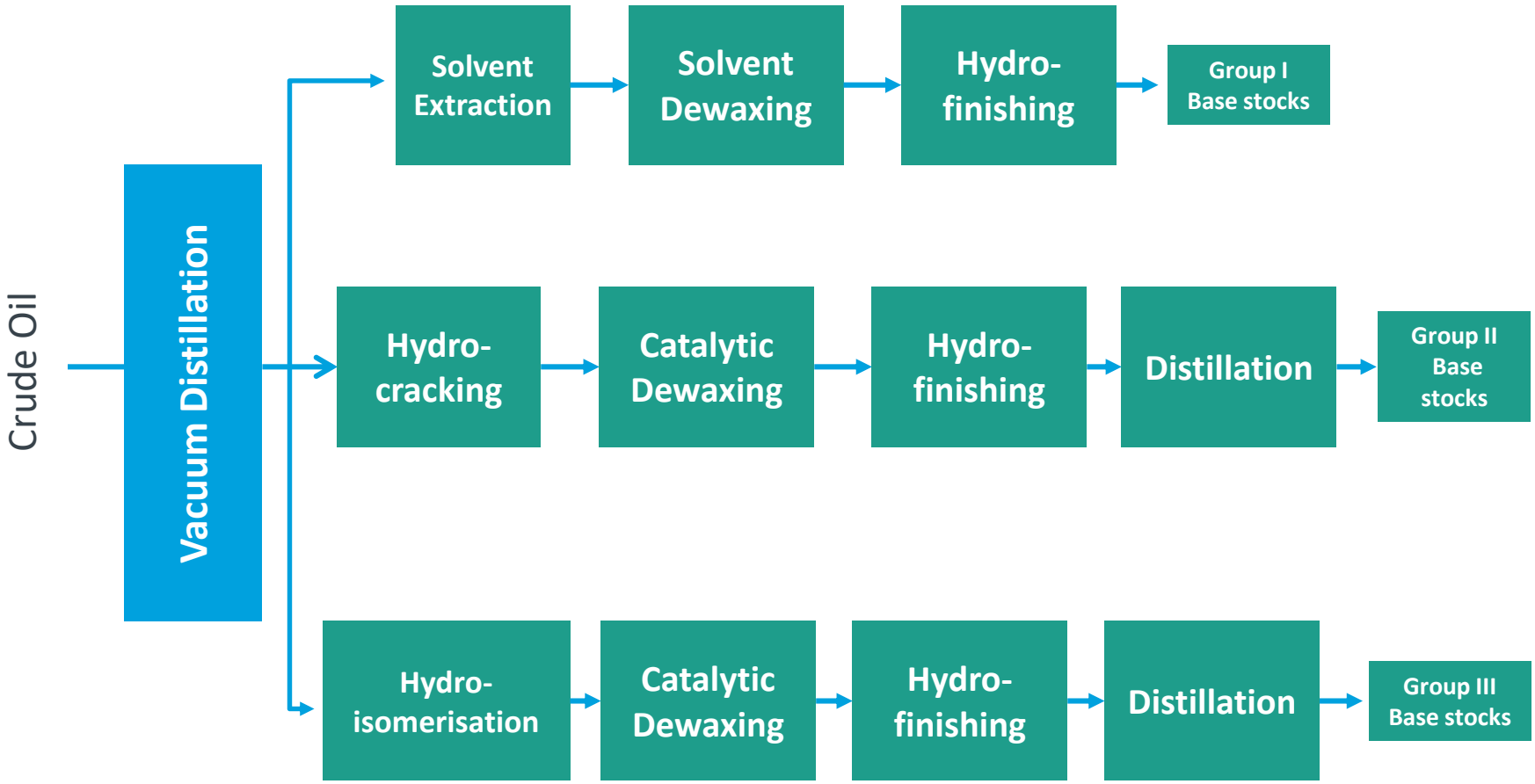
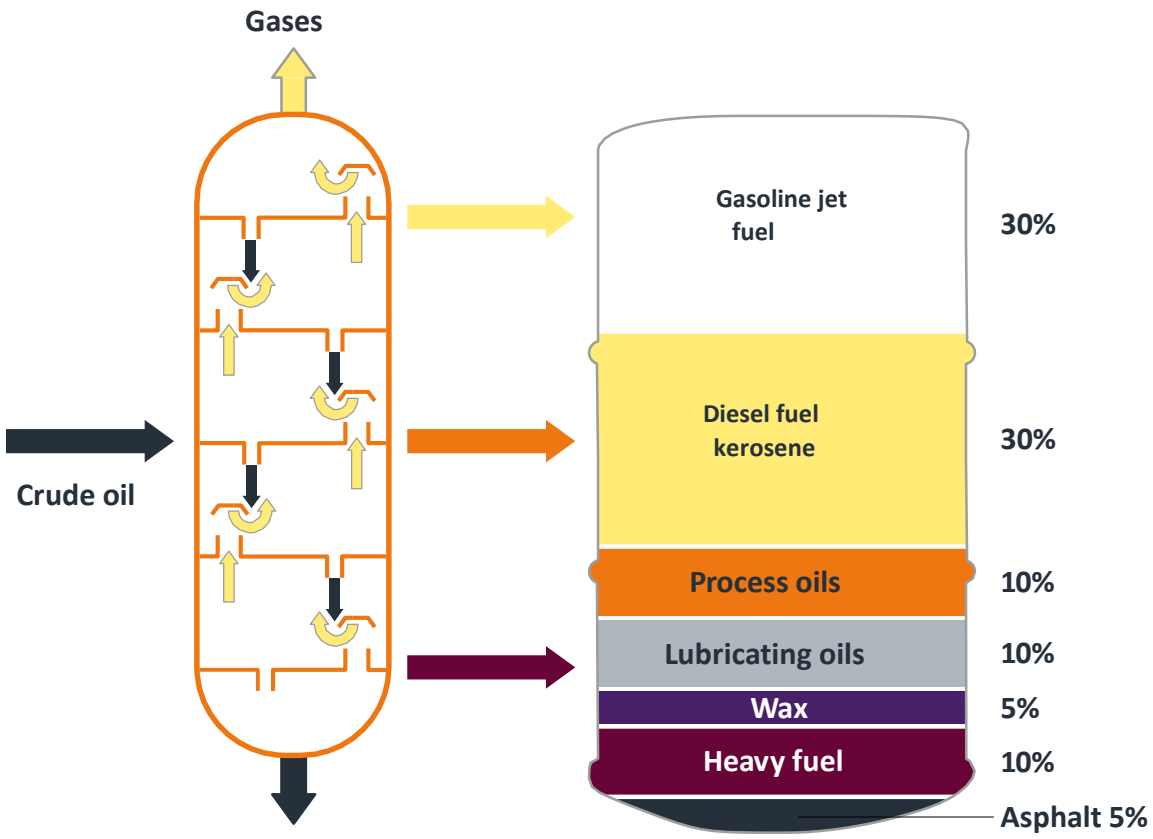
Refining Process



Vacuum Distillation



Distillation:

- Separates lighter from heavier fractions
- Selects viscosity “cut”
- Controls volatility (evaporation)

Solvent Extraction

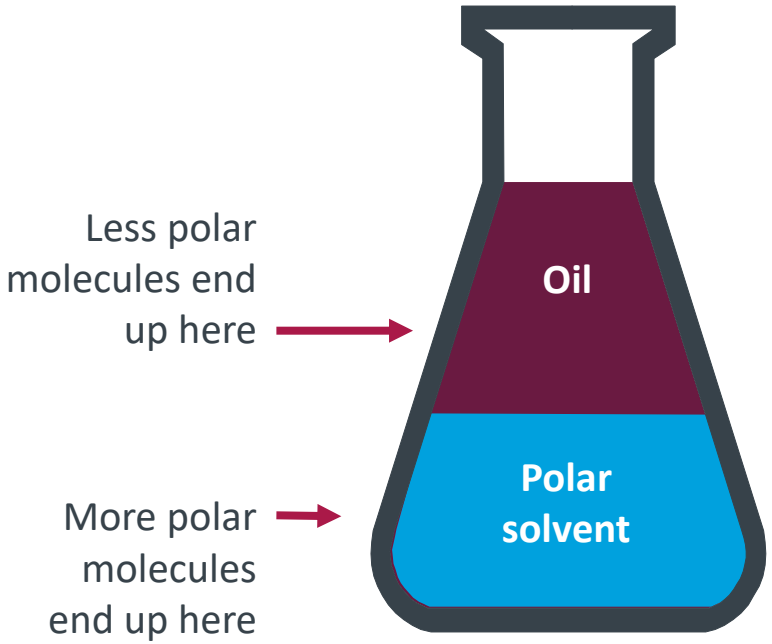
Separation based on solubility

Uses a polar solvent to remove less desirable molecules

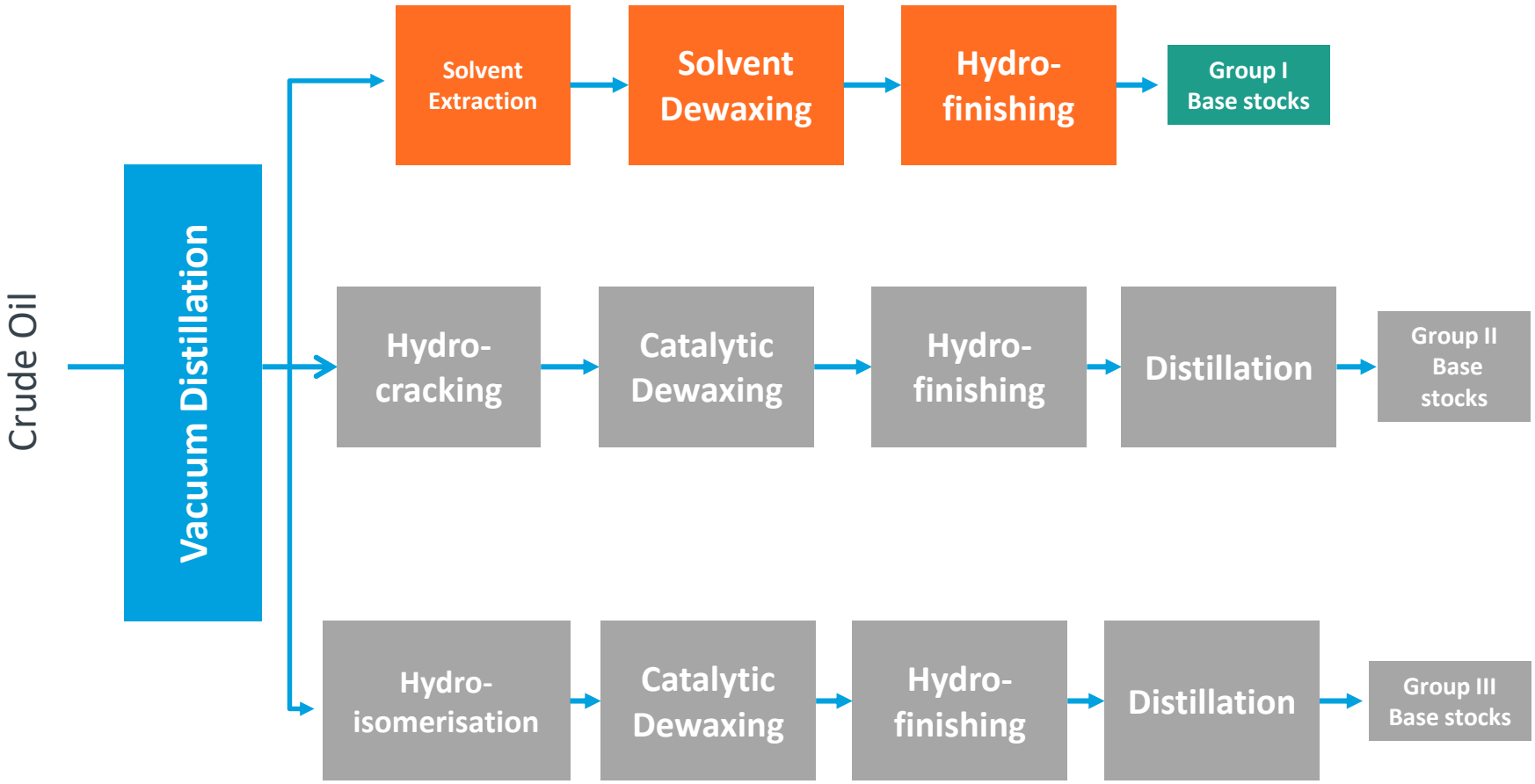
- Aromatics

The more desirable molecules remain in the oil

- Straight and branched chain paraffins
- Naphthenes



Refining Process



Solvent Dewaxing and Hydrofinishing

Solvent Dewaxing

Reduces the pour point and viscosity index of the base oil by removing wax

Separation is based on solubility

Wax is less soluble in solvent than oil

- Oil and solvent mixture is chilled
- Wax is filtered out at low temperature

Hydrofinishing

Improves colour stability and acidity of the base oil

- Sulphur, nitrogen, oxygen removed as H_2S, NH_3 and H_2O
- Slight hydrogenation of unsaturated compounds

Oil is contacted with hydrogen at about 600 psi and 250 – 320°C

Hydrocracking

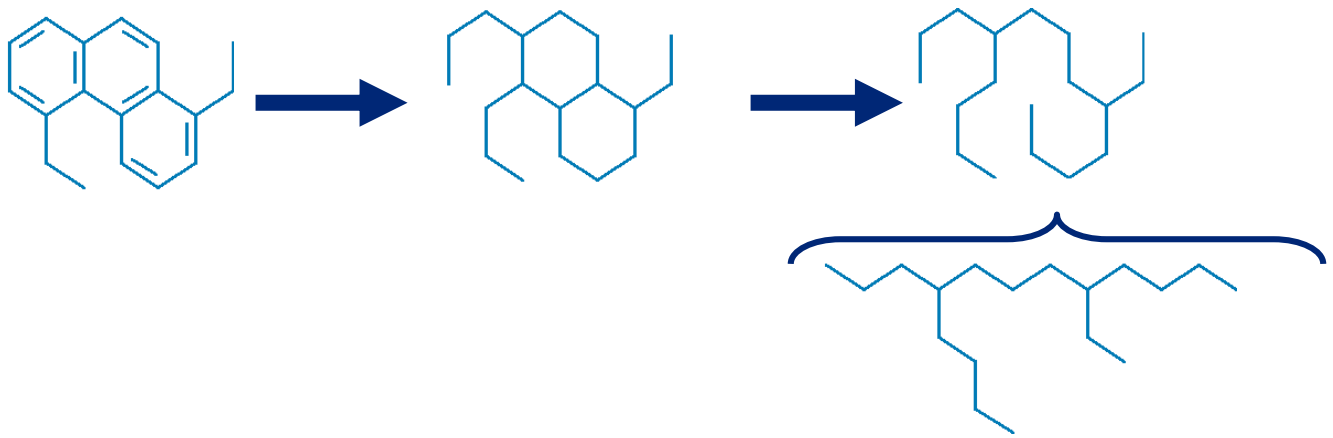
Conversion of unsaturated and aromatic molecules which are less desirable into more desirable saturated chains

'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



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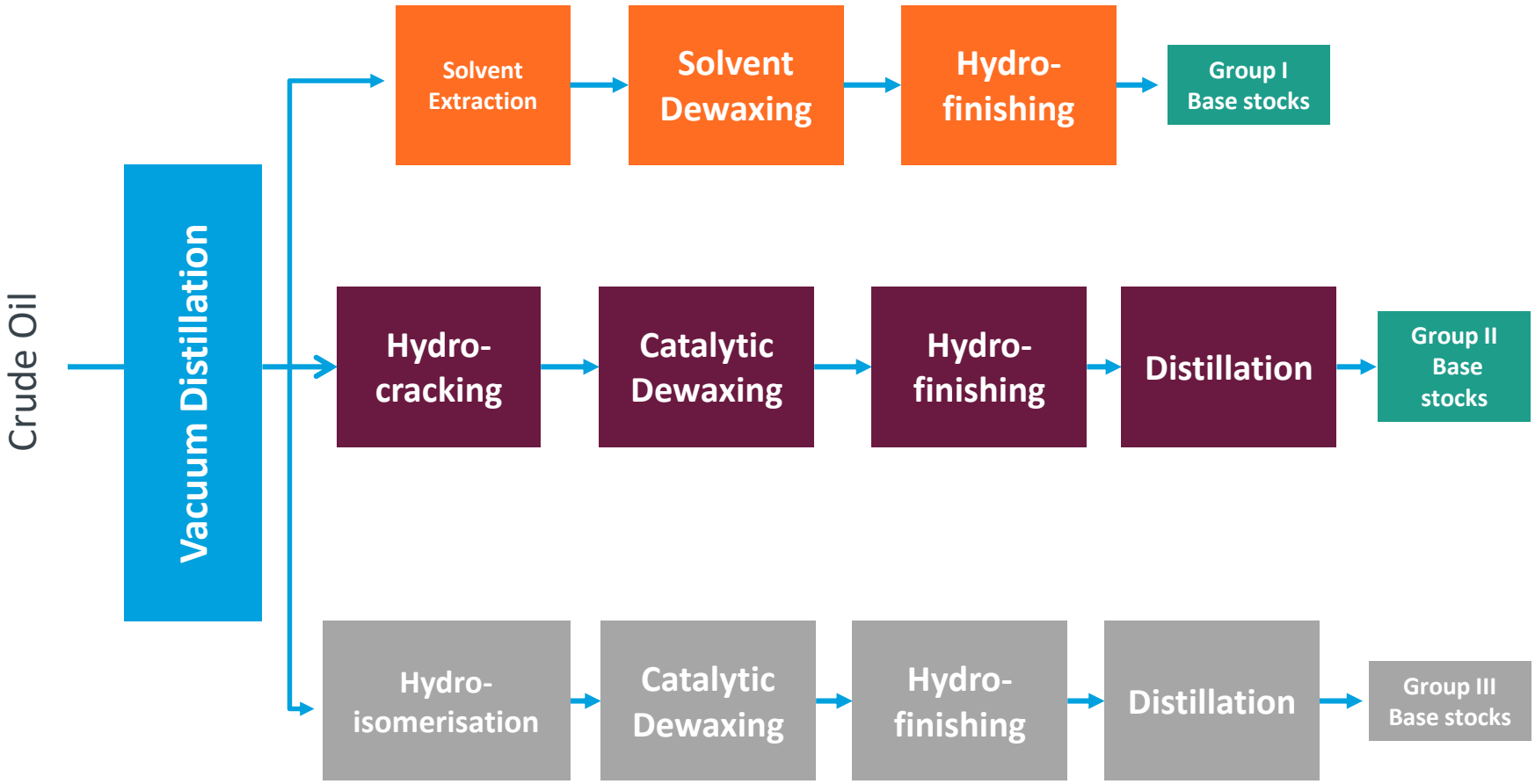
Refining Process



Hydroisomerisation

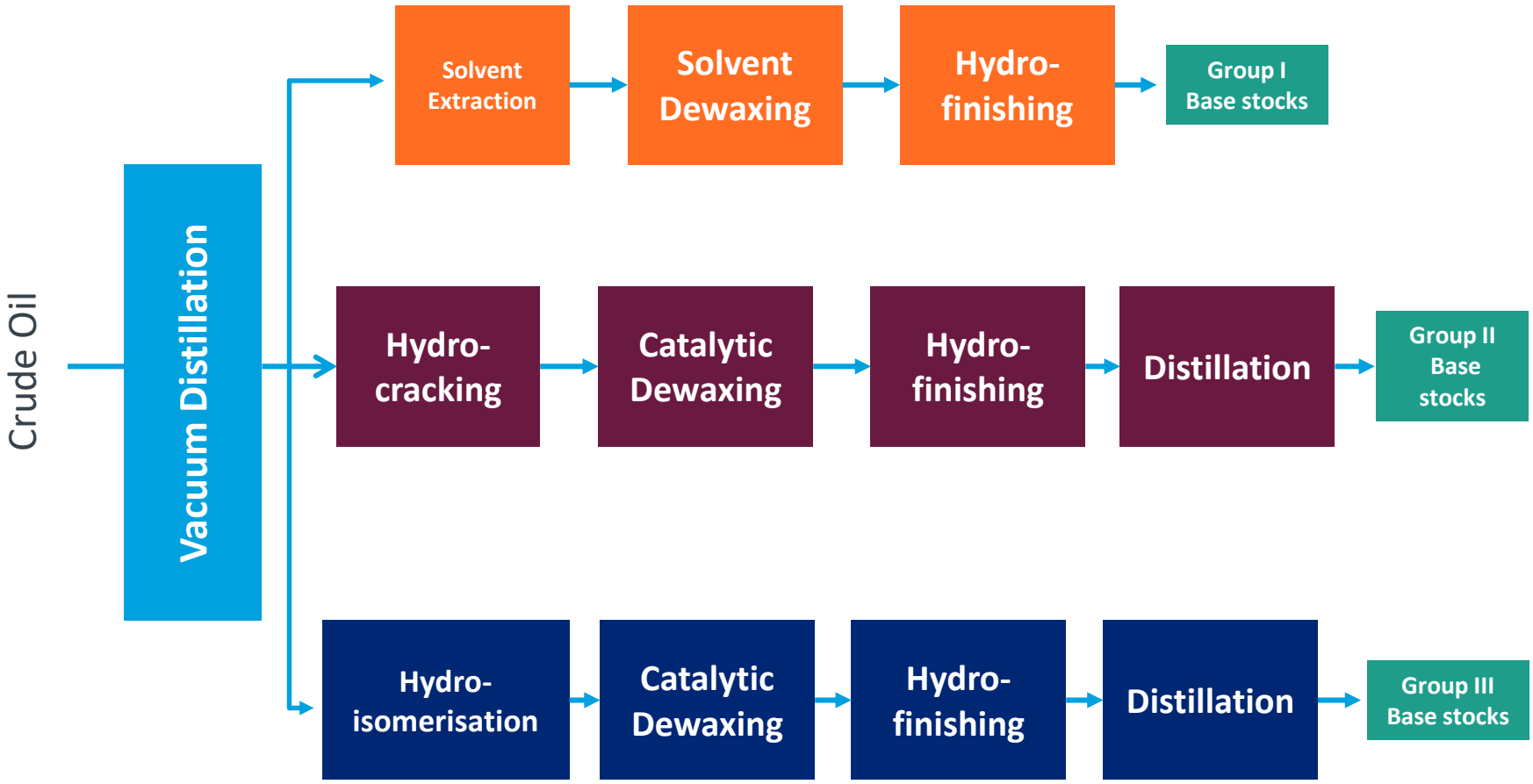
Rearrangement of linear chains to branched chains

- I.e. transforming wax to iso-paraffins

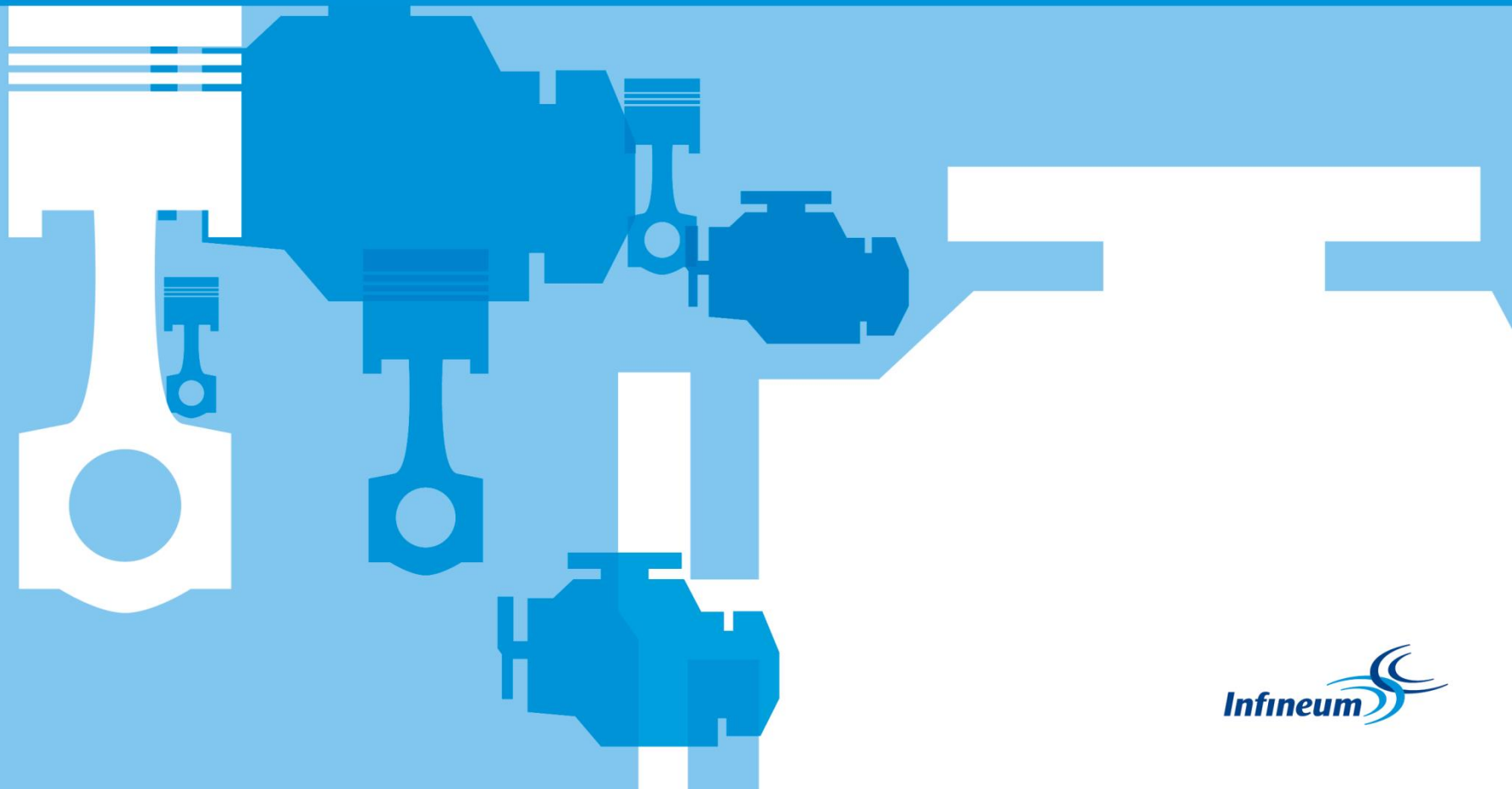
Improves the VI of a base stock

The process varies for each manufacturer and therefore the **properties of Group III base stocks can also be quite different**

Refining Process



Synthetic Base Stocks



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Synthetic Base Stocks

Group I, Group II and Group III base stocks that are manufactured by refining processes are referred to as ‘mineral’ base stocks

The term ‘synthetic’ is used to describe lubricants that have been processed

- This includes Group IV base stocks

‘Synthetic’ is also used when marketing Group III base stocks that have been severely hydrocracked

‘Semi-synthetic’ is a marketing term that does not necessarily reflect base stock quality

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Gas to Liquids (GTL)

Processed from **natural gas**

Performance comparable to Group III / IV base stocks:

- High VI (140+)
- Low Noack volatility
- Low pour point
- Stable
- High Saturates
- No Sulphur or Nitrogen

Classed as Group III by API definition

- But it would be a “synthetic base oil” in all markets!

First used by Shell from 1994

Other oil companies now **investing in GTL production**

Large initial investment but production cost comparable to Group II

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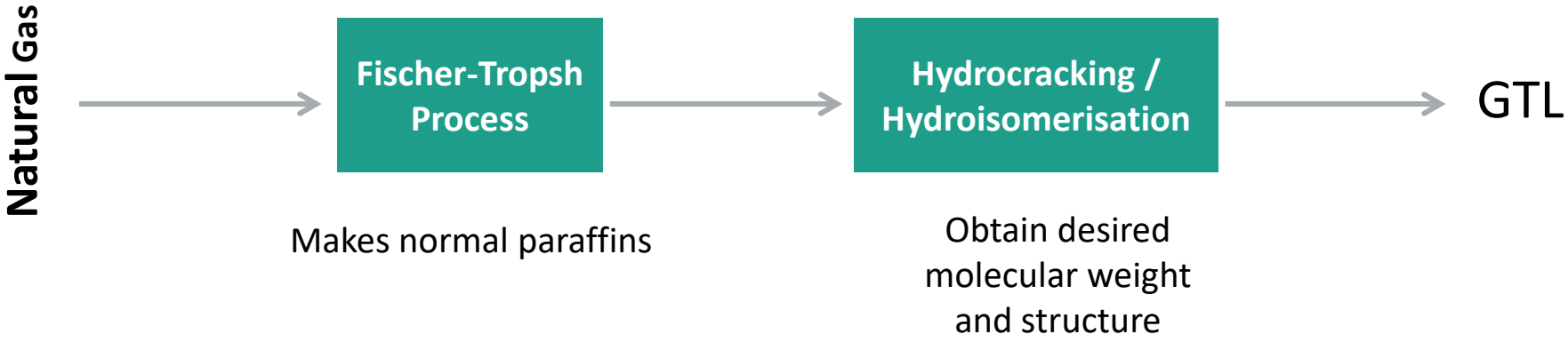
Refinery Process for GTL

GTL produced by reacting the low molecular weight materials found in natural gas to form higher molecular weight materials



Process is well controlled and can be adjusted to make different molecular structures with predictable properties

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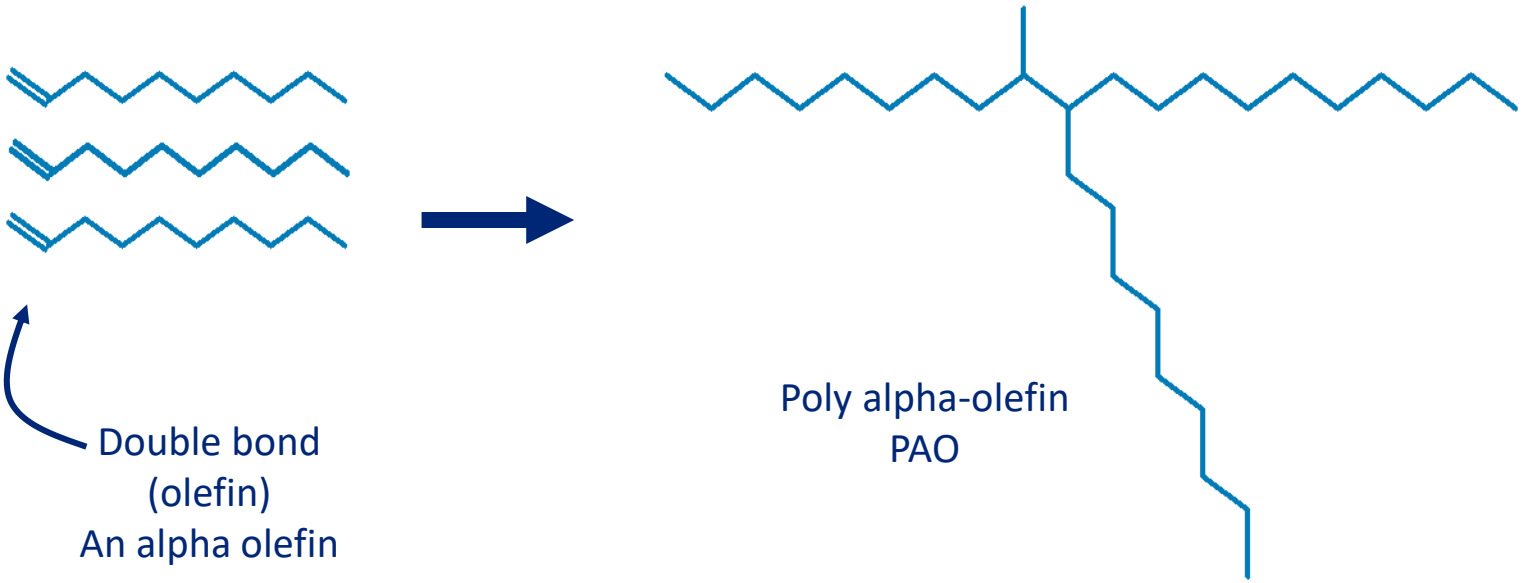
Synthetic Process - PAO

Poly alpha-olefins (PAO) are manufactured **from linear alpha olefins** (typically 1-decene)

They have a branched paraffinic structure leading to desirable properties

- High VI, low NOACK, good oxidative stability

The process is very controlled **leading to narrow properties**



Group V Base Stocks

- **Group V** defined as ‘Everything else’ not classified in the other API groups
- Versatile, custom made for **specialised applications**

Examples of Group V base stocks

Di-Esters

Industrial applications are highest growth
Competitive with PAO in performance attributes

Polyol Esters

High-temperature applications
More costly than PAO, di-esters

Phosphoric Acid Esters

Used in fire resistant fluids

Silicone Oils

Used as heat transfer oils

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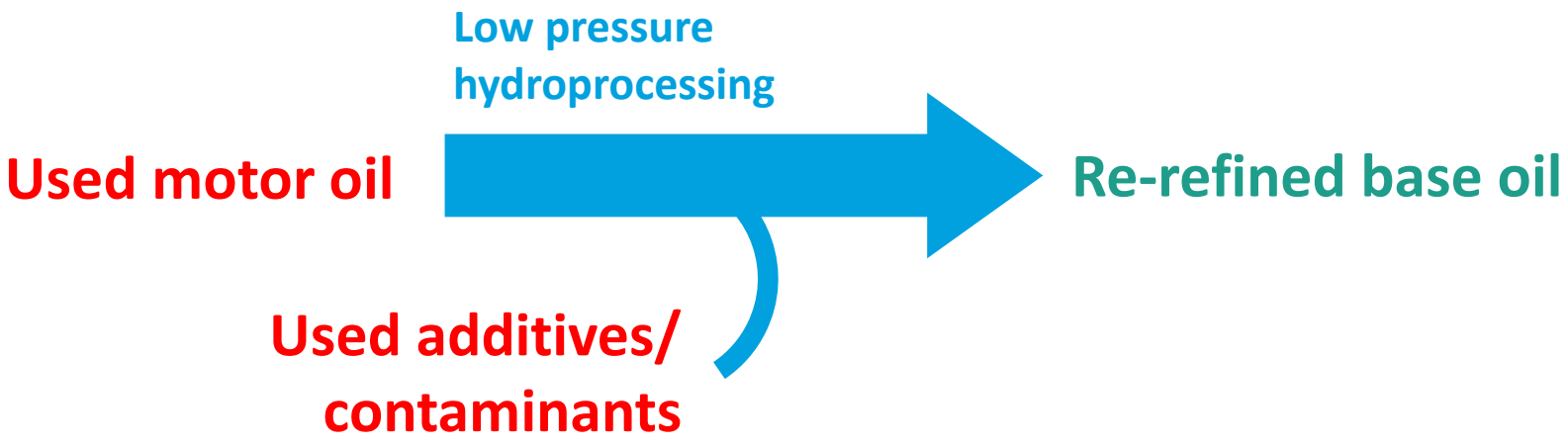
Re-refining



Processing very similar to conventional processes

- Solvent extraction
- Hydrocracking

Quality depends on

- Starting material
- Processes
- Desired targets

Just like conventional base stocks!

Possible to make **Group I and Group II base** stocks with re-refining

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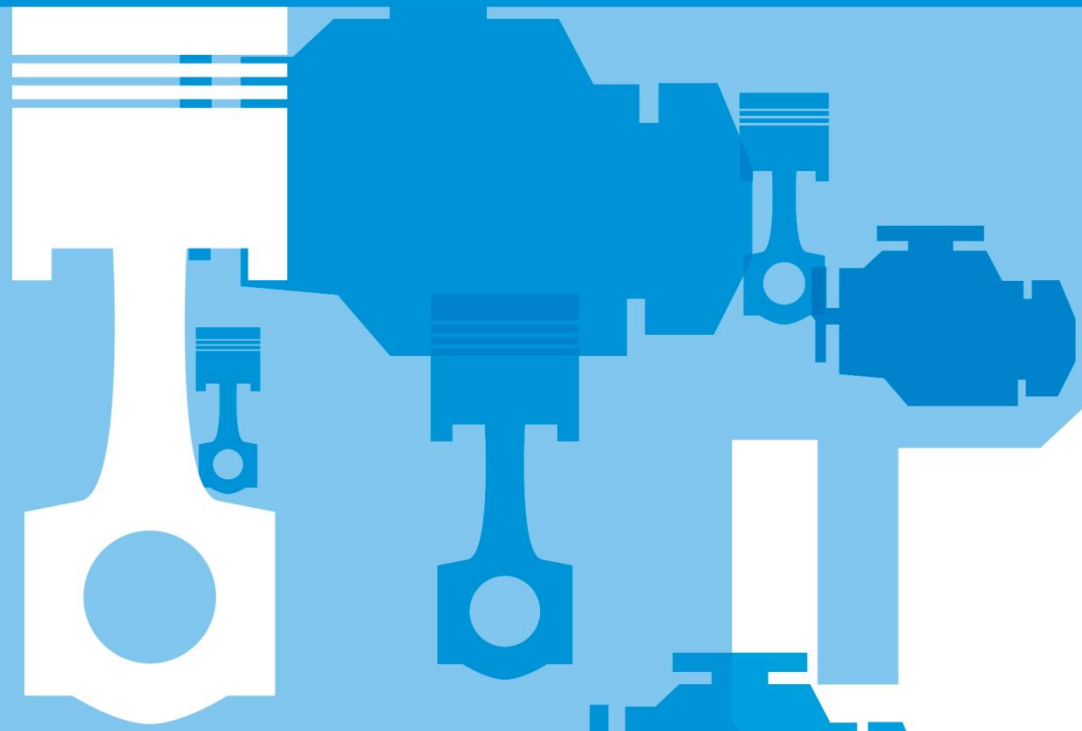
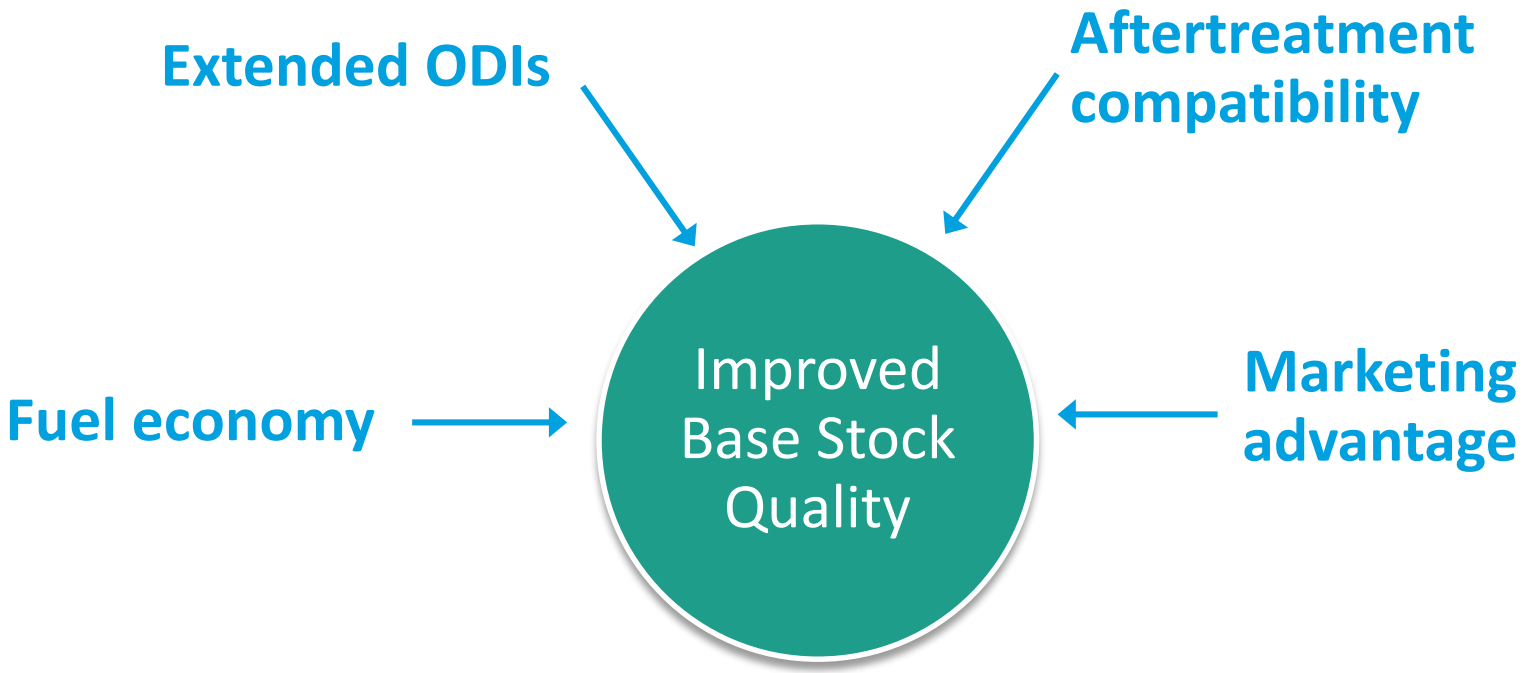
Drivers and Market Trends



Drivers

Many of main drivers for lubricant performance result is driven by need for improved base stock quality



Trend in Base Stock Demand

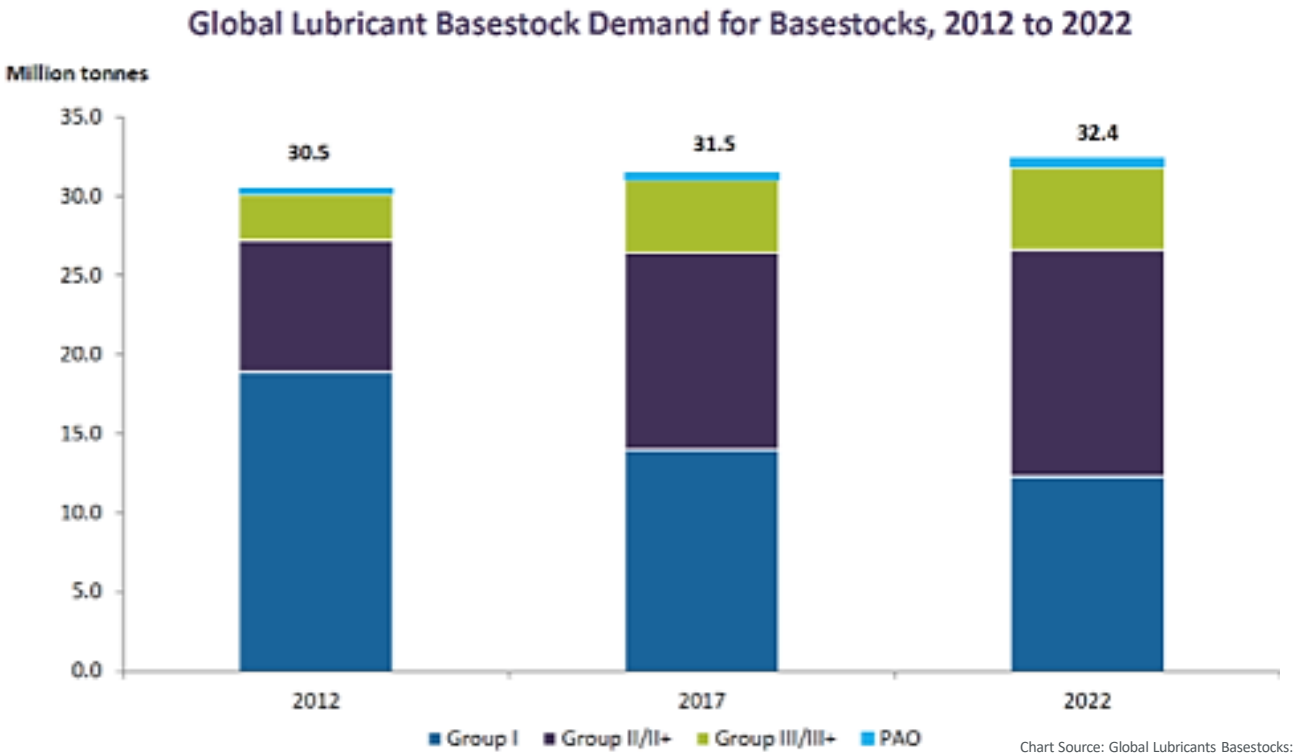
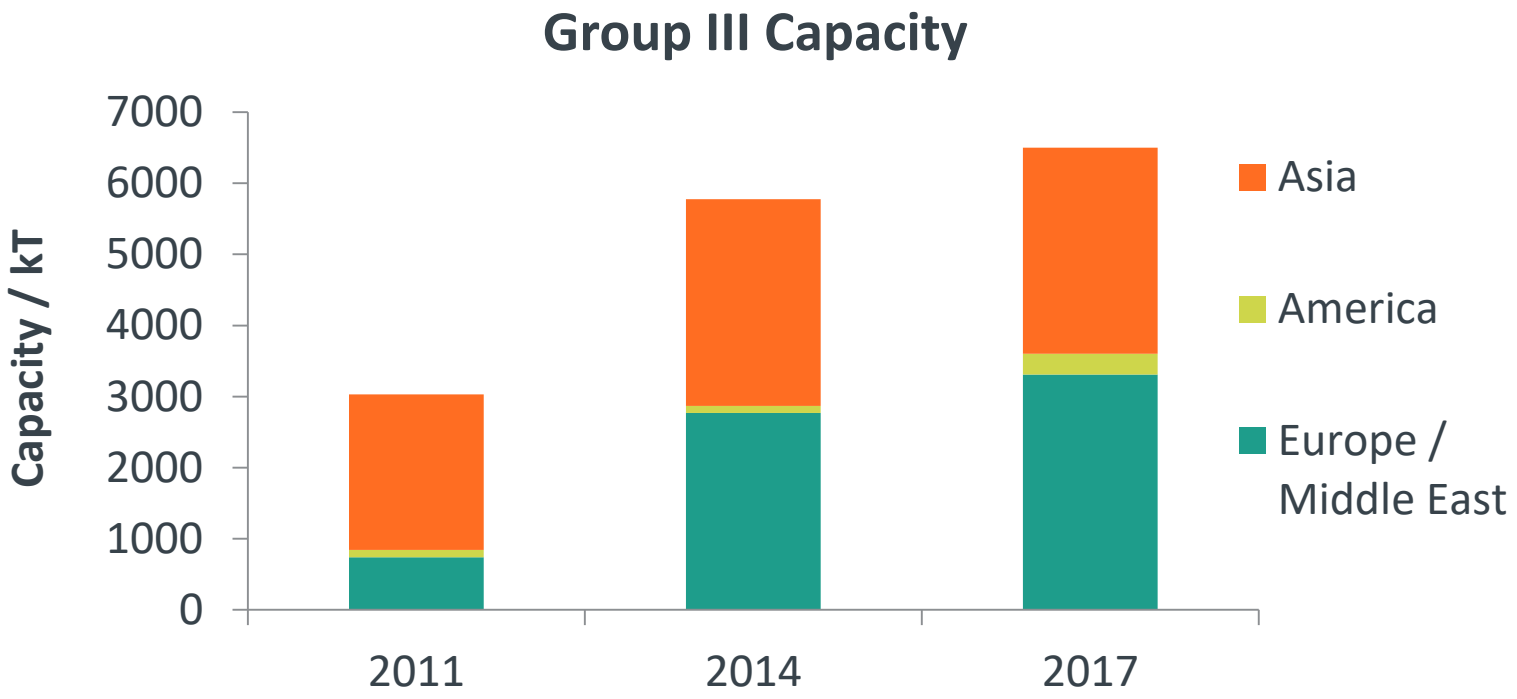


Chart Source: Global Lubricants Basestocks: Market Analysis and Opportunities, Kline & Company. Note: Demand estimates include only Group I, II/II+, III/III+ and PAO basestocks and exclude Group V basestocks.

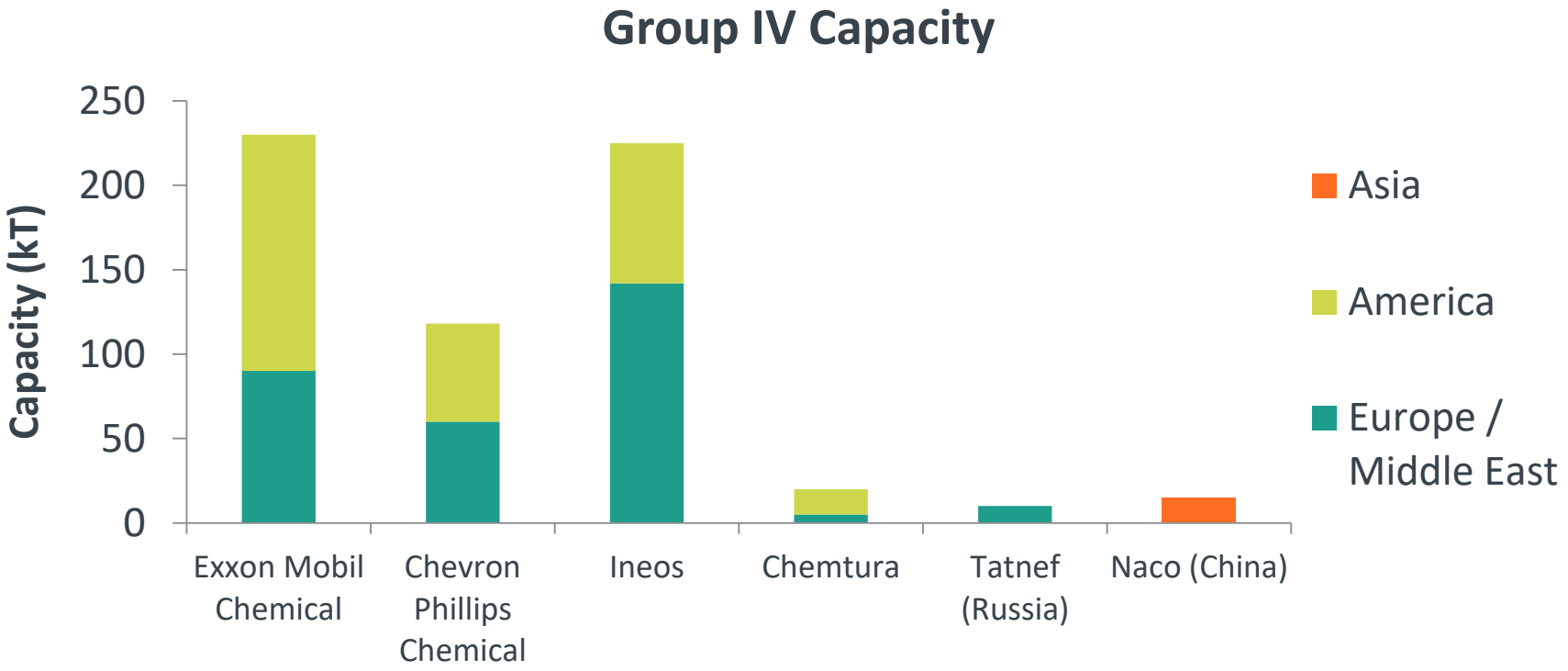
- Decline in demand for Group I base stocks
- Increase in demand for higher quality Group II and Group III base stocks

Trends in Group III Base Stocks



- Increase in Group III capacity from 2011 – 2017
- Largest proportion of Group III production in Asia and Europe / Middle East
- Potential for further investment in USA and Russia

Trends in Group IV Base Stocks



- The PAO market is < 2% of total base stock market
- Main production capacity in US and Europe
- Global demand in PAO is increasing
- Increased capacity in PAO and LAO raw materials have been announced

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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 sulphur 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

General trend is move towards better quality base stocks

- Drive for fuel economy
- Move from Group I to higher quality base stocks

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