A Primer on Base Oils

What is a finished lubricant?

- In most contexts, a finished lubricant is a combination of base fluids and additives
- The net quality of the finished lubricant is a reflection of the quality of the components **AND** the judicious choice of proportions of these components

In other words:

"Putting the right things together in the right amounts to get the overall performance someone is prepared to pay for."

Depending on the application, a finished lubricant can be 70 to 99% base fluid

Purpose of a Base Oil

In a finished lubricant, a Base Oil provides two things:

- some inherent viscosity to lubricate
- a medium in which performance-enhancing additives can either dissolve or suspend

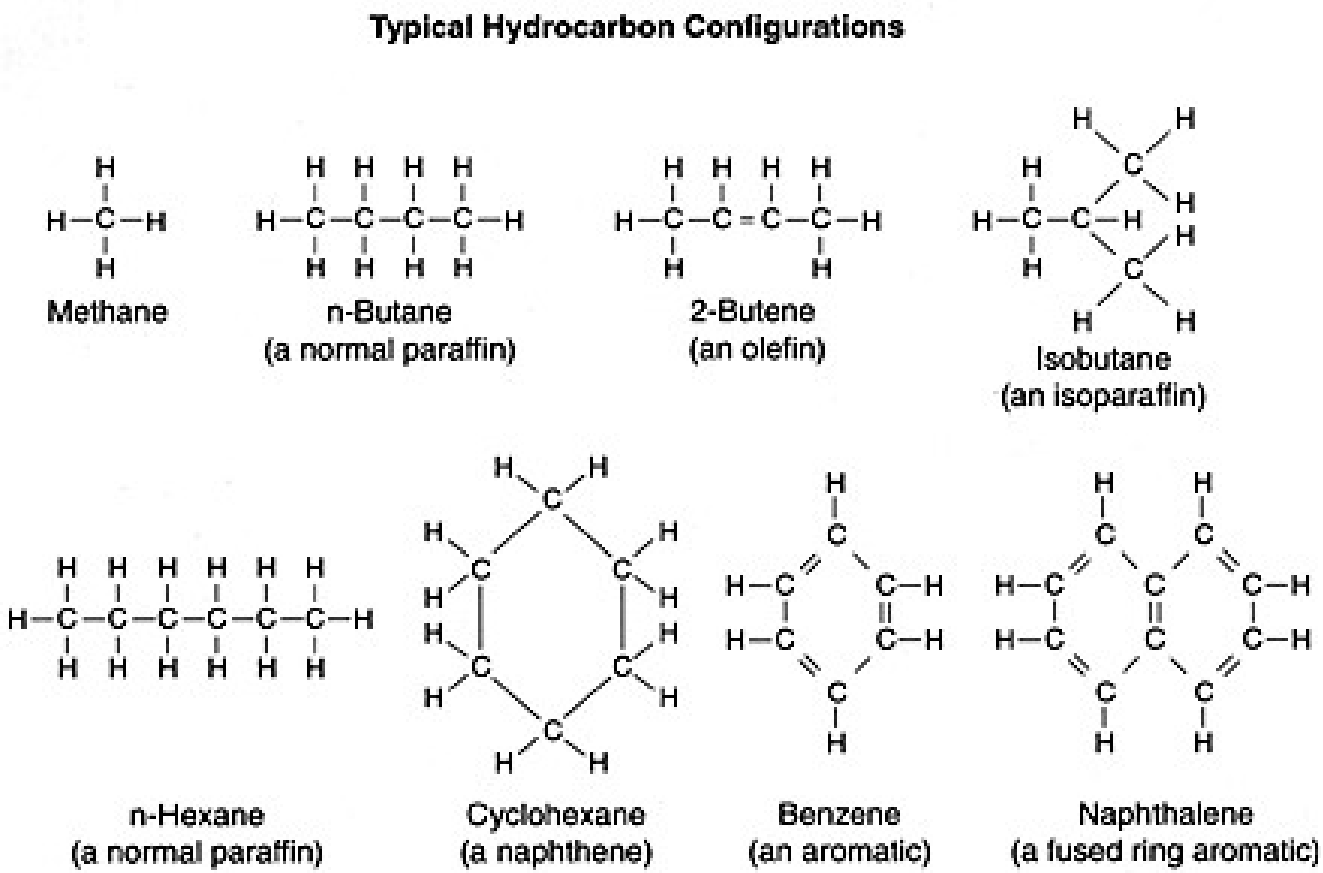
Loosely, then, a Base Oil is a viscous solvent

Part 1. Crude to Lube

Agenda

- A Bit of Chemistry and Crude slang
- Basics of Crude Refining

Hydrocarbon Shapes



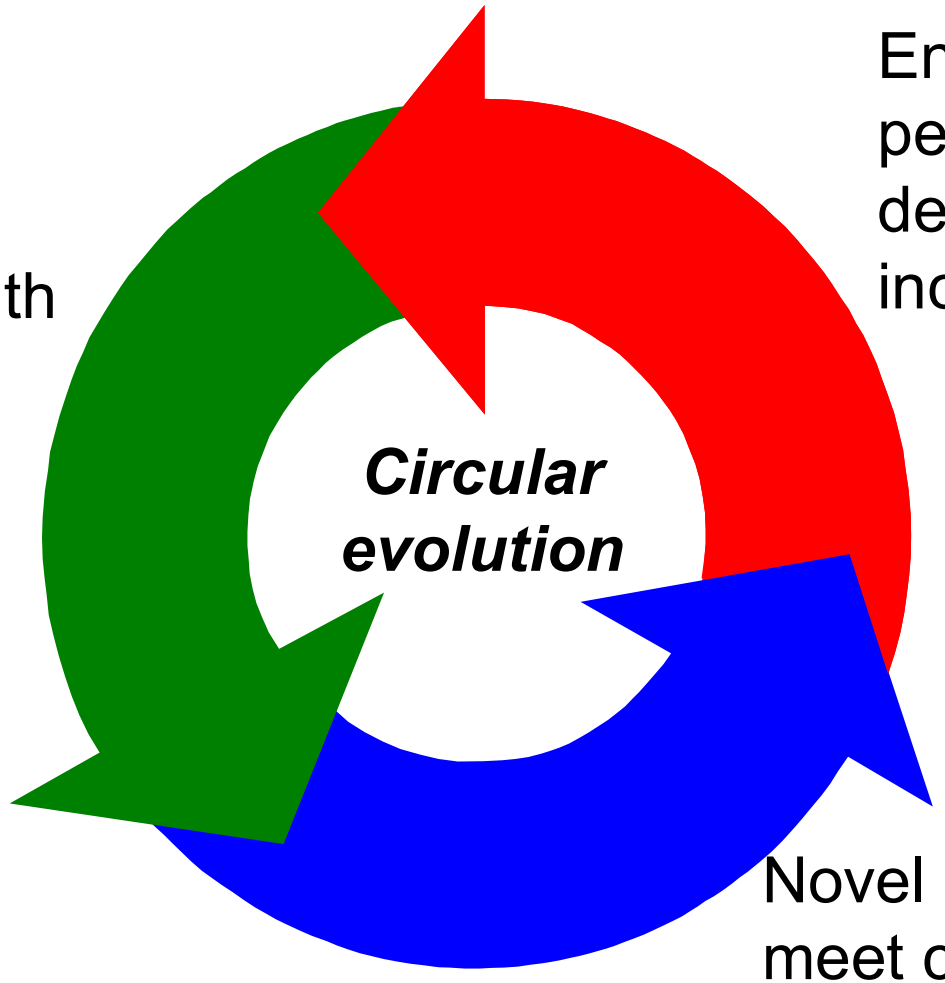
Yields from Crude

Average N. American production from a barrel of crude oil.

• Gasoline	44%
• Distillate (home heat, diesel)	21%
• Kerosene-type jet fuel	9%
• Other (e.g., residual fuel oil, coke, asphalt)	25%
• Lubricant feedstock	1%

Only ~ 2L in a 205L barrel of crude contains molecules fit for mineral base oil manufacture

What drives Mineral Oil Refining Technology?



Engine performance demands increase

Challenge to/with existing lubricants

Novel lubricants meet challenge

Pt. 2. Feed to Mineral Oils

Now that we've assembled a collection of **usable** molecules by fractionation of crude oil, how do we make these molecules **useful**?

- Key Base Oil Properties
- Base Oil Refining
- API Groups
- Refinery Layouts

Key Base Oil Properties

Viscosity/ies:	**Defining property**
Viscosity Index:	Temp/Visc relationship
Pour Point:	Low temperature operation
Flash Point:	High temperature operation
S, N content:	Corrosive potential
Carbon type:	Impacts solvency, stability
Color:	Can indicate high aromatics

Most refining aims to create an optimal tradeoff between all of the above.

- Tradeoff can be performance and/or economic

Refining Operations

Refining operations can be executed in a variety of ways, and in many sequences. However, each operation can be boiled down to one of two intents:

- Upgrade composition
  - Regardless of refining technology used, intent is to get rid of undesirable molecules/character, such as unsaturates, S, N, aromatics
- Enhance Physical Properties
  - Viscosity and Flash Point through one or more distillations
  - Low-temperature properties through wax conversion or removal

Wax

Historically, the refining of paraffinic oils has involved a step called “solvent dewaxing”

This involves crystallizing wax at low temperatures, filtering the wax out, and sending the wax into the wax market.

Why do this? By removing wax, low-temperature properties of the oil are enhanced

Hydroisomerization

Wax largely consists of paraffinic carbon chains.

Hydroisomerization allows conversion of these paraffinic chains to isoparaffinic branched groups.

Once branched, the isoparaffins can't organize into crystals.

$\Rightarrow$ Good low-temperature properties without "wasting" wax!

"Hydro-, Hydro-, everywhere..."

You now have a sense of what "Hydro-isomerization" does.

Other important "Hydro-" terms:

- (mild) Hydrotreating
- Hydrofinishing
- Severe Hydrotreating

These 3 are all intended as purification steps

Purification

- Solvent refining: Leaves a fair bit of sulfur behind, and often about 20% aromatics
- (mild) Hydrotreating, Hydrofinishing: “Polishes out” some of the sulfur and aromatics, but still leaves up to 10% aromatics behind
- Severe Hydrotreating: Sulfur down to ppm levels, aromatics << 1%. Destroys a lot of naphthenic structures, by converting them to paraffinic structures.

API Groups: Properties

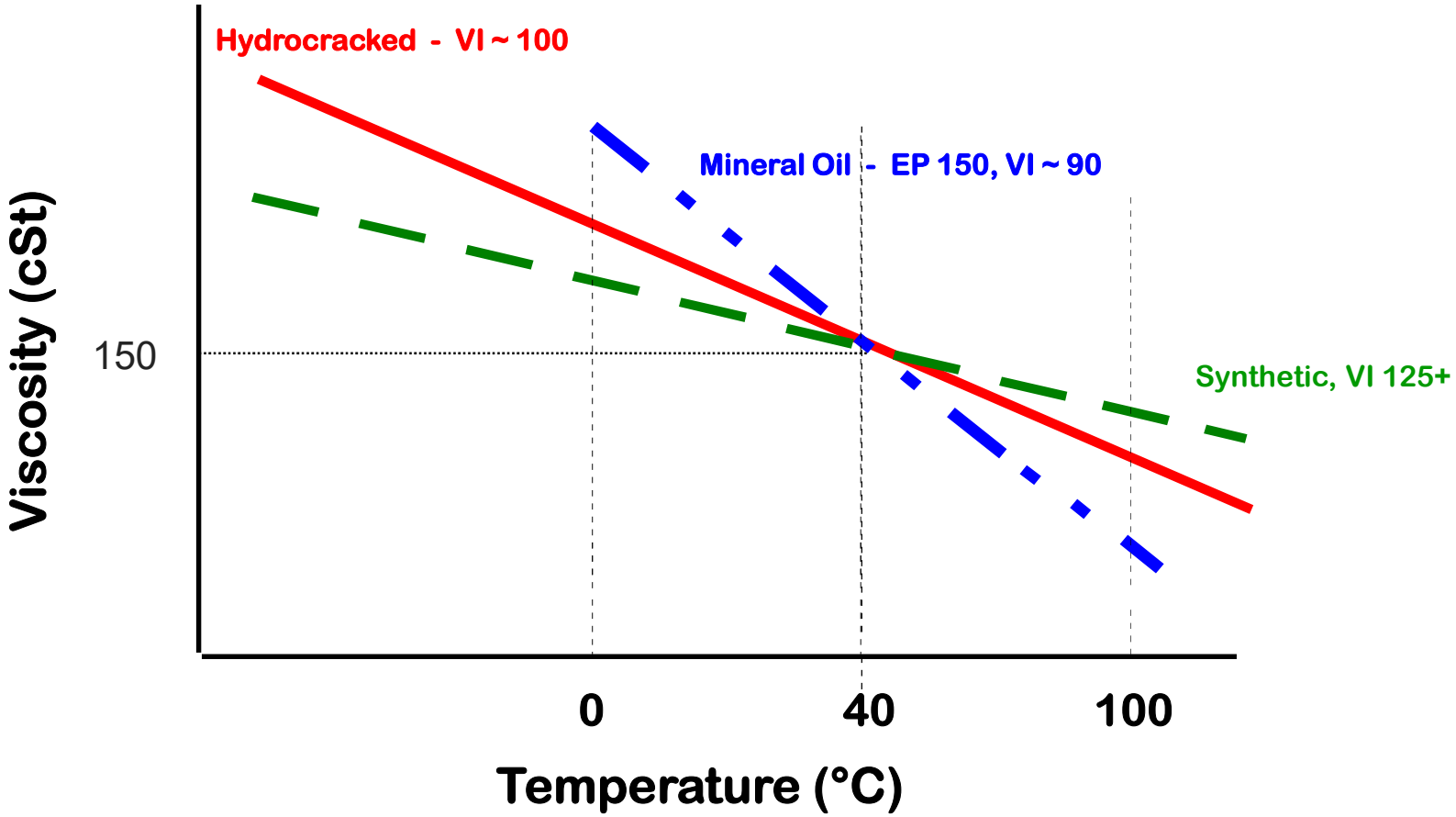
Basic Terminology

Viscosity Index (VI): Liquids frequently become less viscous as temperature increases. VI can be described as a measure of a liquid's **resistance** to this effect.

VI is a key property for a Basestock. It gives information about:

- temperature / viscosity relationship
- what processing technology was used
- the composition of the oil (esp. paraffinic/naphthenic ratio)

Impact of VI


Hydrocracked - VI ~ 100
Mineral Oil - EP 150, VI ~ 90
Synthetic, VI 125+
Viscosity (cSt)
150
0
40
100
Temperature (°C)

Key Pros/Cons of High VI

In formulating a finished product, higher-VI base oils directionally offer the following benefits:

- Increased oxidative and thermal stability
- Reduced volatility
- Reduced treat rates of some of the additives, such as:
  - VI improvers
  - Antioxidants
  - Pour Point depressants
- One key drawback: High VI generally means high saturates content…which can mean lower solvency

API Group Definitions

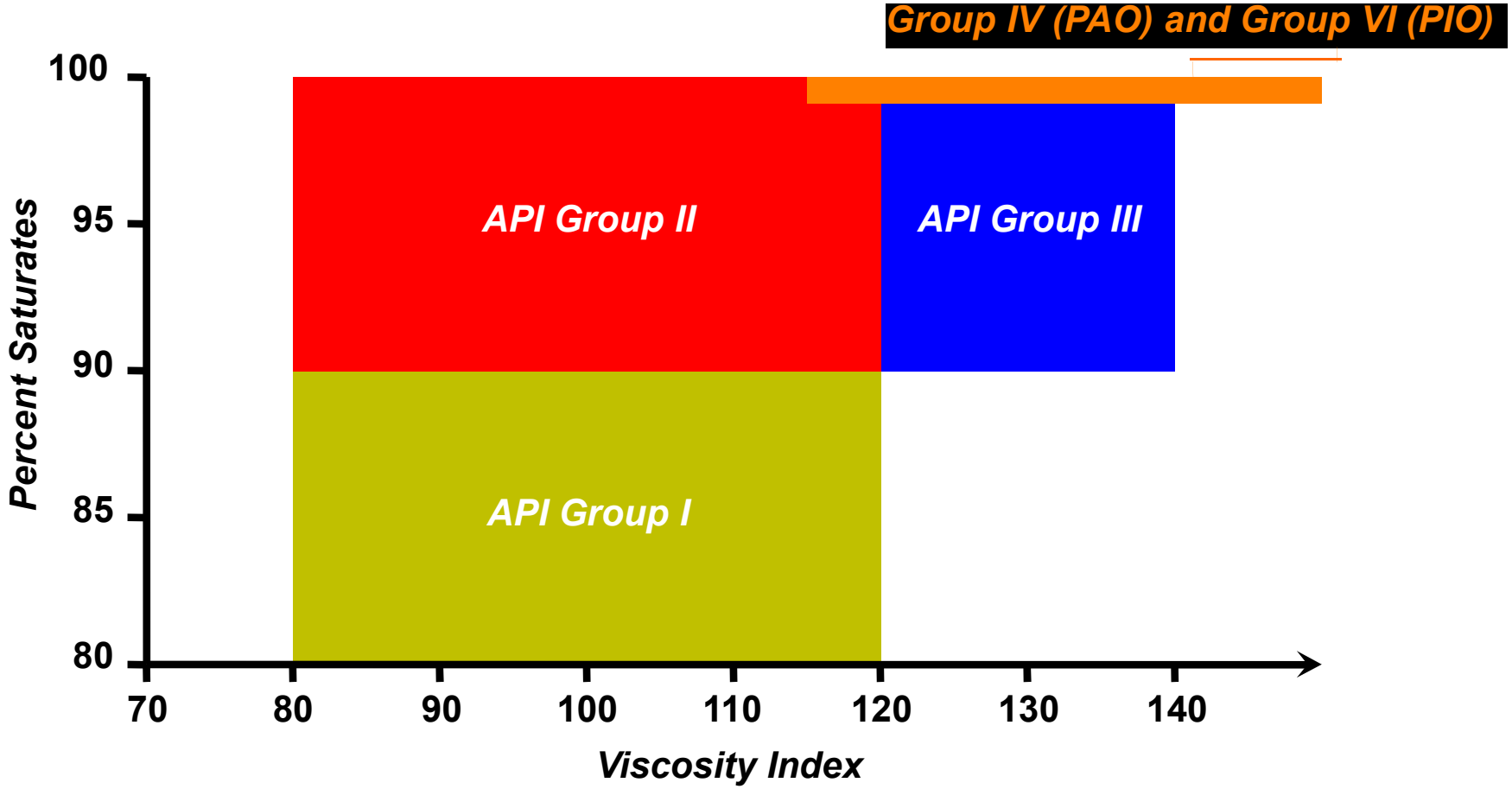
API Groups: The American Petroleum Institute (API) has classifications for lubricant basestocks:

Group	Weight % Sulfur	Weight % Saturates	VI
I	> 0.03	< 90	80 - 119
II	< 0.03	> 90	80 - 119
III	< 0.03	> 90	120+
IV	Synthetic PAOs		
V	Other Synthetics (diesters, PAGs, etc.)		

Europe is now touting a Gp VI, PIOs

Hydrocarbon Base Oil Groups

(This chart ignores Sulphur content criterion)



Why do we have API Groups?

The creation of a new engine oil, in principle, requires extensive engine testing

- Full API license program is **very** expensive …$500K to $4M
- Don't want to have to test everything, every time

API Groups allow creation of guidelines for "Base Oil Interchange":
replacement of one base oil for another that is reasonably similar, without need to re-test <u>everything</u>

An Example of BOI

Table E-5—Sequence VE/VG Tests Required for Interchanging the Base Stock

Base Stock in Original Test Oil	Interchange Base Stock				
	Group I	Group II	Group III	Group IV	Group V
Group I	Not Required if sulfur ≤ and saturates ≥ original	Not Required	Not Required	≤50% Not Required ----- > 50% Required	Required
Group II	Required	Not Required if saturates ≥ original	Not Required	≤50% Not Required ----- > 50% Required	Required
Group III	Required	Required	Not Required	Required	Required
Group IV	Required	Required	Required	Not Required provided the interchange Group IV meets the original manufacturer's specifications in all physical and chemical properties	Required
Group V	Required	Required	Required	Required	Required

Source:

http://www.api.org/certification-programs/engine-oil-diesel-exhaust-fluid/~/media/Files/Certification/Engine-Oil-Diesel/Publications/Appendix-E-REV-09-01-11.ashx

API Groups: Key Points

1. They are **purely pragmatic**
   Their intent is to minimize tests, while ensuring formulation can protect engines as intended.

2. They make **no explicit** statement about **superiority** of one group over the other…just about "different/not different enough to worry about"
   Superiority, real or perceived, is a marketing concern

3. They are **strictly automotive** in scope…and only rigorously apply to **engine oils!!**

Spillover…

- Even though API groups are intended only for use in engine oil work, the trends found in that market in terms of volatility, robustness, etc. are applicable in most other lubrication areas.
- Therefore, the API designations (and consequences as regards “synthetic” groups) get used outside the engine oil market, from gear oils to compressor fluids.
- This is also true of Base Oil grades outside the normal range for an engine oil…they inherit some of the labels associated with processing technology.

Pour Point

- The **Pour Point** refers to the lowest temperature at which an oil will flow
- Solidification at low temperatures is due to:
  - Wax crystals settling out
  - Oil too viscous to move
- Most oils lubricate down to approximately 10°C above their pour point

Low-Temperature ≠ Pour Pt.

- True low-temperature performance is better reflected by Brookfield Viscosity than by Pour Point.
- Brookfield Viscosity is ***loosely*** *but* ***not directly*** correlated to Viscosity Index and Pour Point

In fact, a low pour point can hurt Brookfield Viscosity performance in a finished product.

Some low-temperature properties

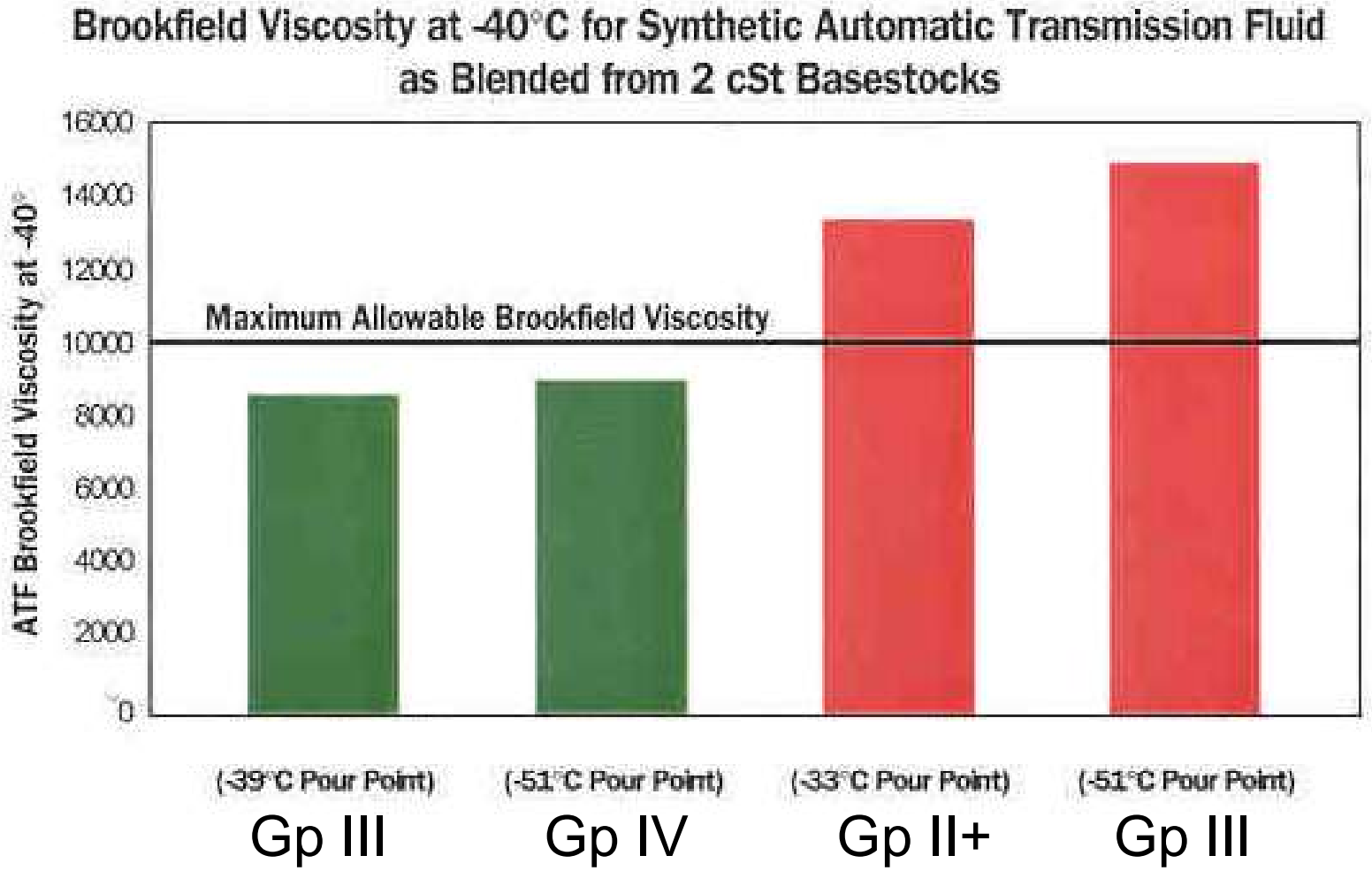
The table below demonstrates the difference between "static" (pour point) and "dynamic" (Brookfield) methods of measuring low temperature properties.

Product	Pour Point (°C)	Viscosity (cP@ -40°C)
ATF Type F	- 39	27,700
ATF DEXRON® III MERCON®	- 51	12,060
HDEO XL 0W30	-48	28,500
All-weather Hydraulic	-48	9,250
Synthetic Gear Oil 75W-90	- 51	67,200
Part Synthetic 75W-90	- 48	118,000

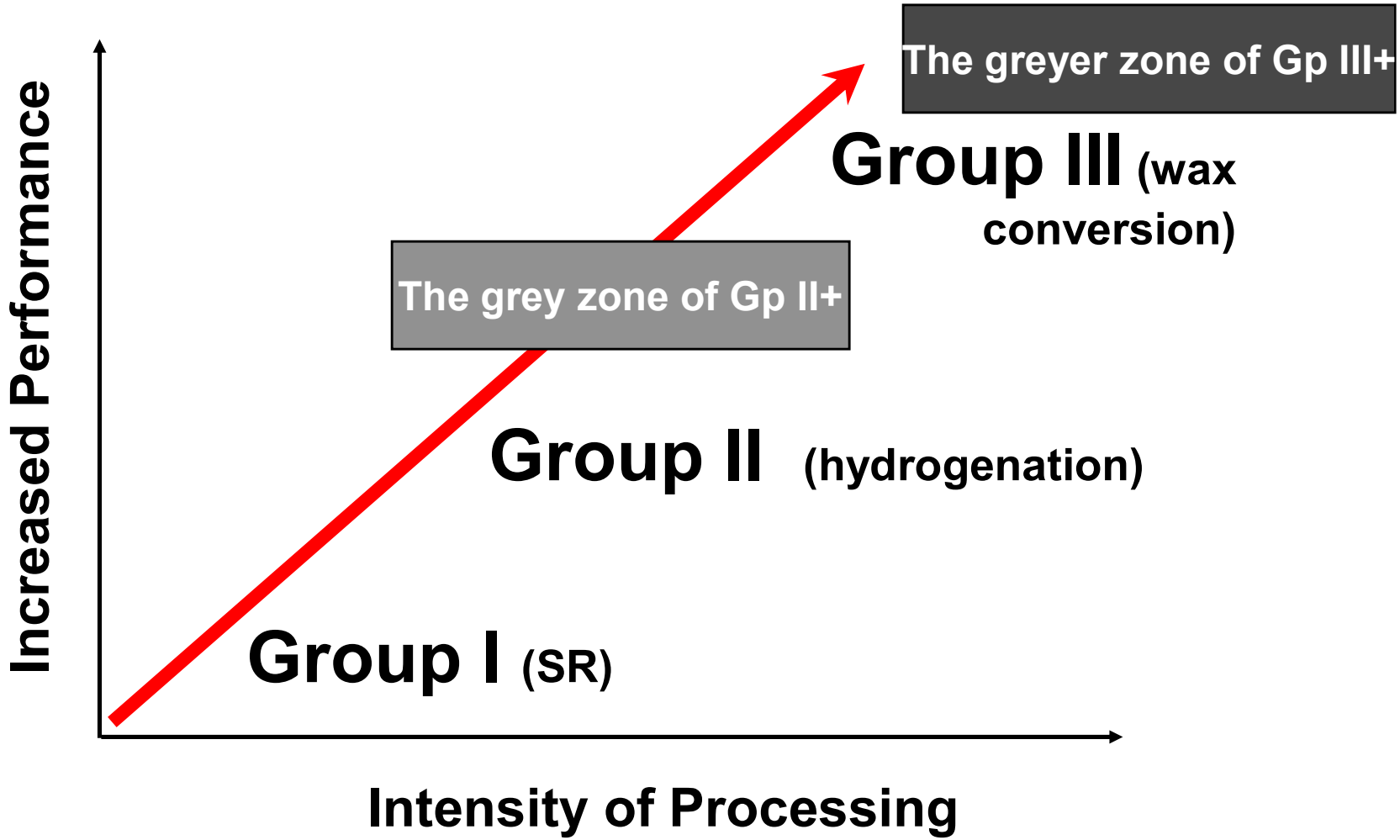
Low-Temperature ≠ Pour Pt.

- Some years ago, one major North American OEM launched an automatic transmission fluid explicitly built around Group III stocks.
- This fluid's specification doesn't allow PAOs!!
- Incorporation of various fluids into the specified formulation allows us to compare finished product performance, as a function of base fluid

Finished product performance



Advanced Mineral Base Oils



So why "Group II+ and III+" ?

Gp II+ is not a rigorous term in the "API groups" context, but has widespread recognition in the market. It emerged during the development of API SL.

What is SL?

It was an API category for engine oils. It put new demands on base oils, especially as regards oxidation resistance, volatility, and to some extent, fuel economy.

Group III+ is also non-rigorous, but points to VI ~ 135. Stocks marketed as "Group III+" are intended as PAO replacement stocks.

Service Category

"Current State" defined by API; today we mostly have SN required in the passenger-car market,

…and "CJ-4" in the Heavy Duty market

For more info, consult:

http://www.api.org/certification-programs/engine-oil-diesel-exhaust-fluid/~/media/Files/Certification/Engine-Oil-Diesel/Publications/MOM_GUIDE_ENGLISH_2013.pdf

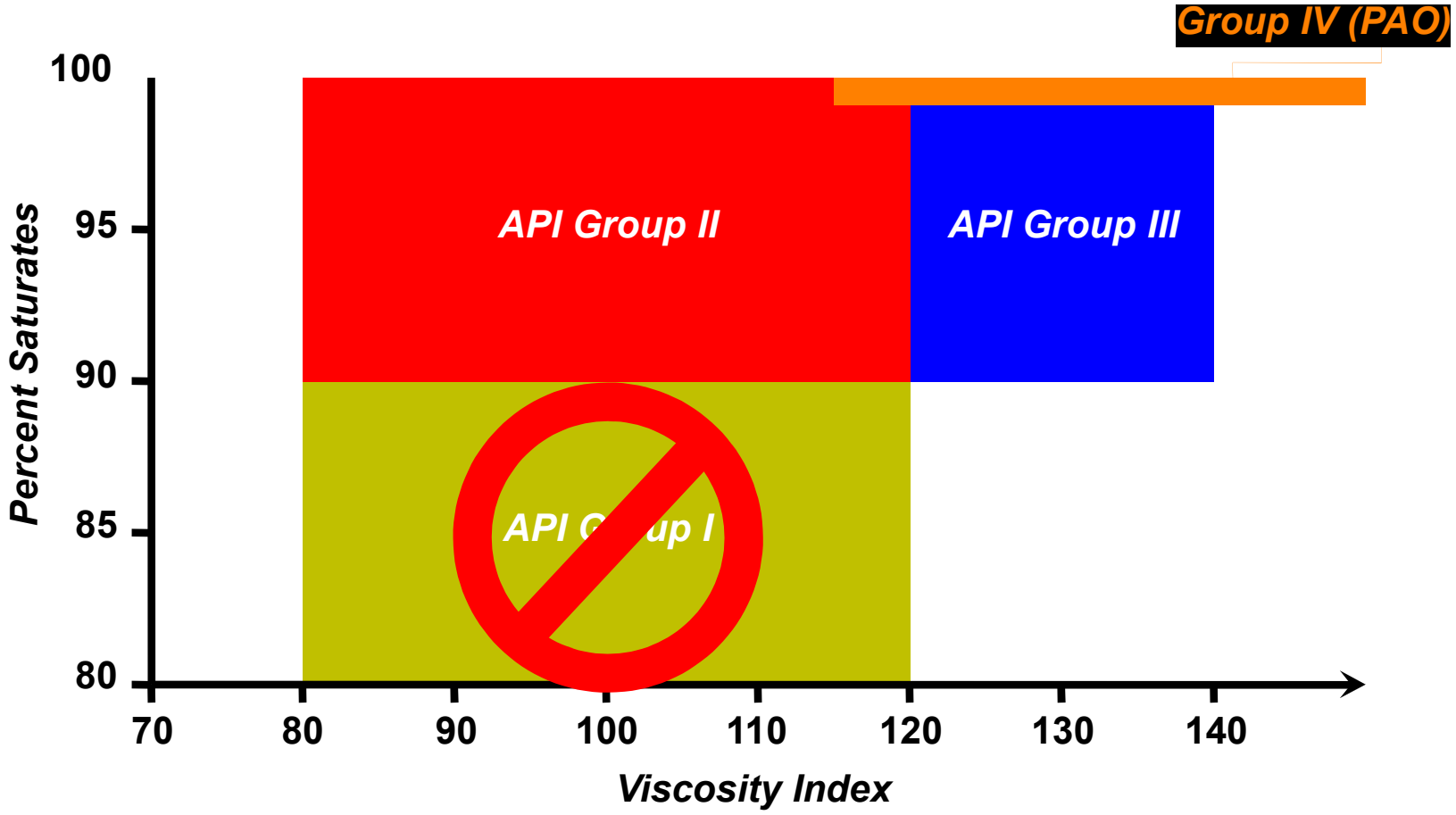
This transition to SL was a long time coming!
•Desired/defined by Auto Manufacturers
•Major Challenge to Group I formulations

In fact, “pure” Group I formulations did not, in general, survive the transition from SJ to SL, especially for “energy conserving” or “resource conserving” multigrades like 5W-30.
Group II, Group III and/or Group IV stocks were frequently needed to give “performance kicks” that Group I could not deliver on its own.

Believe it or not, the successor to SN was being discussed just a few months after “SN” hit the shelves.

“PC-11” (“CK-4”?) is in its early development stage, as well.

Future Base Oil Quality?



Today, Group I still has a place

- For many non-automotive applications (e.g. hydraulic fluids, industrial gear oils, etc.) the industry specifications still allow use of Group I stocks
- However, many historical producers of Group I are moving into the Group II arena, so the "pool" will tighten, especially in the engine oil viscosities (100 to 200 SUS oils, roughly ISO 22 to 46)
- Note that some user specifications (for instance, GM's LS2 specifications) and emergent specs (e.g. in the Hydraulic Oil realm) may squeeze out Group I formulations through constraining requirements

Group I and high-viscosity finished lubricants

- Group II/III refining is hard-pressed to create base oils with a viscosity greater than ~120 cSt at 40°C
- Therefore, ISO grades above 100 (e.g. ISO 150, ISO 220, or higher) cannot be readily formulated with Gp II or Gp III stocks alone.
- Group I refining allows creation of “Bright Stock” and “Cylinder Stock”. These are used to blend higher grades.
- As Group I refineries close, the availability of Bright Stock and Cylinder stock decreases. Many formulators are turning to synthetic, high-viscosity stocks instead

Part 4. Synthetics

- What is or isn't synthetic has become a key marketing question, especially in light of evolving trends.
- For many years, base fluids in Groups IV and V were the only acknowledged Synthetic Groups.

In the public eye…

PAOs probably have the reasonably-informed consumer's ear when it comes to "synthetic". The average consumer generally only deals with motor oil, and PAOs have a historic position in that market.

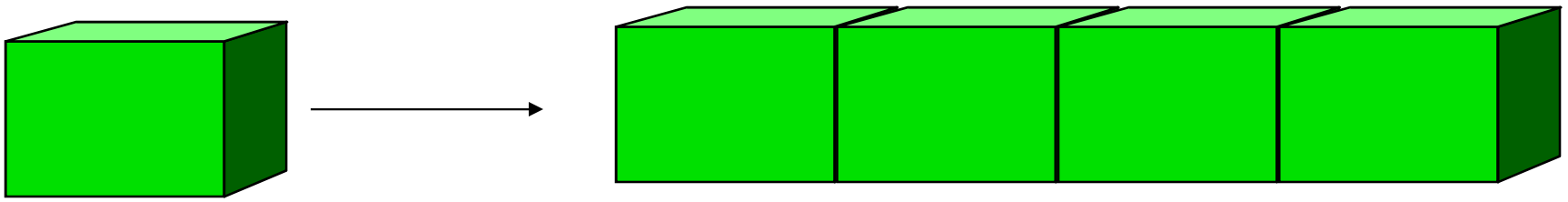
To the slightly less-informed consumer, "Synthetic" is widely held to mean "expensive but high-performance"

To the uninformed consumer, brand loyalty and/or price are more likely to be factors in product selection

Traditional View of Synthetics

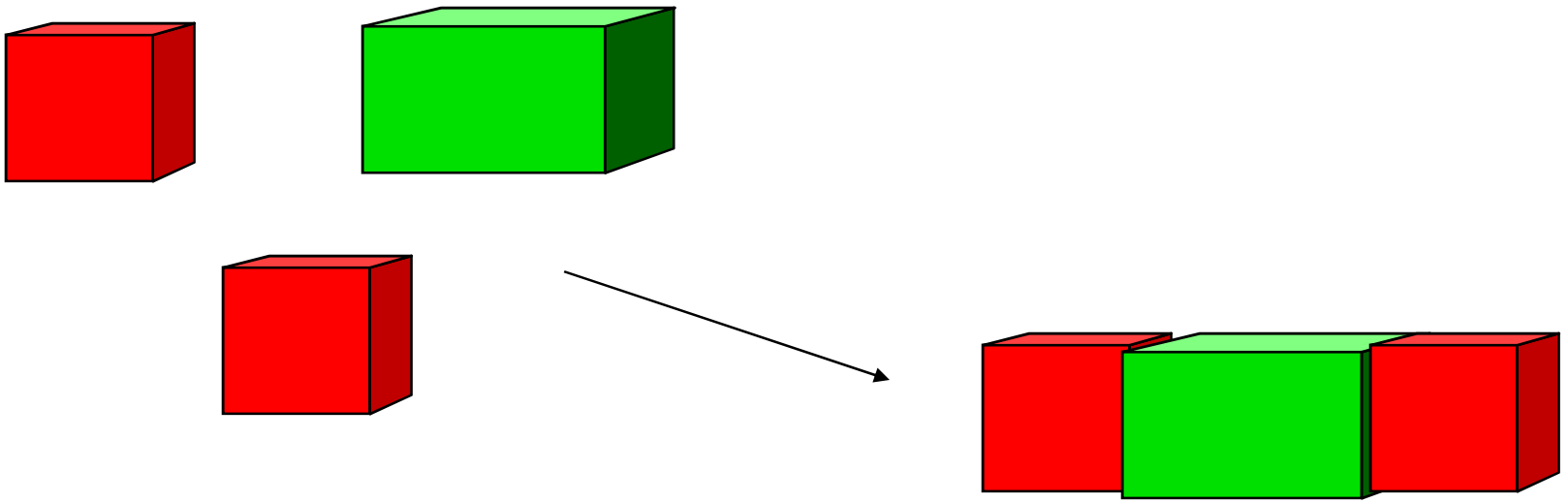
Synthetics have long been considered to arise from a controlled, “building-block” approach to preparation

A single “alpha-olefin” can be conceptually coupled to twins of itself to produce a poly-alpha-olefin



Traditional View of Synthetics

The blocks don't have to be identical; other synthetics, such as Group V diesters, can be built from varying kinds of blocks. However, they have to be brought together under human control to be "traditional" synthetics.



But traditions are sometimes forced to evolve

Market Evolution: ***The Mobil-Castrol Dispute***

Mobil was a longtime supplier to Castrol for PAOs

Castrol suddenly started buying less from Mobil…but Mobil couldn't determine new supplier source

Mobil eventually analyzed the product (marketed as a synthetic) to find Group III, not Group IV, molecules present!

Given Mobil's long investment in the "PAO is synthetic" argument, legal action was taken before the *National Advertising Division* (NAD)

The NAD Ruling, in a nutshell

NAD decision states that base oils made through hydroisomerization, severe cracking and reforming processes may be marketed as synthetic.

Therefore an opportunity exists for finished lubricant formulations, based on Group III base oils, to be labelled as synthetic.

This has yet to be fully accepted in the market, and is in fact rejected in some jurisdictions (such as Germany).

Summary

- A *finished lubricant* is a combination of Base Oil and additives
- The net quality of the finished lubricant is a reflection of the quality of the components **and** the judicious choice of proportions of these components
- Mineral Oils are Base Oils derived from crude oil, and correspond to API Groups I, II and III.
- Processing of Mineral Oils is intended to maximize the hydrocarbon content, and to optimize physical characteristics
- API Group IV is defined as PAOs, a special type of hydrocarbon

Summary

- Group V contains a variety of other chemical classes, including diesters, poly-alkylene glycols (PAGs), alkylbenzenes, phosphate esters, halocarbons, silicones, carbonates, polybutenes, etc.

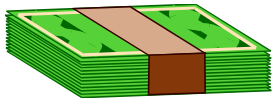
Recommended reading: L.R Rudnick and R.L. Shubkin, eds., "Synthetic Lubricants and High-Performance Functional Fluids", 2nd ed., Marcel Dekker, New York, 1999, ISBN 0-8247-0194-1

- Selection of a Group V base fluid will generally be dictated by a special application requirement.
- API Groups are intended only for use in Base Oil interchange, i.e. for engine oils. However, they are useful in marketing Base Oil outside the engine oil area.

Summary

- Groups IV and V have traditionally been associated with the “Synthetic” label. Group III now can be legally incorporated into that category in the N. American market (and in many other regions as well).

Summary of the Summary:

- Base Oil selection is a large part of delivering good/better/best performance in a finished lubricant; make sure you really get the promised BANG! for the   you pay for