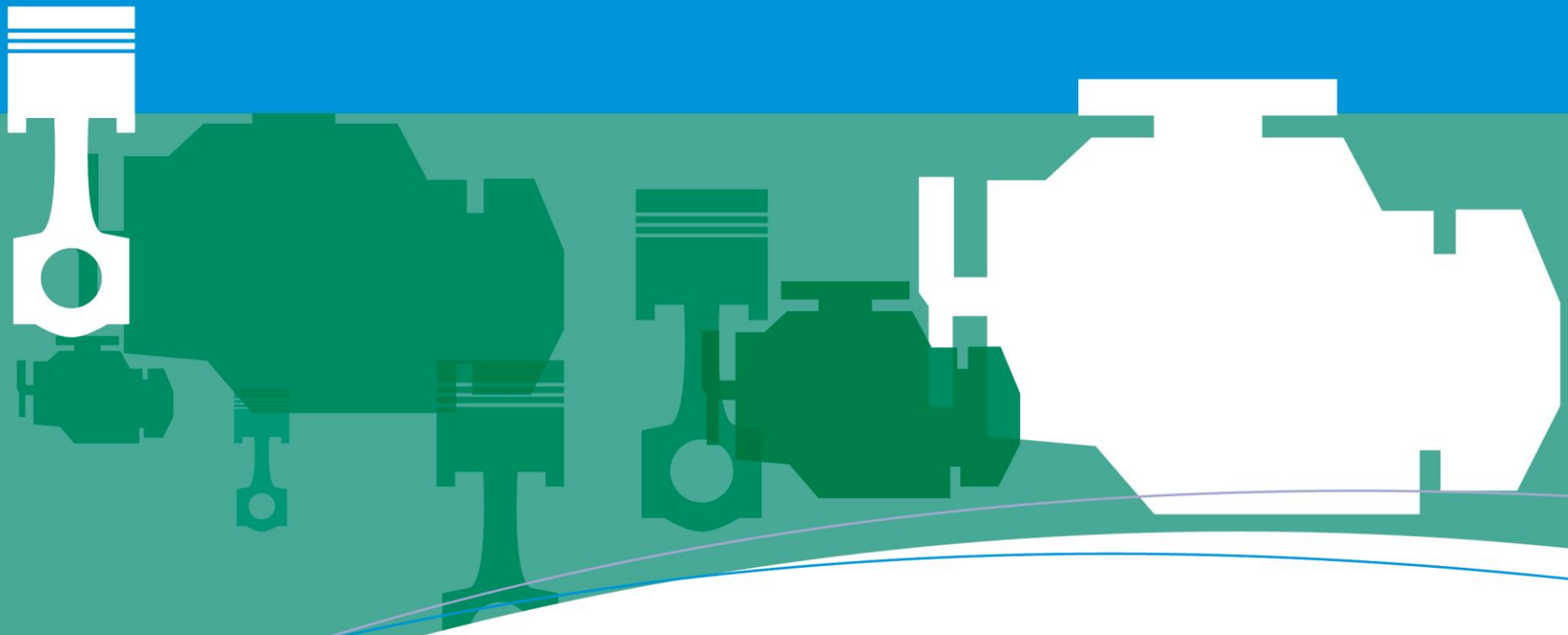
Performance you can rely on.

Lubricant Base Stocks



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Outline

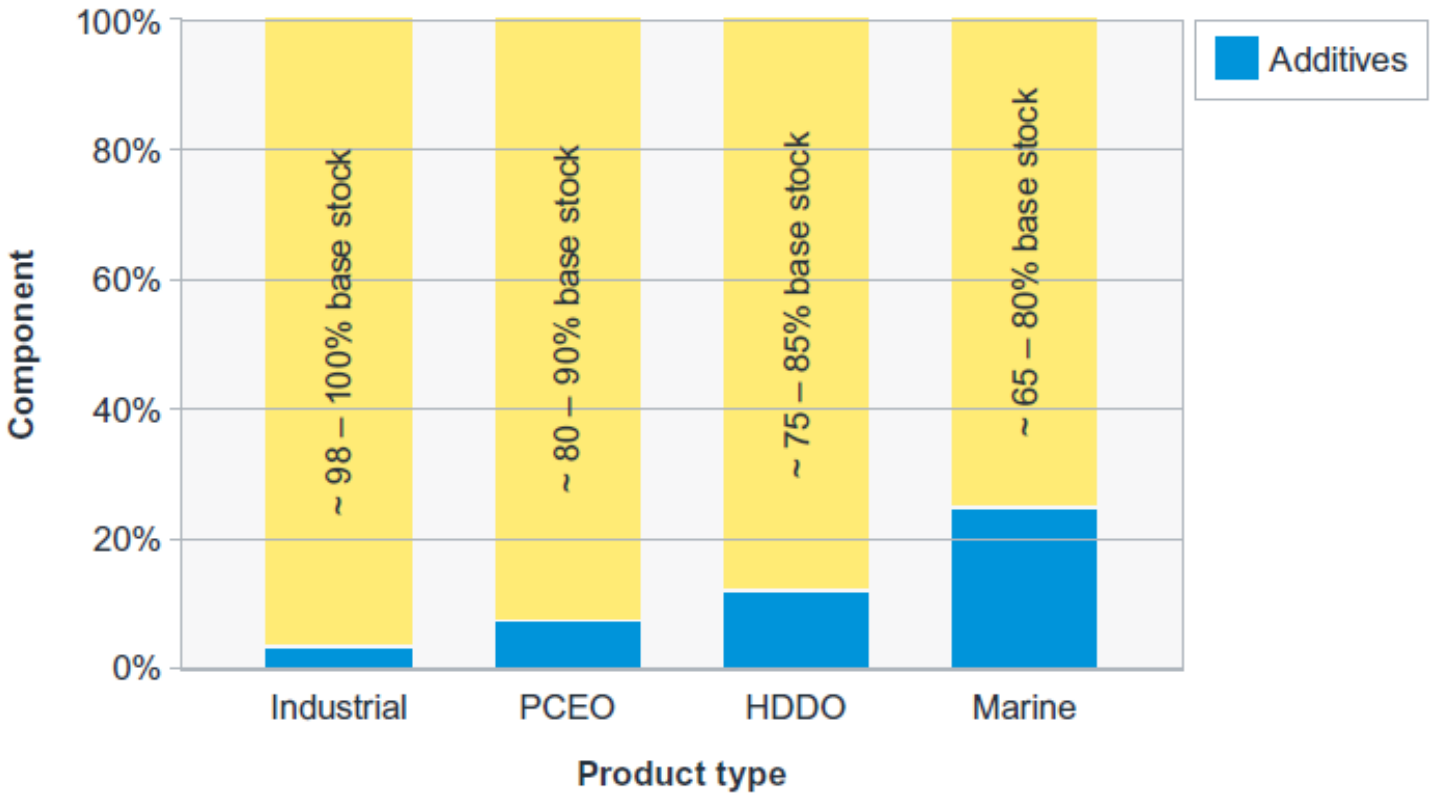
- Introduction
- Why are base stocks important?
- Basic chemistry
- Properties of base stocks
- Base stock classification
- Refinery processes
- Synthetic base stocks
- Drivers and Market Trends

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

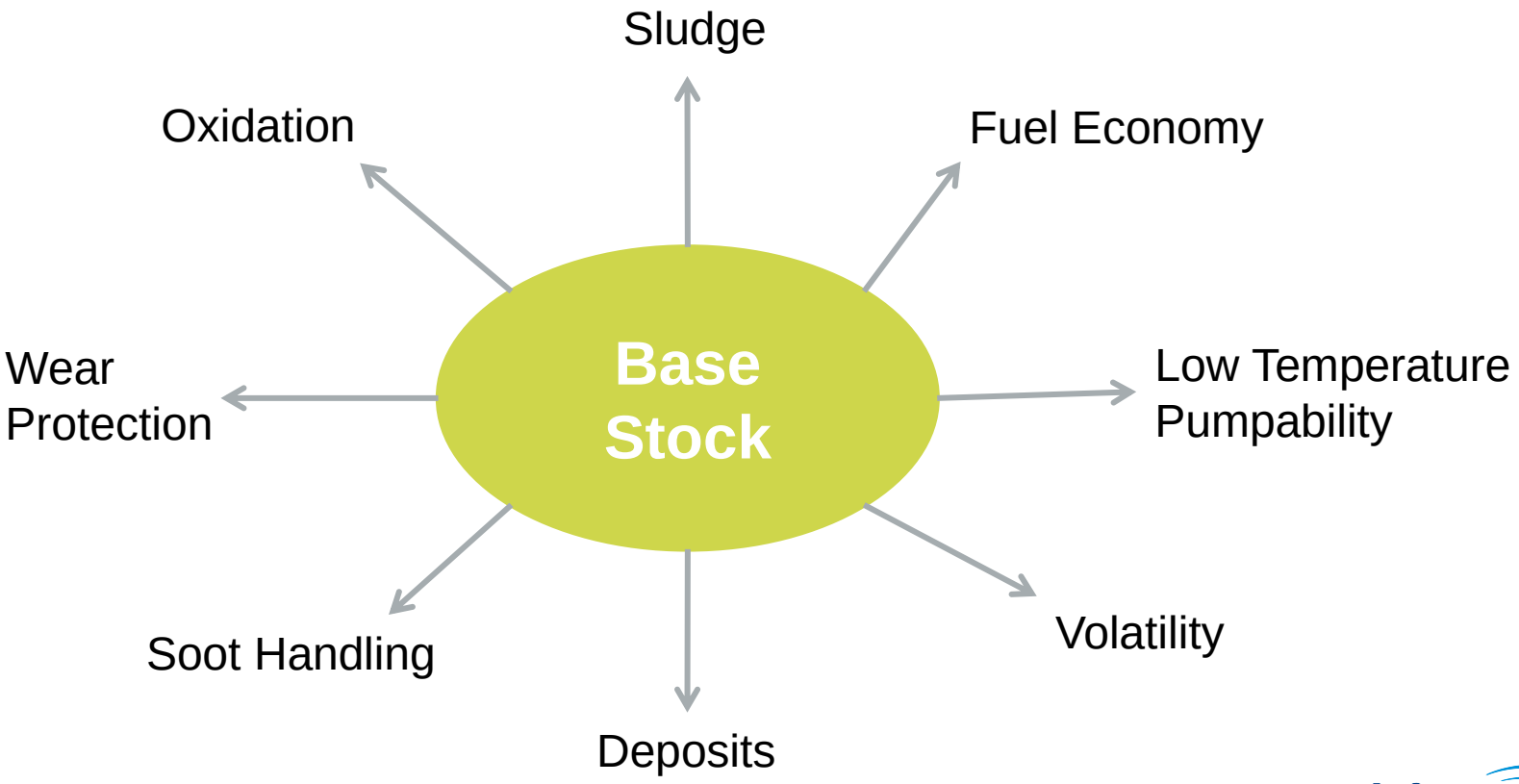
Why are Base Stocks Important?

- It is the major component in lubricants
- Amount varies from segment to segment

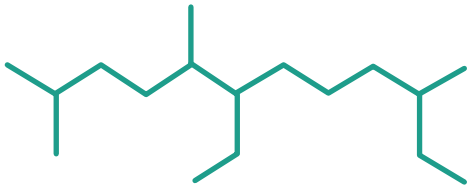
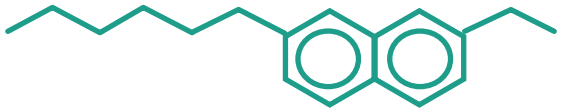
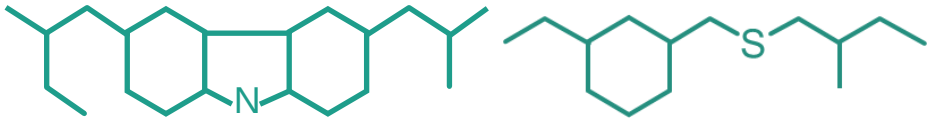


Why are Base Stocks Important?

- 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	

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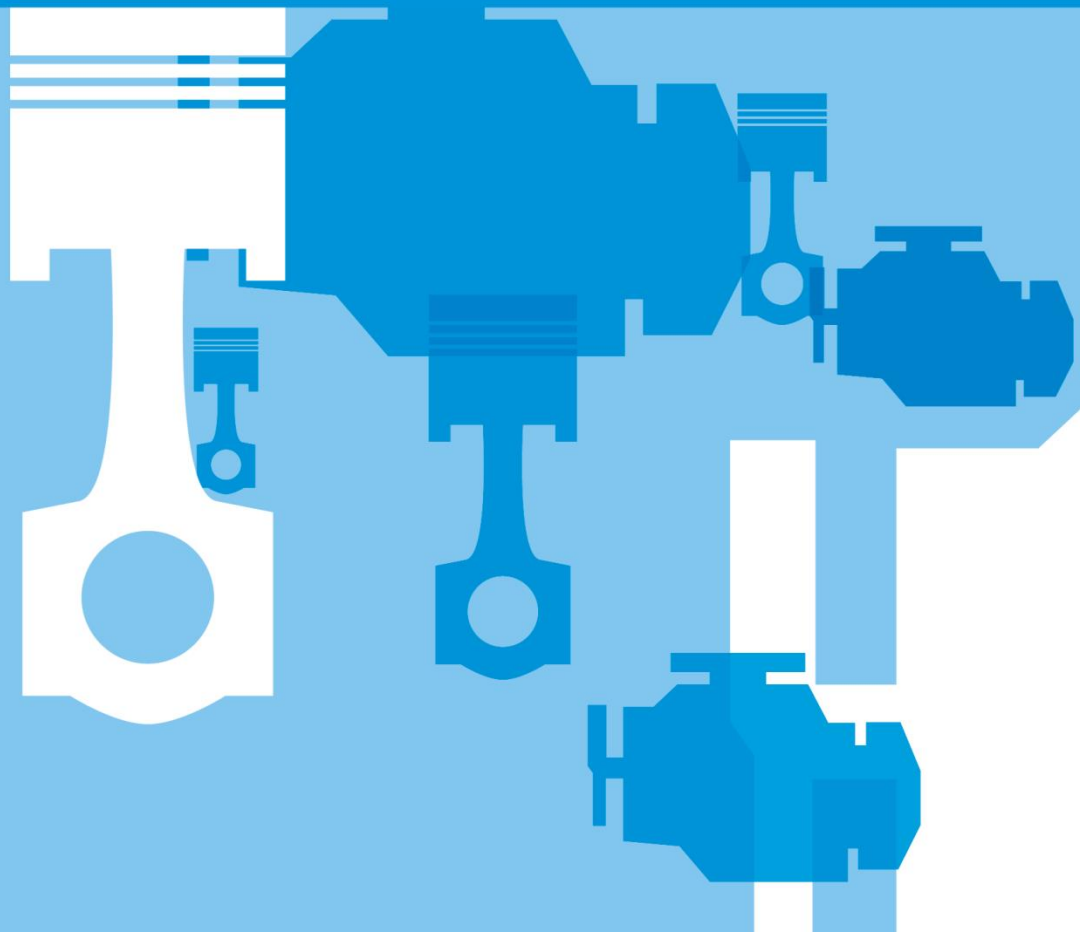
Properties of Base Stocks



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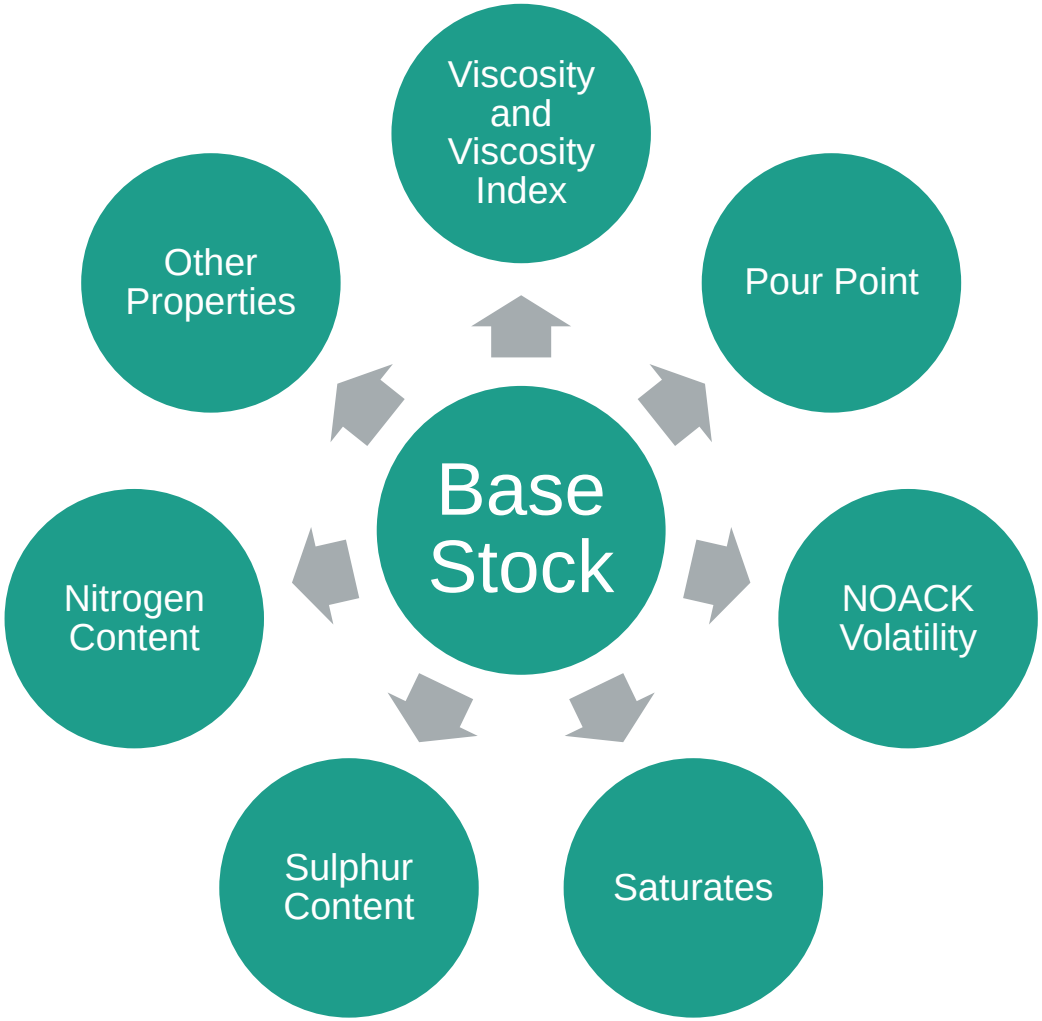
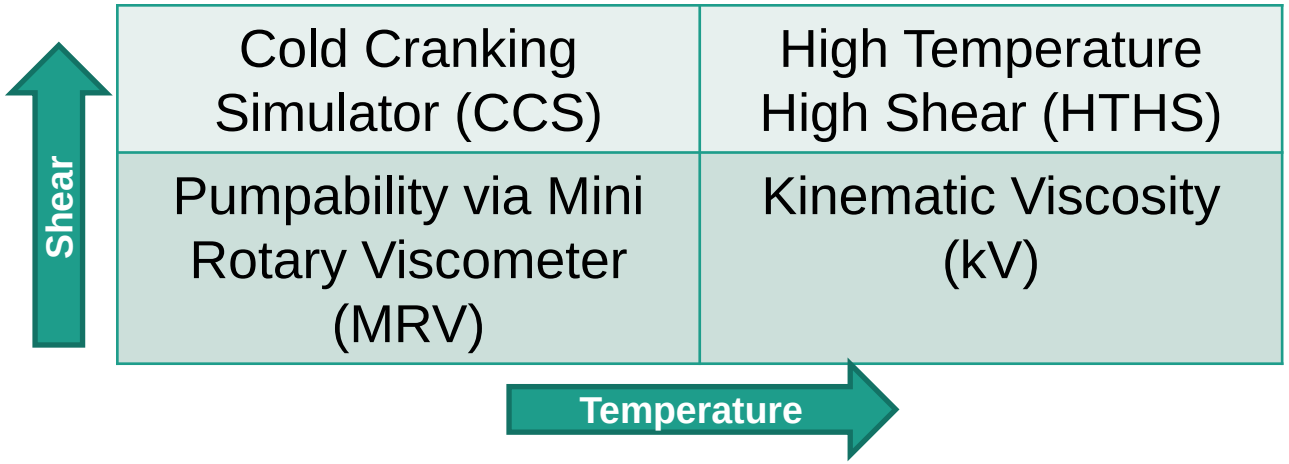
Key Base Stock Properties



Viscosity

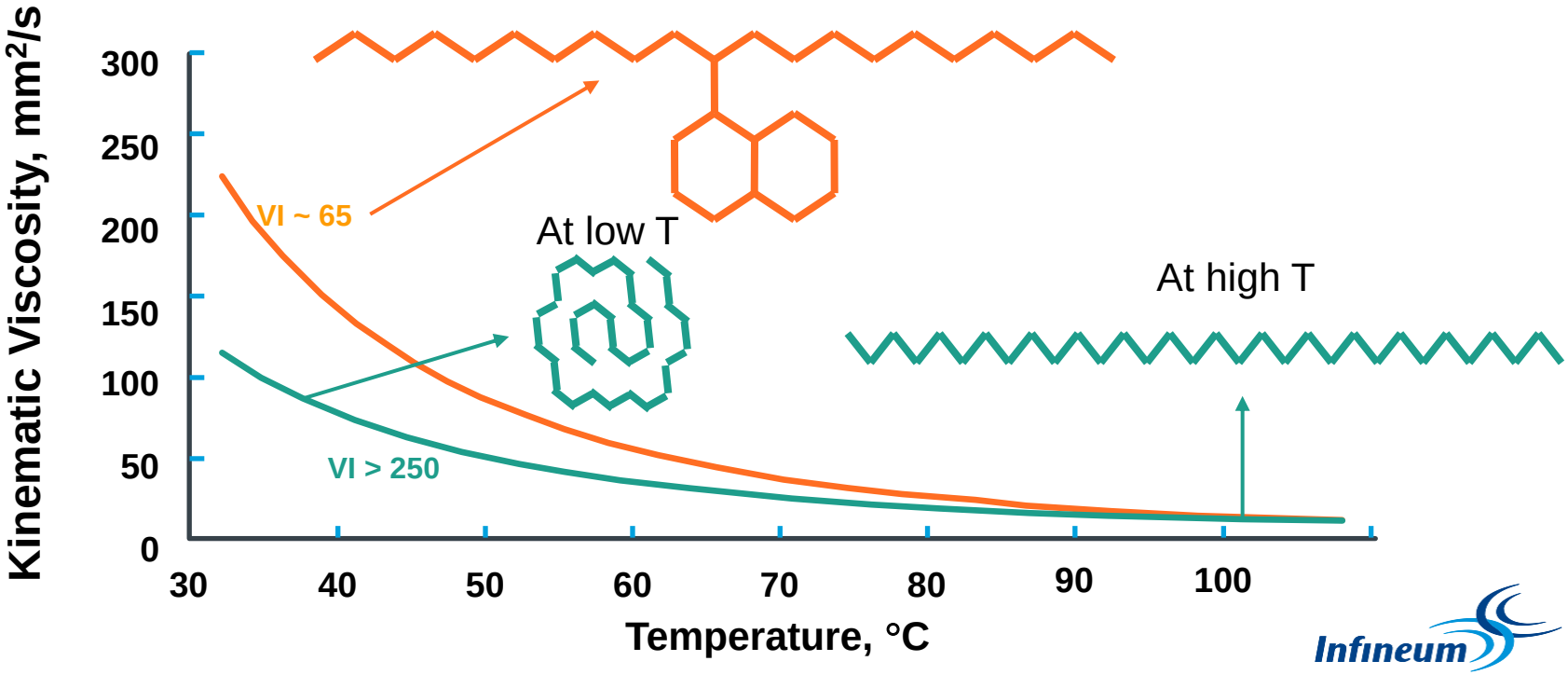
- Dependent upon distillation conditions
- Different measures depending on temperature and amount of shear



Impact on engine performance:
Fuel Economy
Wear

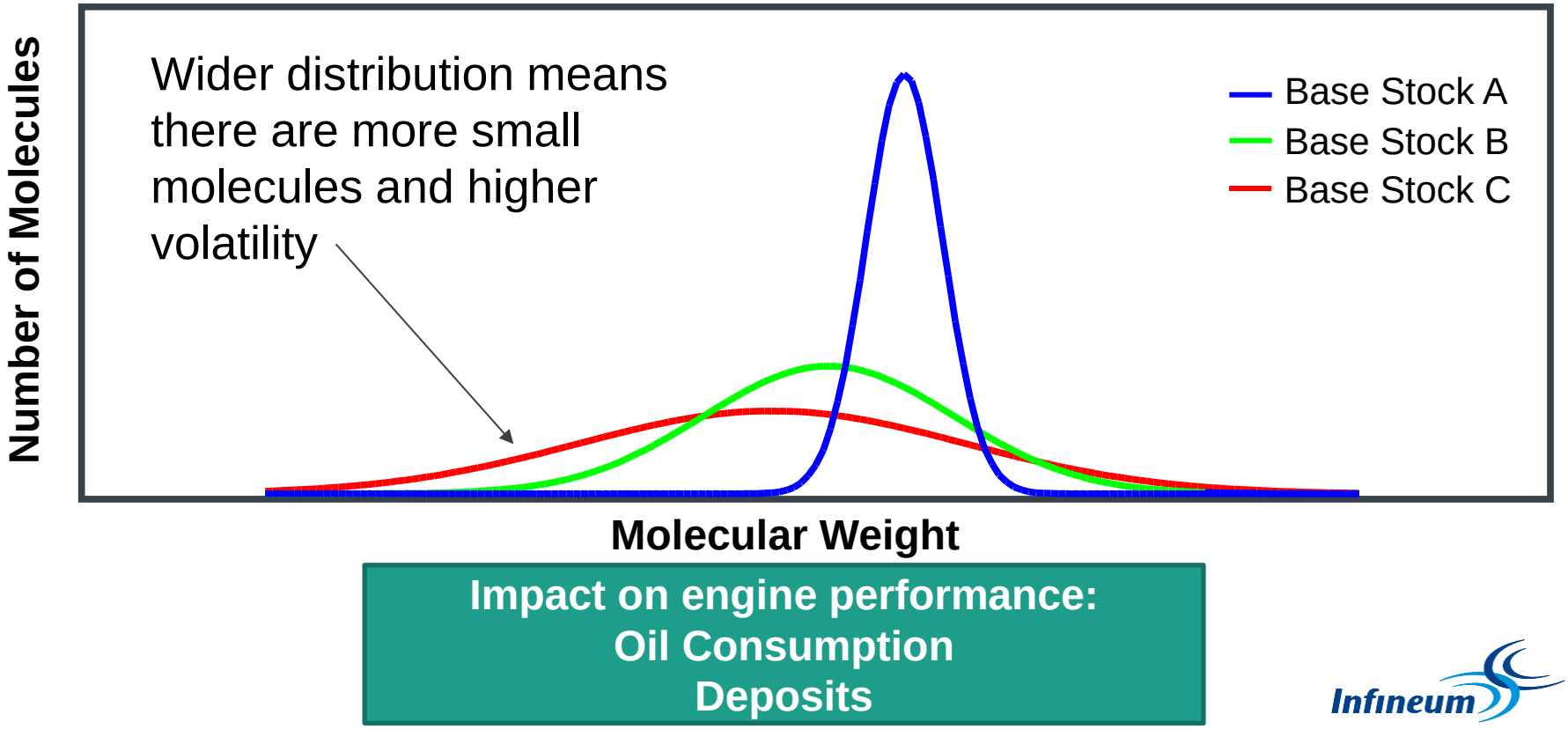
Viscosity Index (VI)

- 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 the evaporative loss
- Dependent on small molecule content of the base stock (“light ends”)



Impact on engine performance:
Oil Consumption
Deposits

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Pour Point

- Defined as the temperature at which the base stock becomes semi-solid and loses its flow characteristics
  - Related to melting point
  - Effect is seen in low temperature crystallisation
- Depends on the 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

Saturates

- Dependent upon processing conditions
- Level of saturates impacts
  - Susceptibility of the base stock to undergo oxidation
  - Solvency and additive compatibility

Impact on engine performance:
Oxidation
Seals 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
Viscosity Increase

Other Properties

	Test	Description
Polarity	Aniline point	Lowest T at which aniline and mineral base oil are miscible; indicator of base oil composition/solubility
Polarity	Demulsibility	A measure of a fluid's ability to separate from water
Chain length	MRV	Mini-Rotary Viscosity – High shear viscosity test
Chain length	kV	Kinematic Viscosity – Low shear viscosity test
Chain length	End point	Highest vapour T during distillation
Chain length	Flash point	Temperature at which vapors can ignite
Impurities	Colour	Indicator of refining
Impurities	Cloud Point	Temperature at which wax crystals precipitate
Impurities	Carbon Residue	Coked material remaining after base oil has been exposed to high temperatures
Impurities	Density	Indicator of base oil composition

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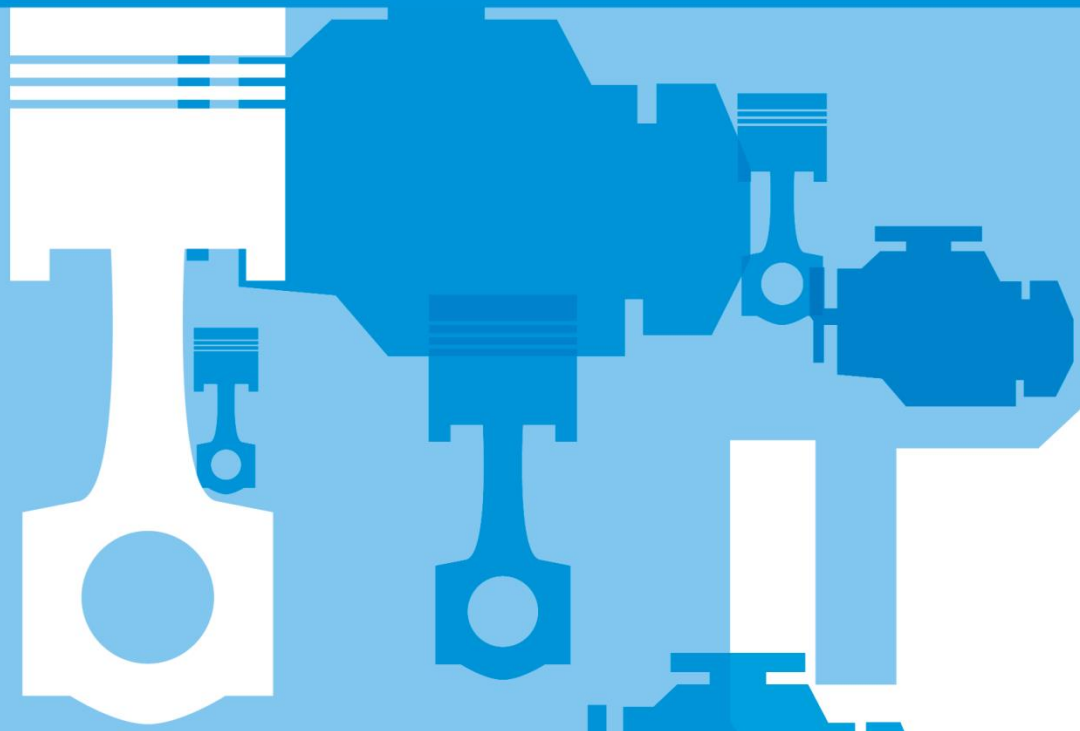
Base Stock Classification



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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

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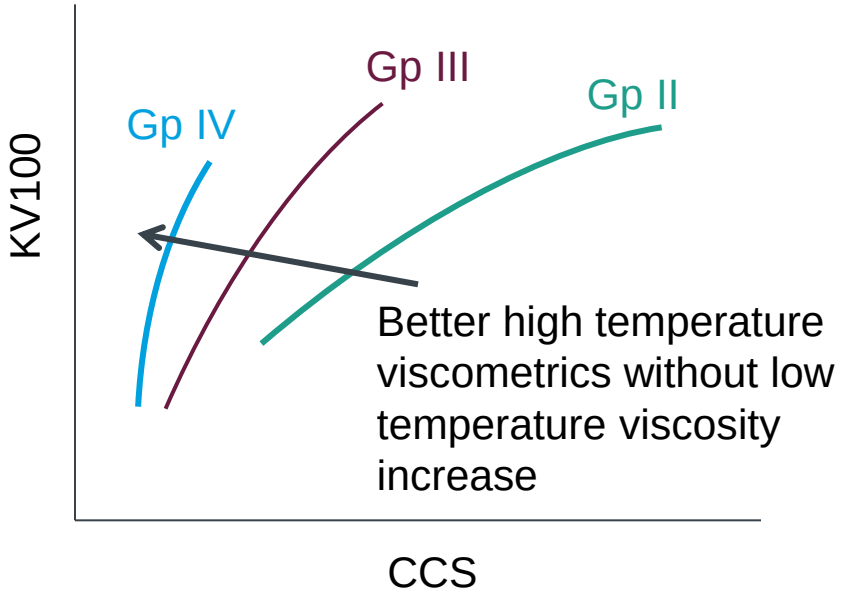
Comparison of Base Stock Groups

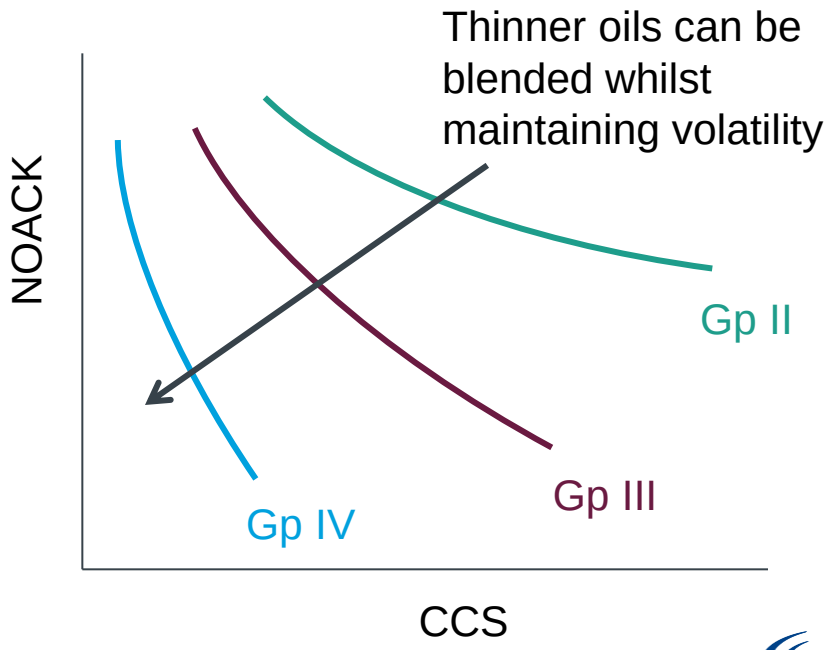
Group	Saturates	Sulphur Content	Volatility	Oxidative Stability	Cost
I	Low	High	High	Variable	Low
II	High	Low	Medium	Medium	Medium
III*	High	Low	Low	High	Medium
IV	Very High	Very Low	Very Low	Very High	High
V**	Very High	Very Low	Very Low	Variable	High

* Includes GTL
** Polyol ester used to improve polarity

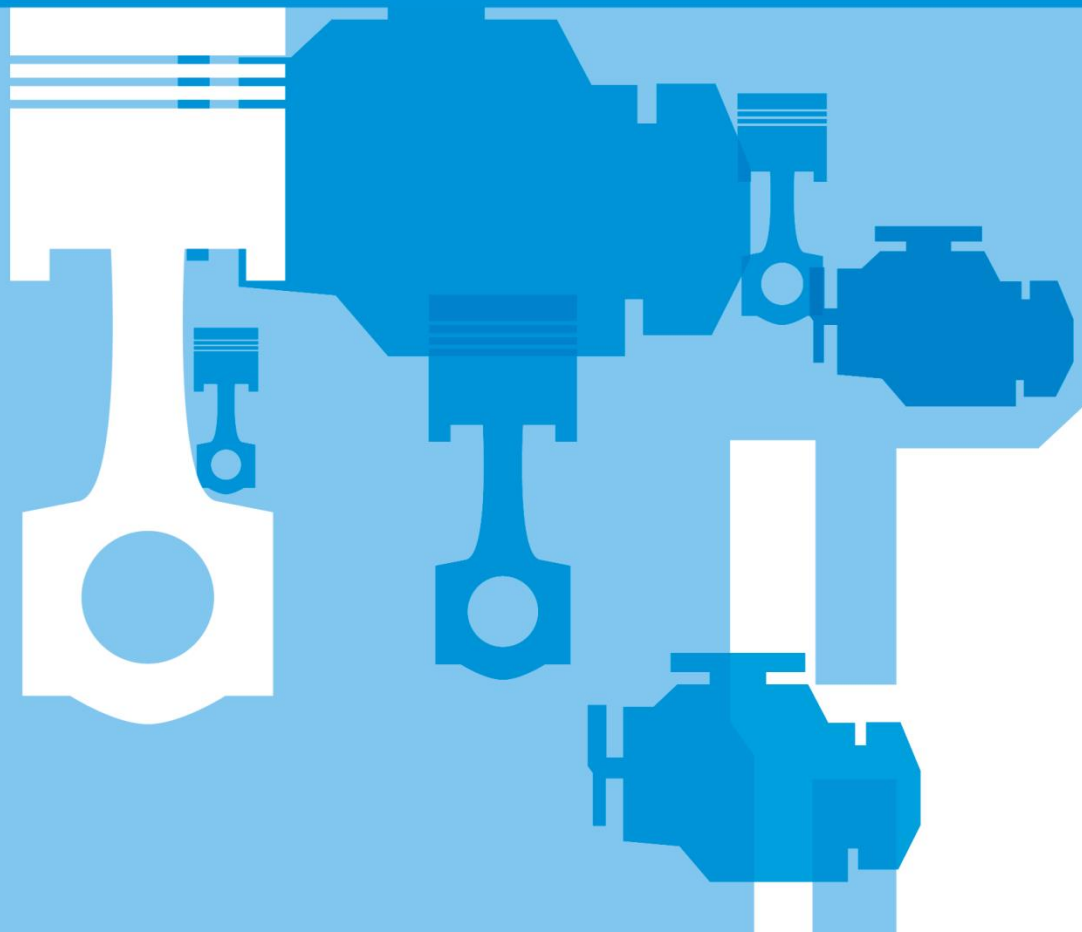
Selecting a Base Stock

- 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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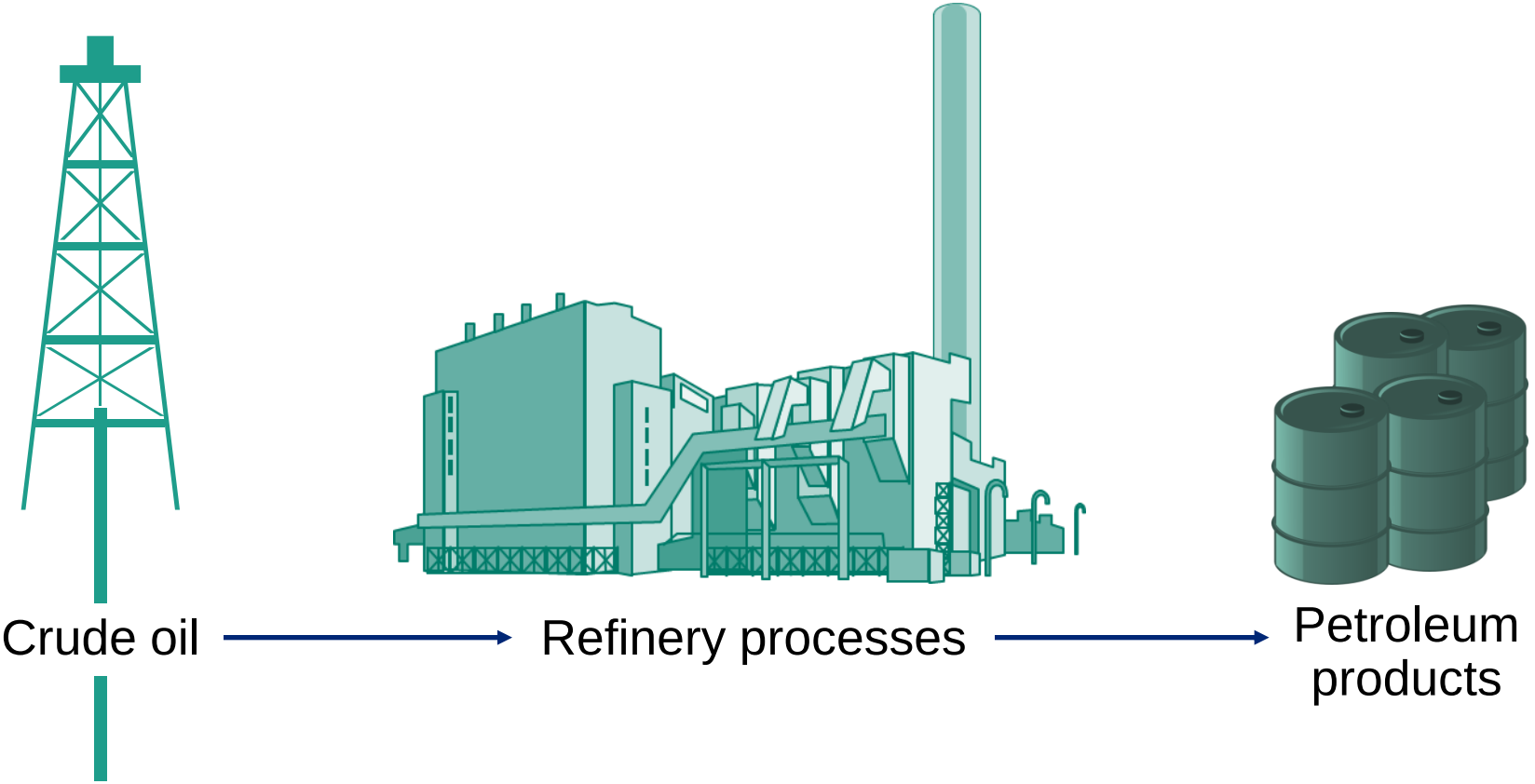
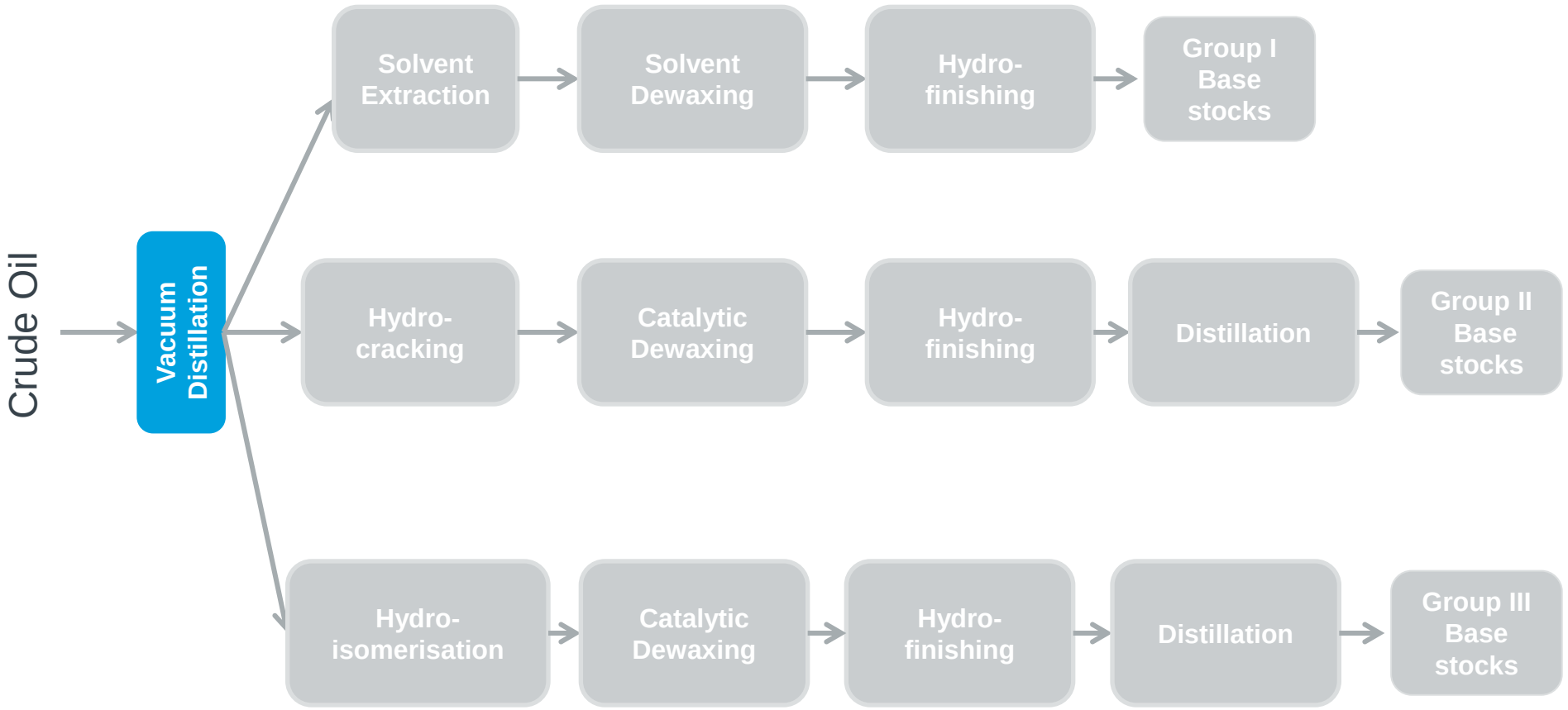
Refinery Overview



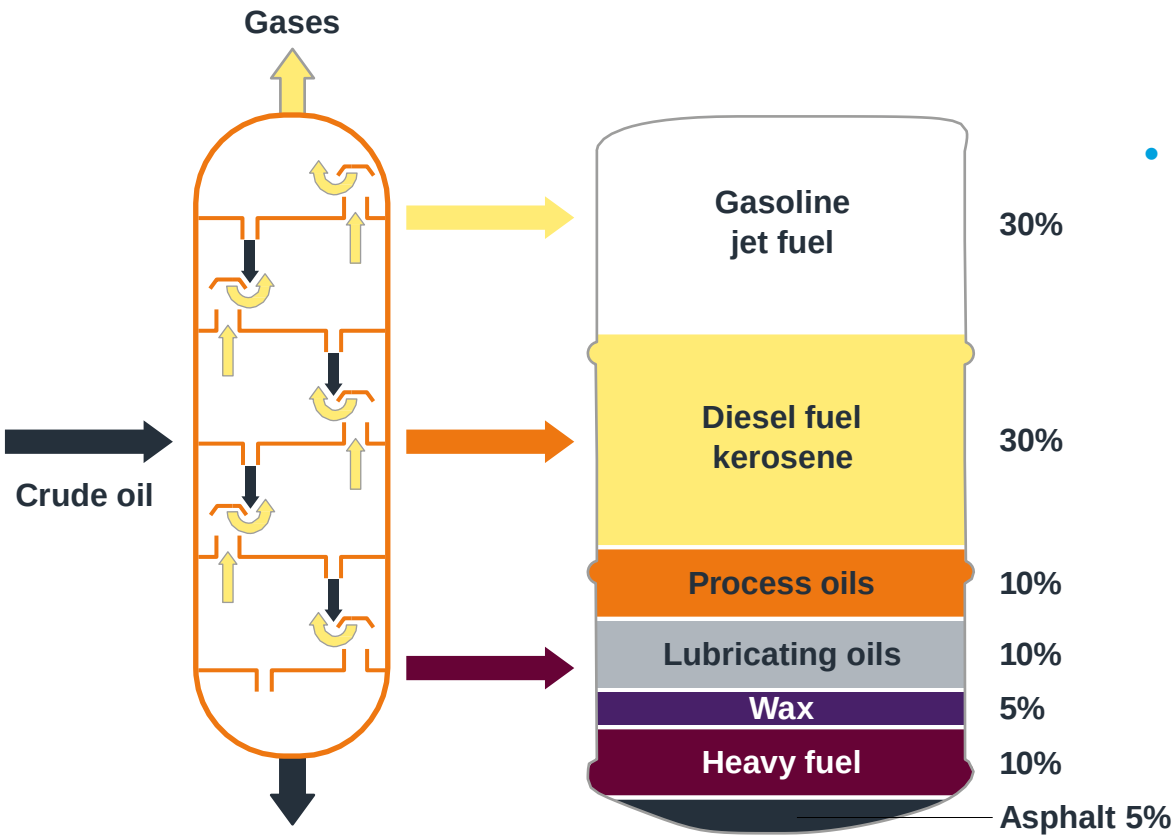
Crude Selection

- 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

Refining Process

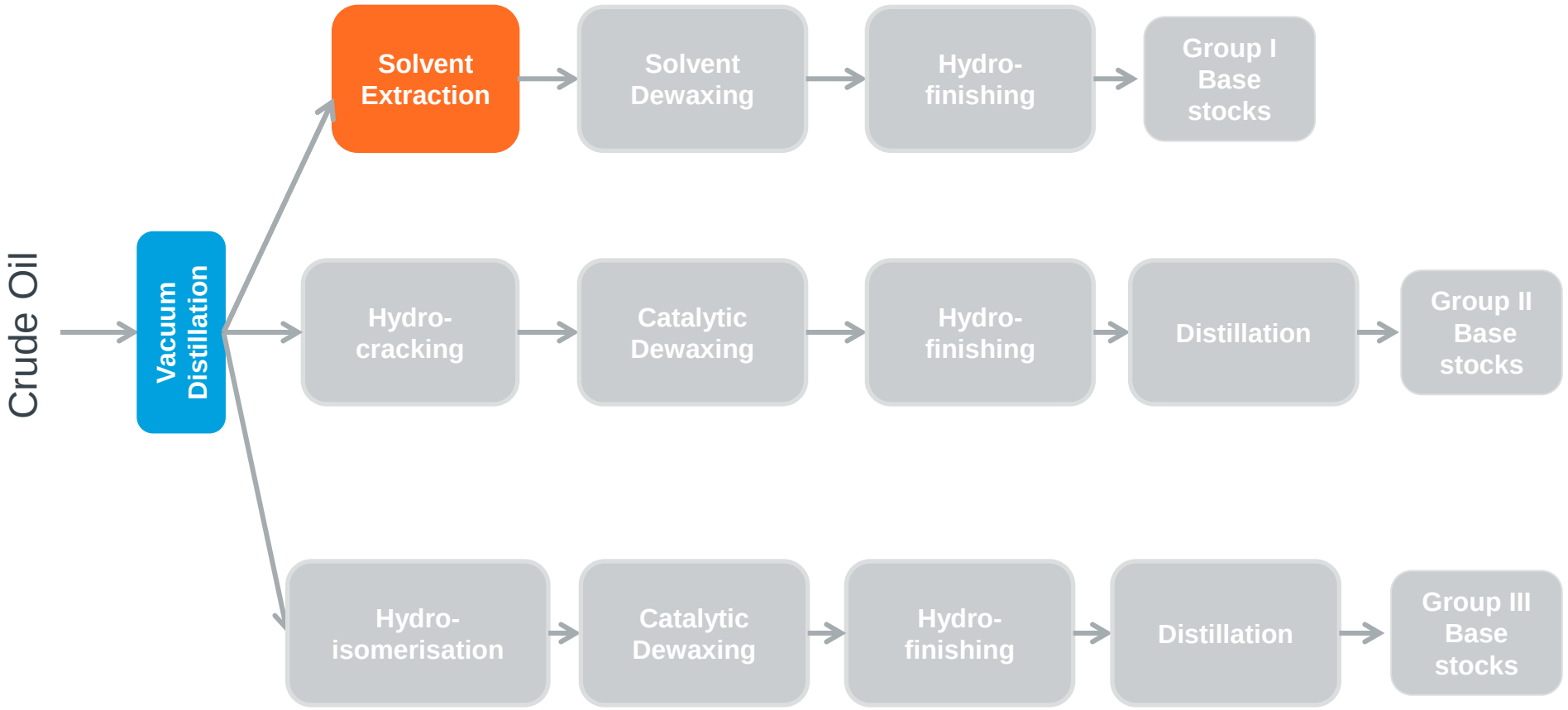


Vacuum Distillation



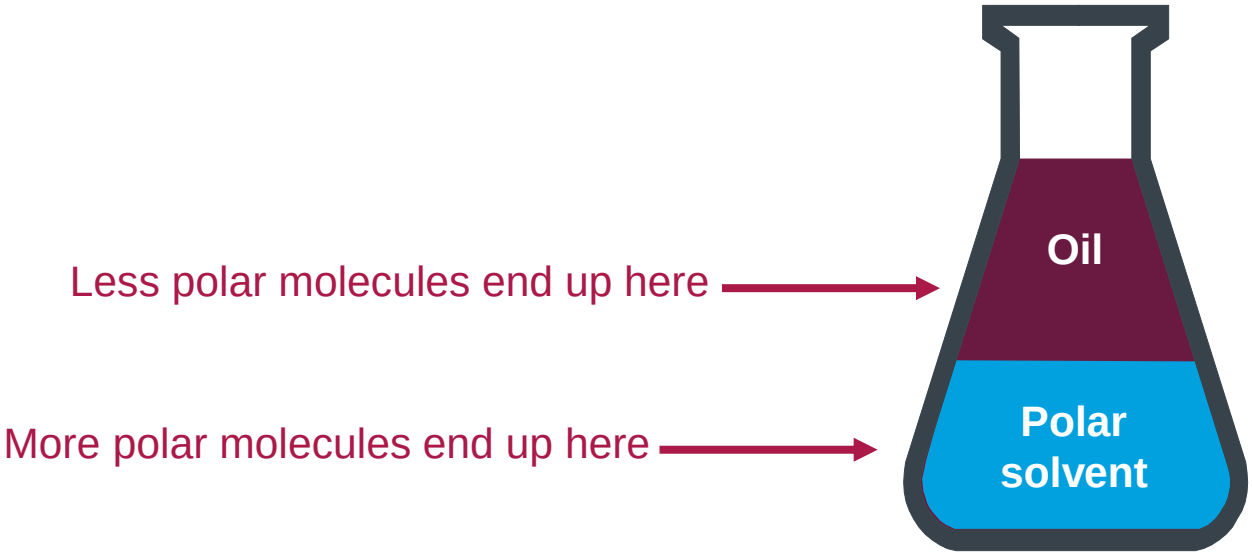
- Distillation
  - Separates lighter from heavier fractions
  - Selects viscosity “cut”
  - Controls volatility (evaporation)

Refining Process

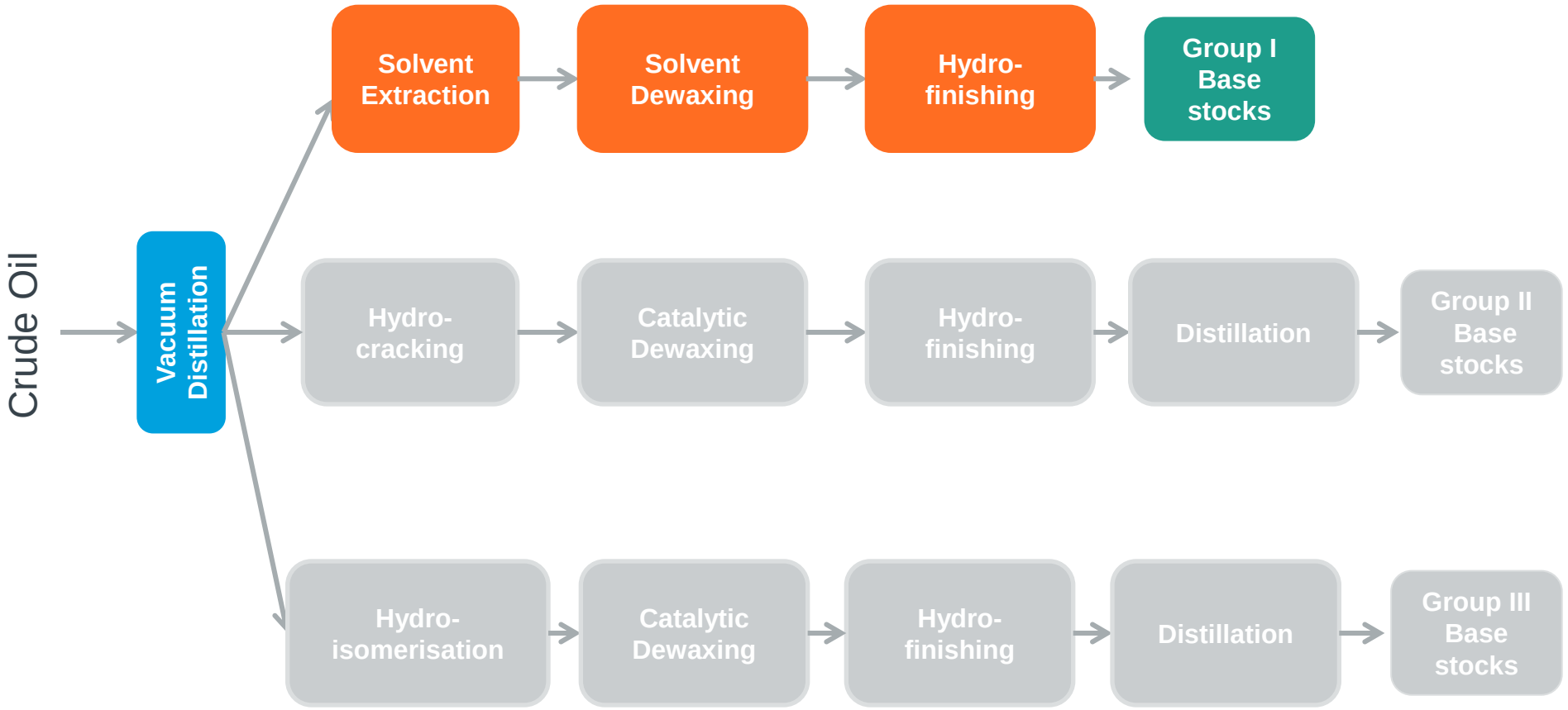


Solvent Extraction

- 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

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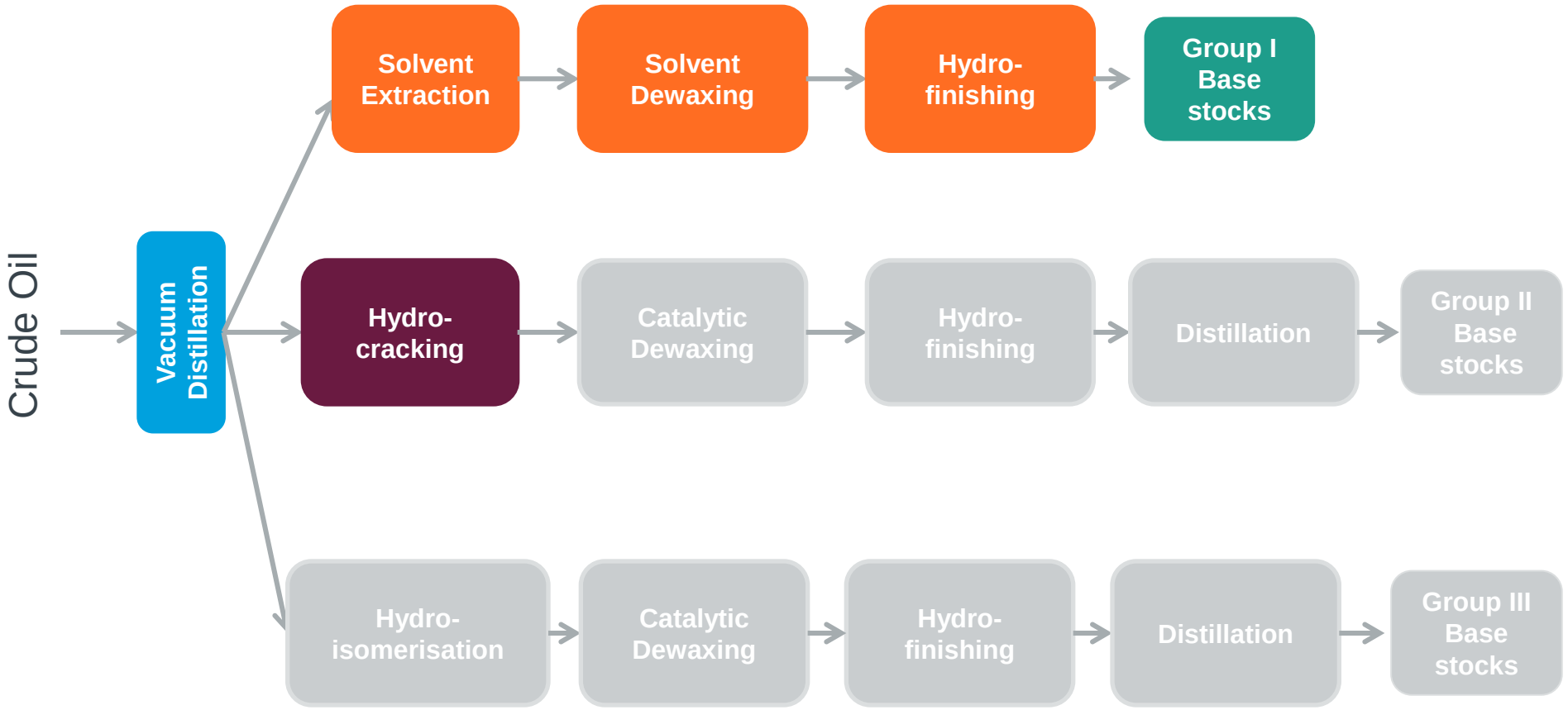
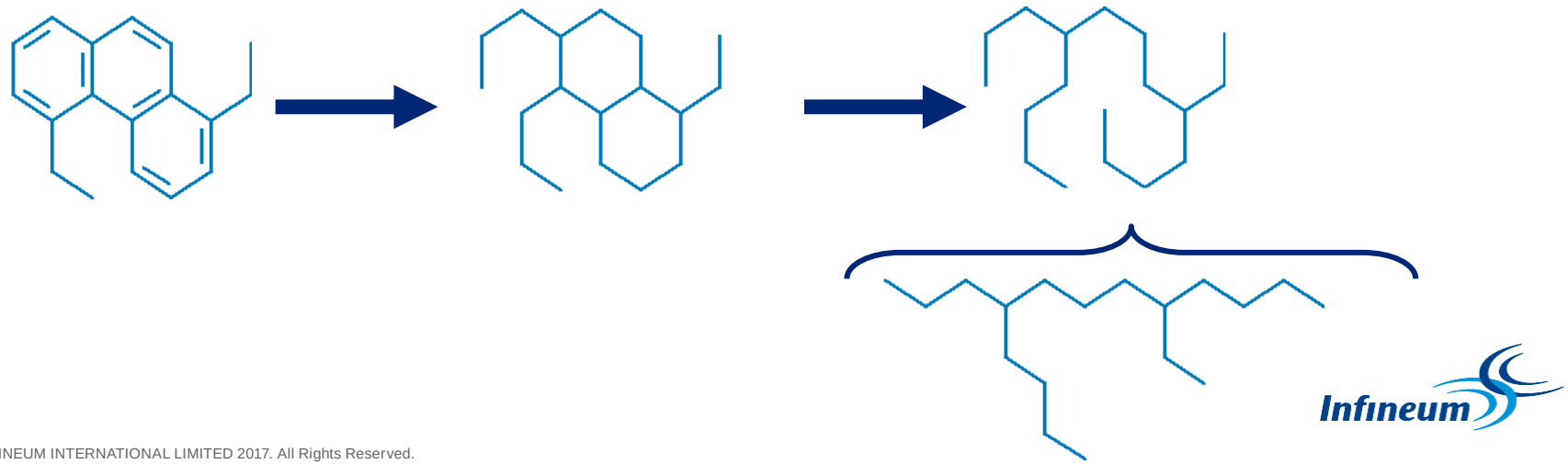
Refining Process

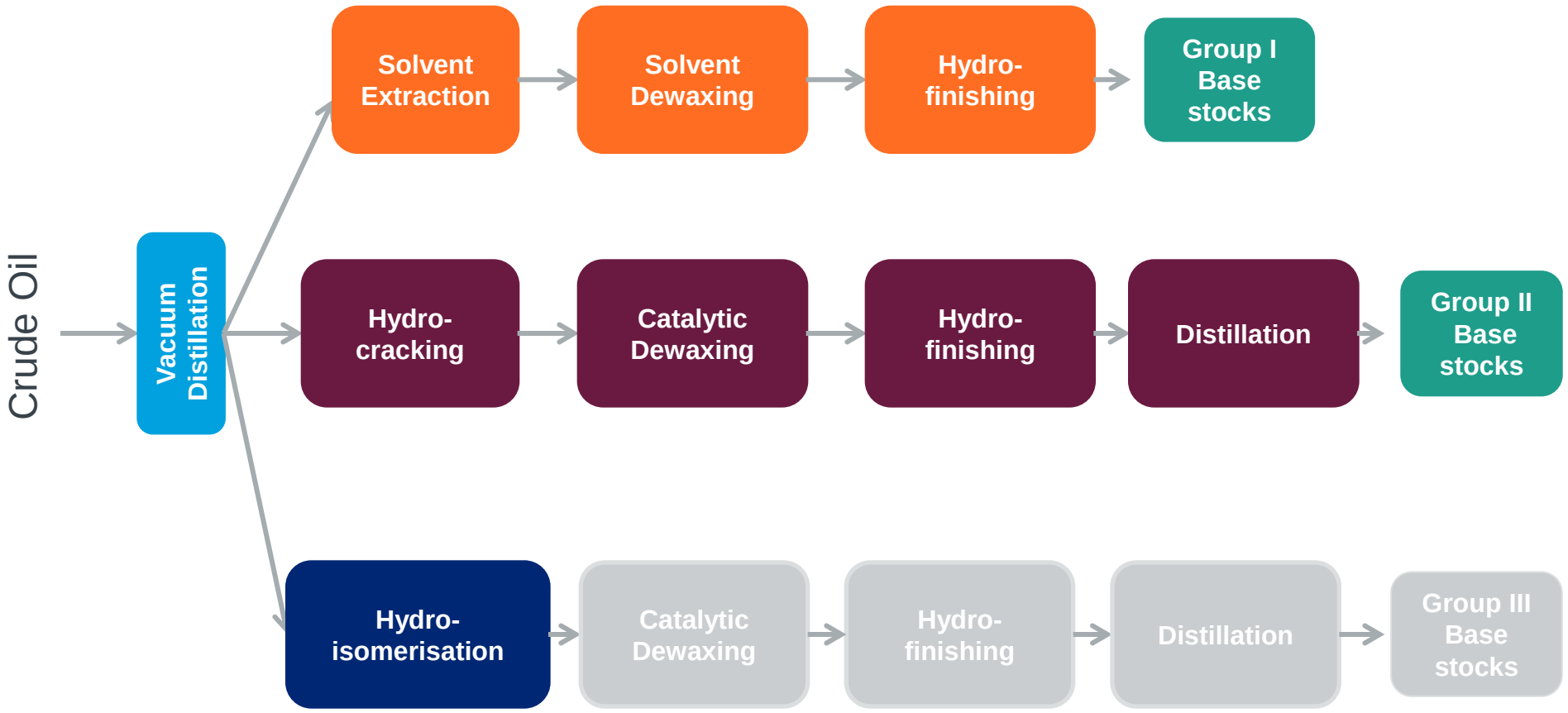


Hydrocracking

- 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



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

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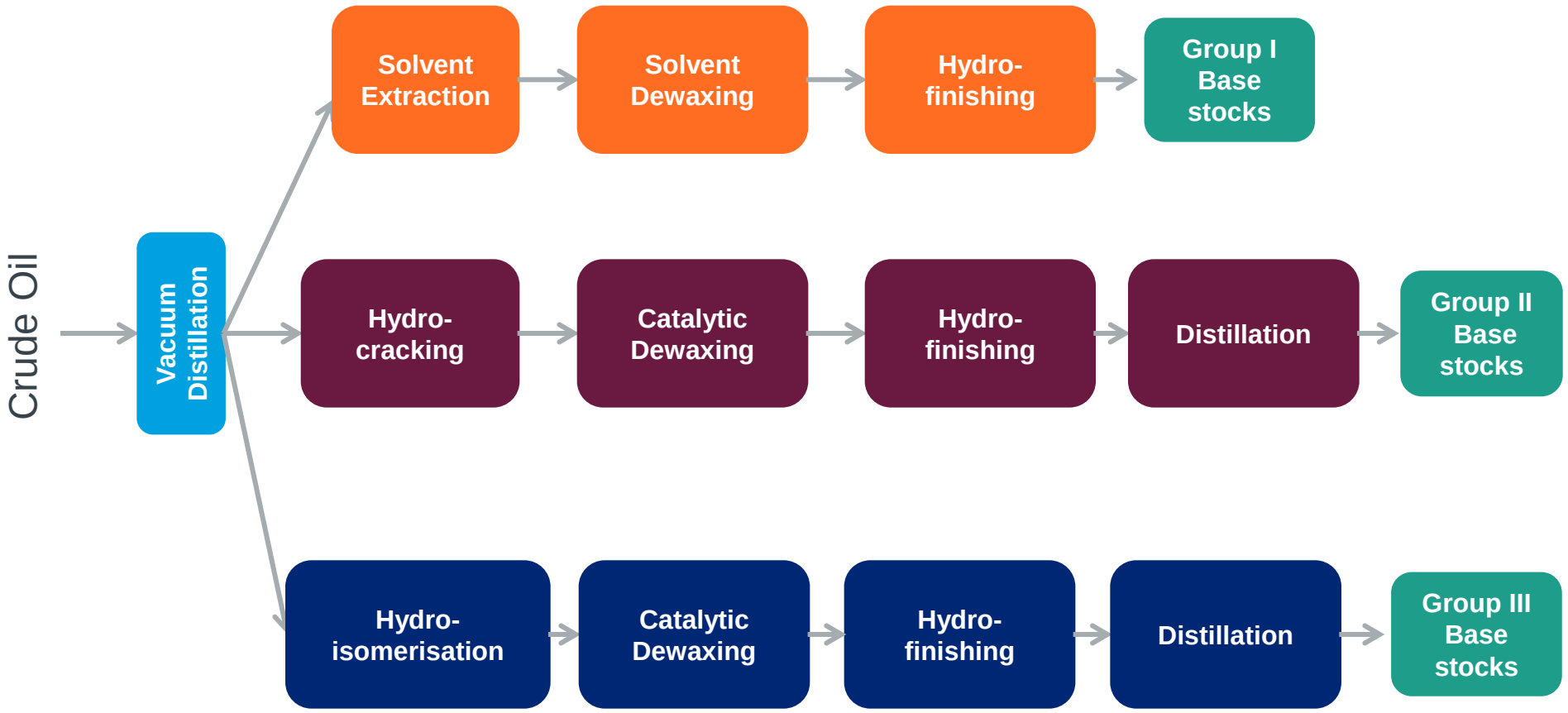
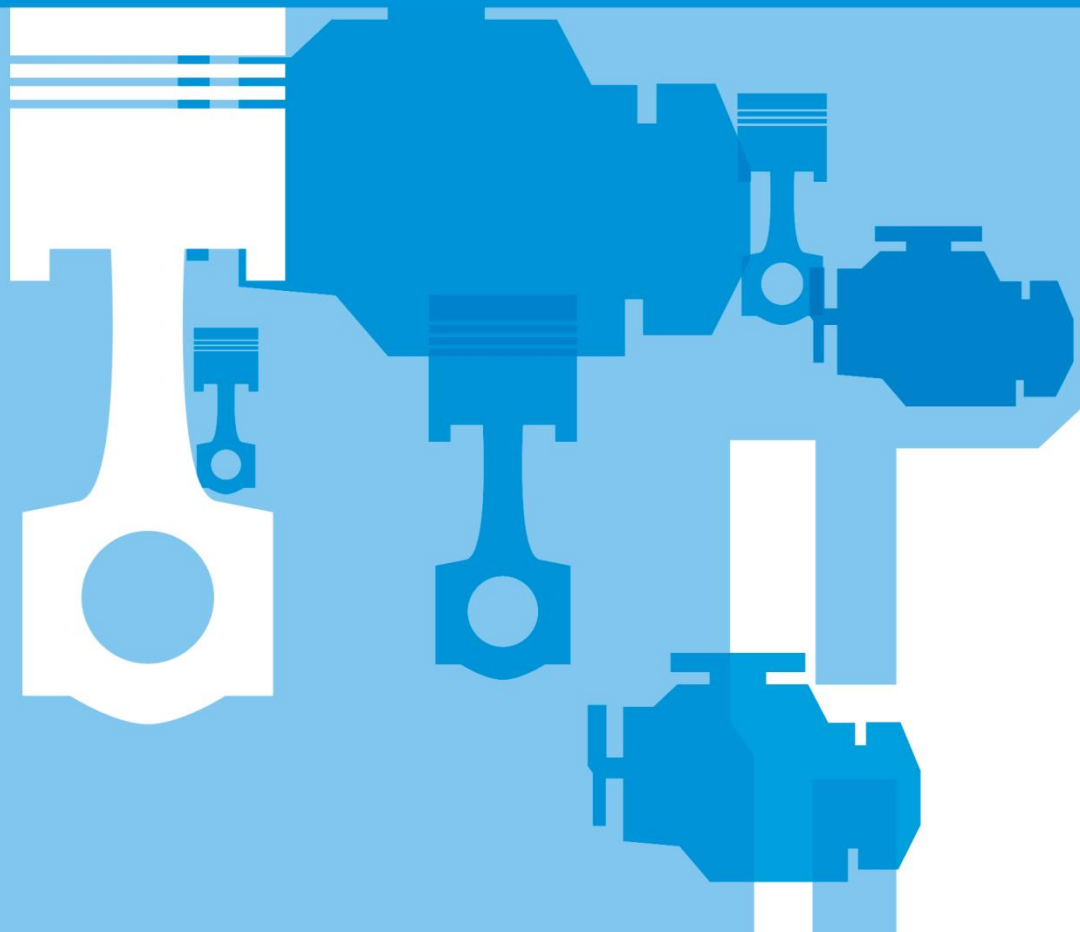
Refining Process



Performance you can rely on.

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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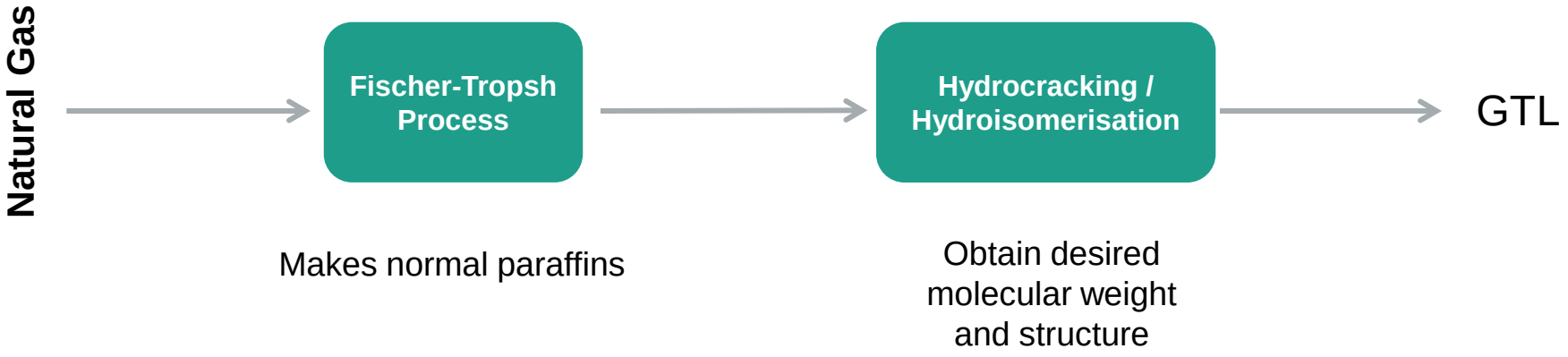
Gas to Liquids (GTL)

- 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

Refinery Process for GTL

- GTL is 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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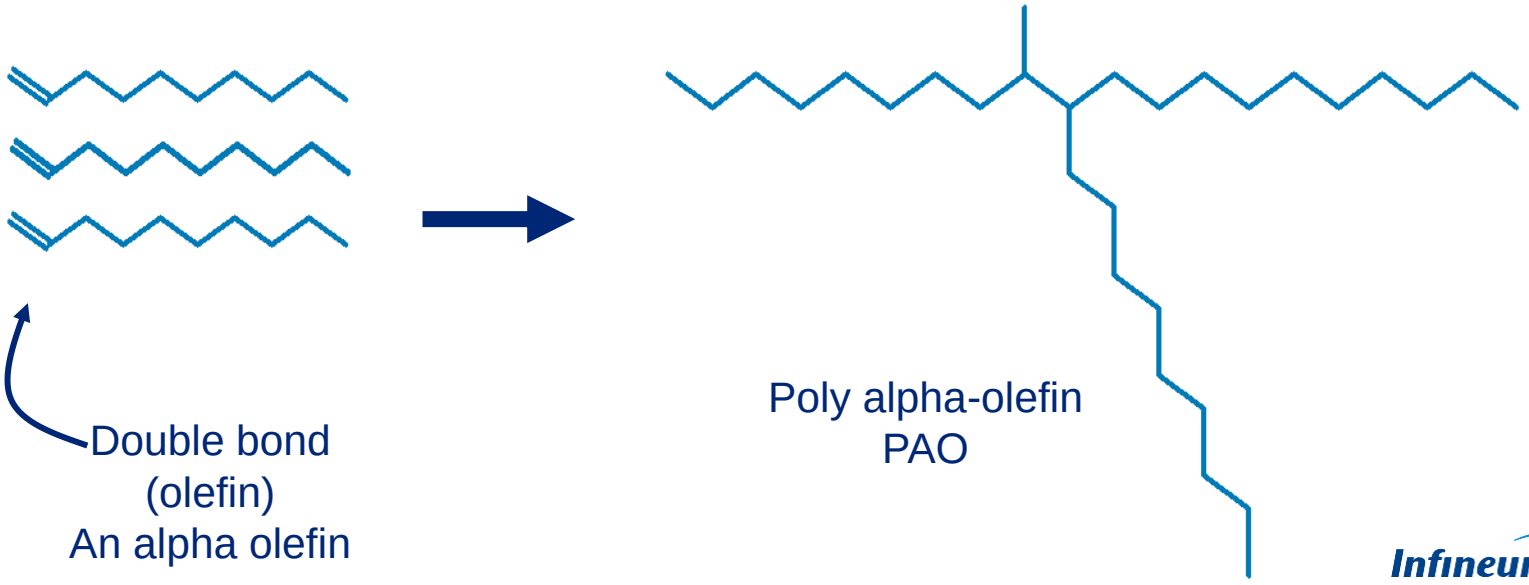
Synthetic Process - PAO

- 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 is defined as ‘Everything else’ not classified in the other API groups
- Versatile, custom made for specialised applications
- Examples of Group V Base Stocks are:
- 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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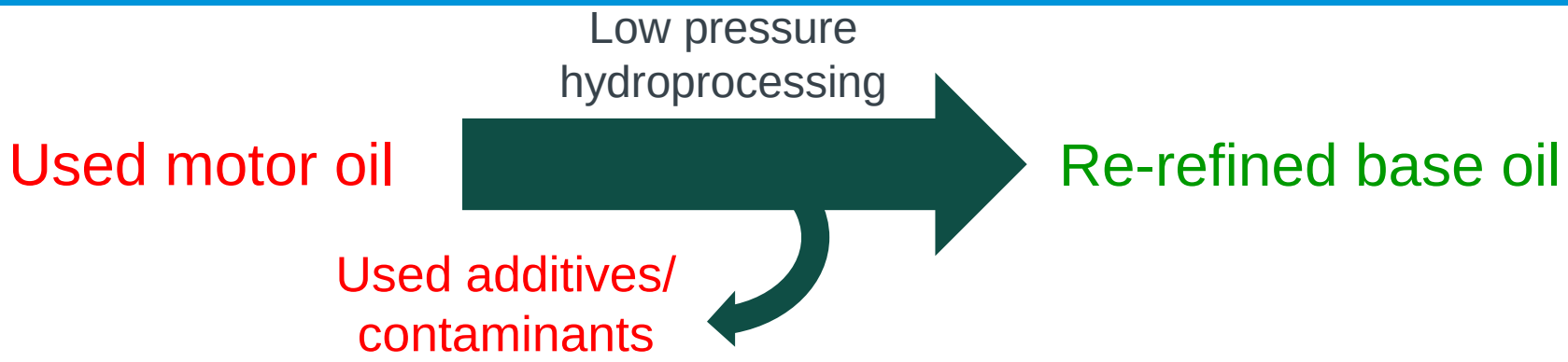
Re-refining



- Processing is 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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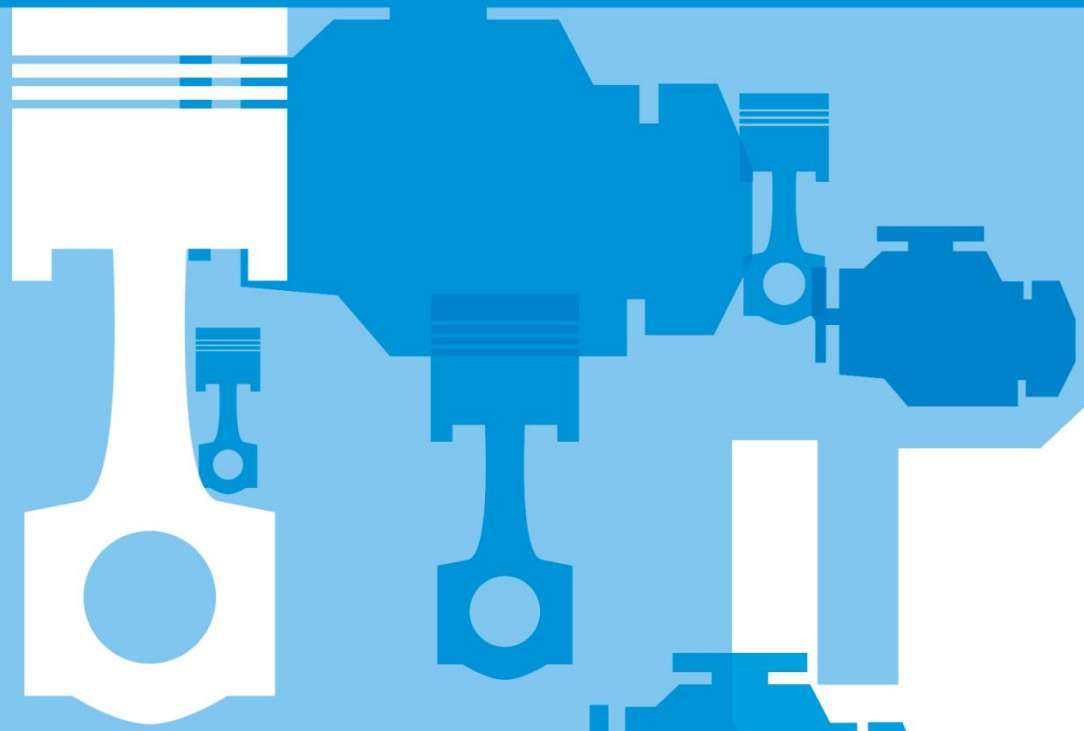
Drivers and Market Trends



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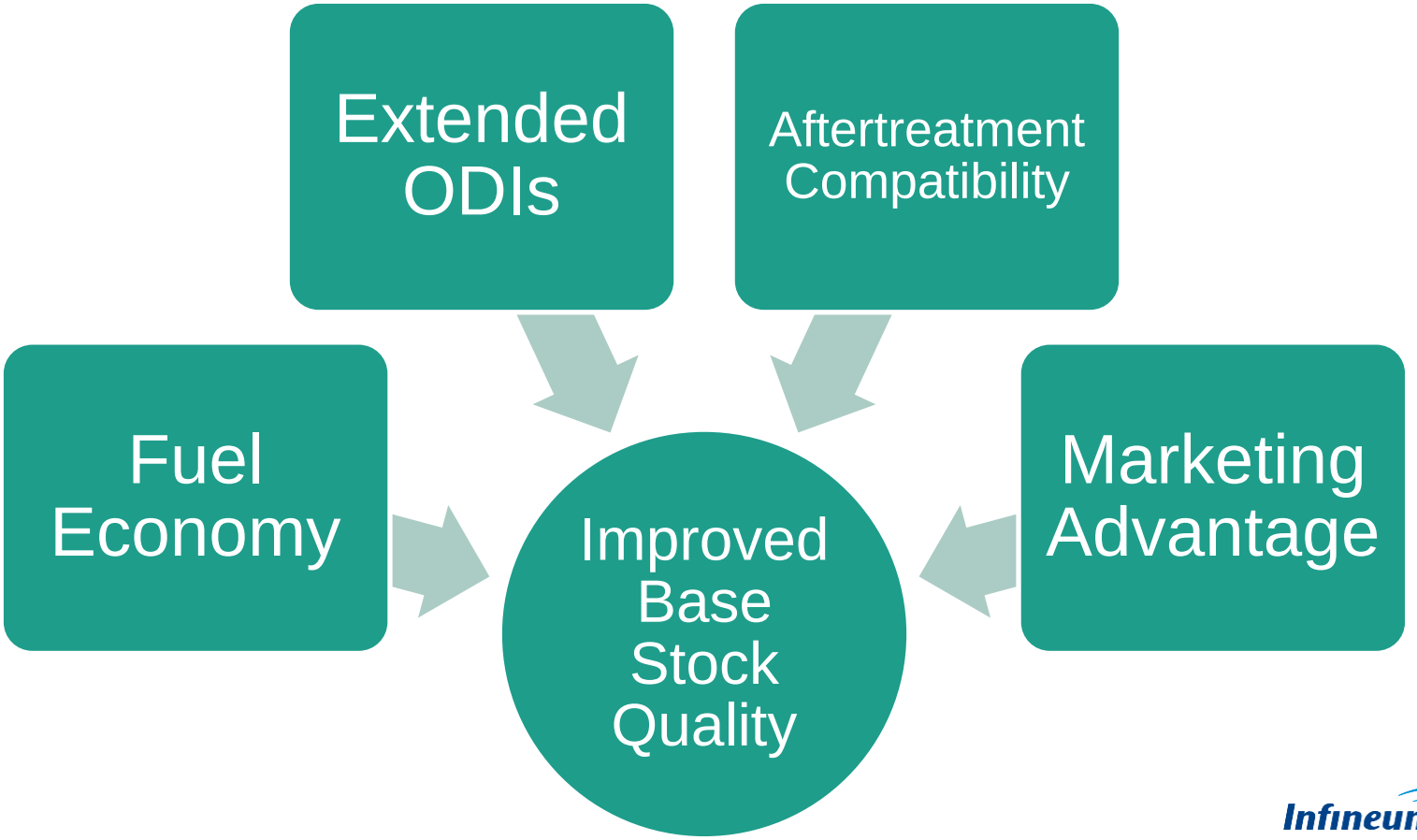
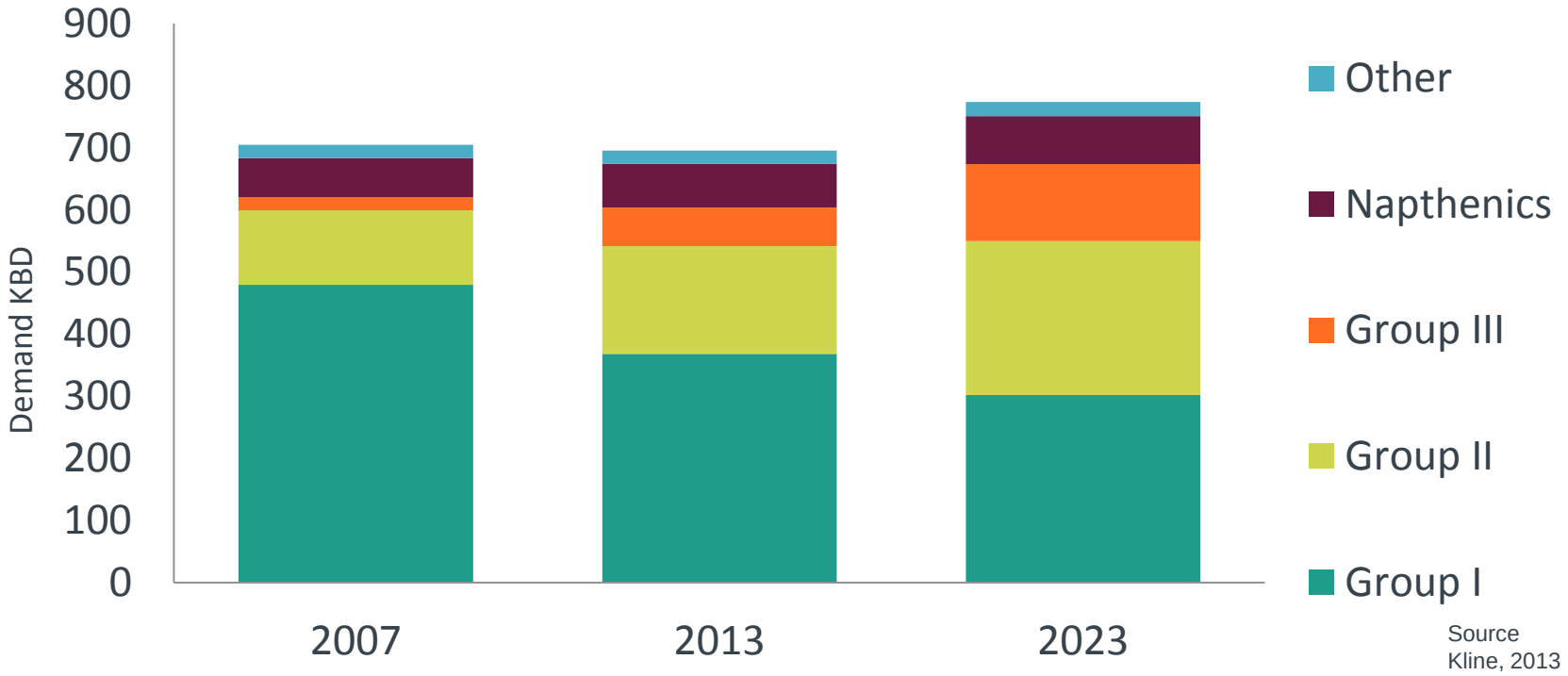
Drivers

Many of the main drivers for lubricant performance result in a need for improved base stock quality



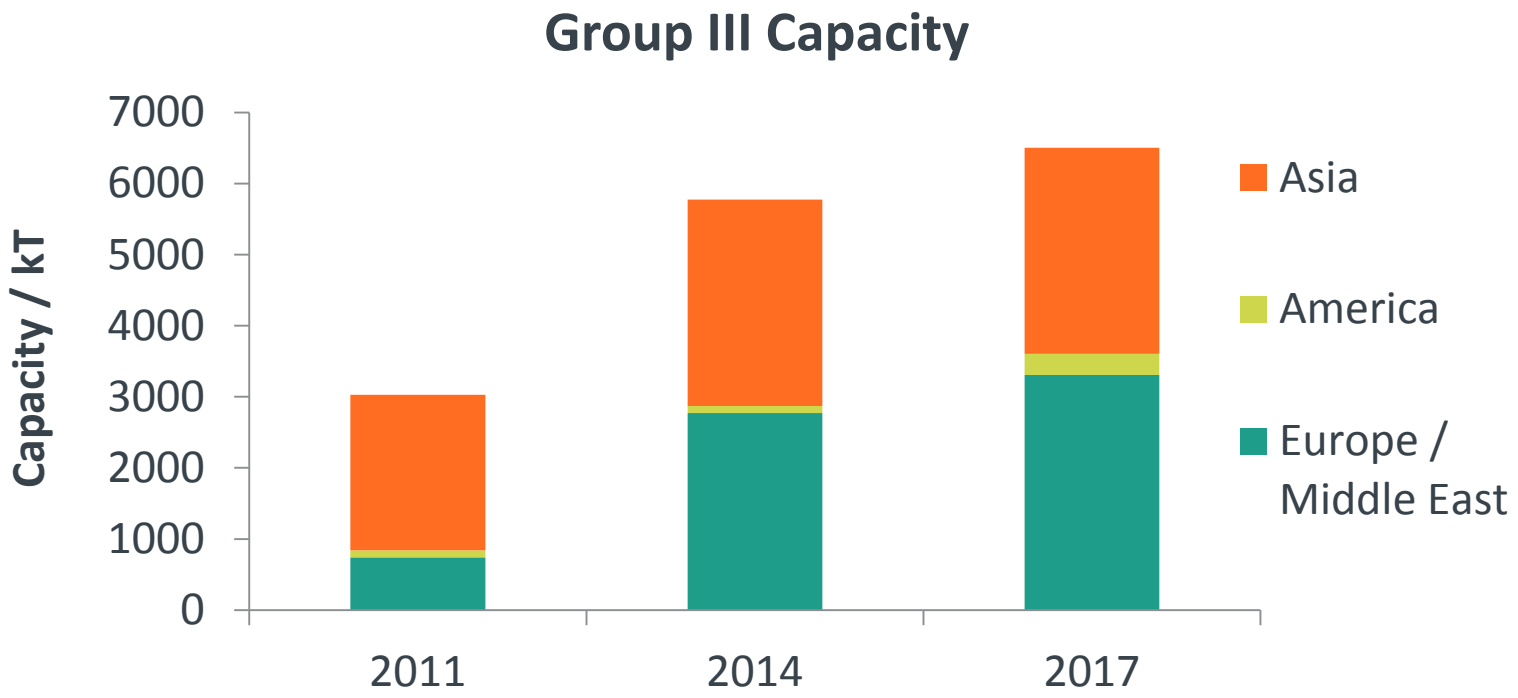
Trend in Base Stock Demand



Source
Kline, 2013

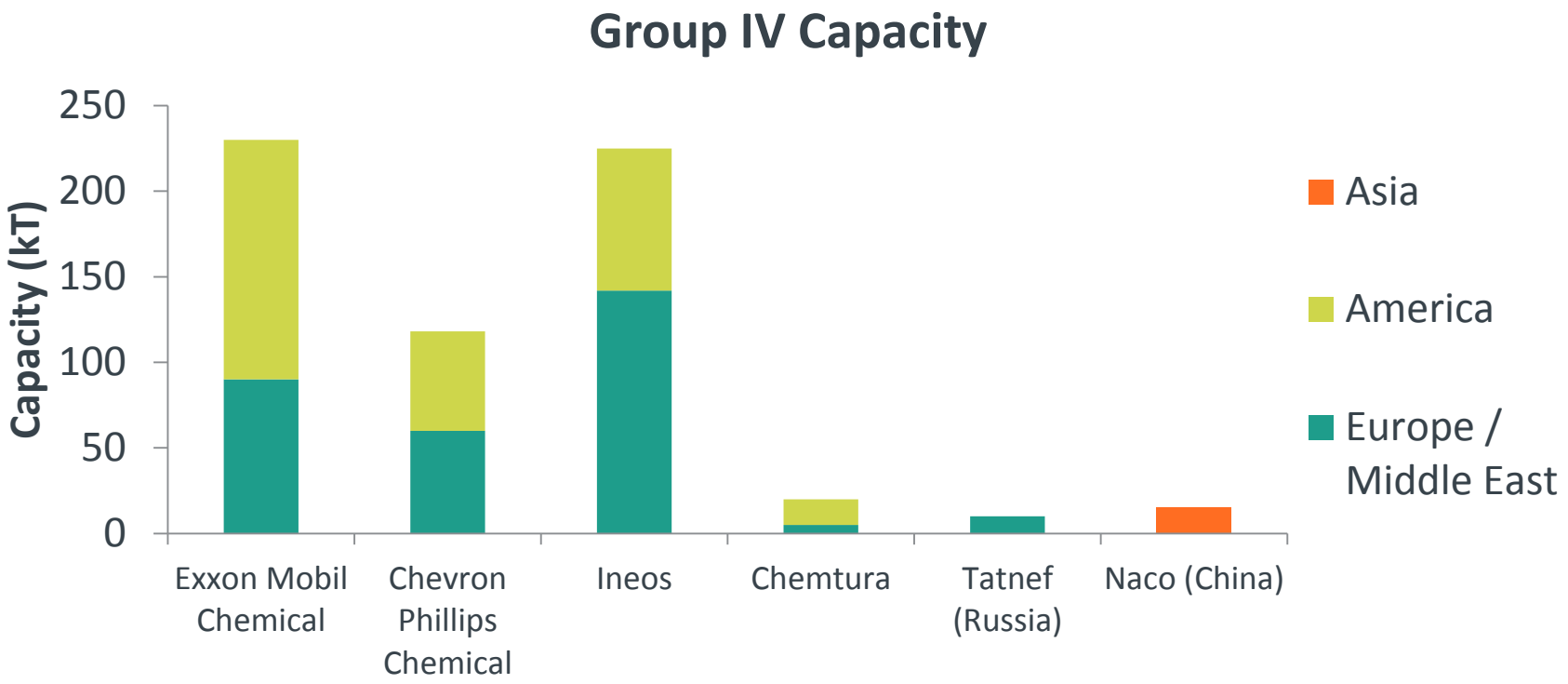
- Decline in demand for Group I base stocks
- Increase in demand for higher quality Group II and Group III base stocks

Trends in Group III Base Stocks



- There has been an increase in Group III capacity from 2011 – 2017
- Largest proportion of Group III production is in Asia and Europe / Middle East
- There is potential for further investment in USA and Russia

Trends in Group IV Base Stocks



- The PAO market is < 2% of the total base stock market
- Main production capacity is in the 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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