

Modern Base Oils & Blending for Optimal Performance

Meeting the Evolving Needs of the European Lubricant Market

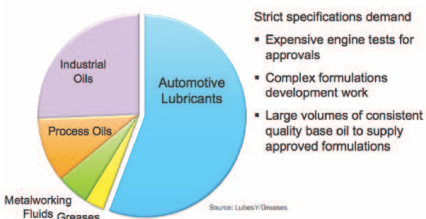
The lubricants industry in Europe is at a crossroads. Historically, lubricant formulations have been based upon optimising Group I, Group III or a Group I/III blend with a proven additive package.

Relying on Group I and Group III has served the European lubricants industry exceptionally well. Group I is readily available, and typically, is the least expensive base oil. Historically, it has been the dominant ingredient in many lubricant formulations, particularly industrial lubricants and automotive formulations with a lower viscosity index (VI). As a result, Group I has become the 'work horse' base oil throughout Europe, whilst Group III has been used to deliver higher performance and lower viscosity.

With tightening environmental legislation this historical balance is being challenged. In order to meet 'green' initiatives, the Automobile Manufacturers Association (ACEA) is pushing for tighter engine oil specification standards.

This has created a maze of OEM requirements that call for emission system protection and extended drain intervals from both Passenger Car Motor Oils (PCMO) and Heavy Duty Motor Oils (HDMO). Meeting those specifications requires lubricants with lower viscosity and lower volatility.

Automotive oils dominate demand for base oil—require 20 Million Tonnes per year of base oil

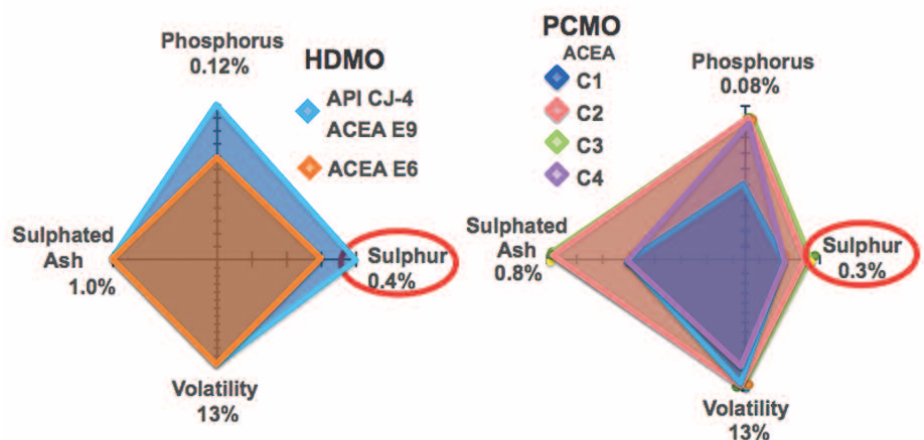


Strict specifications demand

- Expensive engine tests for approvals
- Complex formulations development work
- Large volumes of consistent quality base oil to supply approved formulations

In addition to tightening performance requirements for crankcase lubrication, automatic transmission fluids, greases and industrial oils are also facing tougher challenges. Automatic transmissions are

Mid and Low SAPS HDMO and PCMO specifications require the use of low sulphur base oils



being redesigned to boost fuel economy and are moving to fluids that can provide fill-for-life performance. Greases are being subjected to higher loads, higher bearing speeds, and higher temperatures that require formulations with better oxidation and thermal stability. Similarly, users of industrial lubricants want better thermal stability and longer oil life.

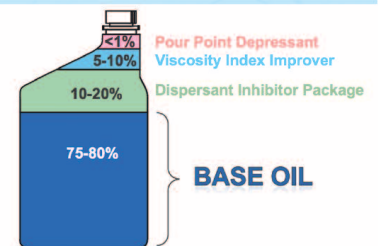
Generally speaking, these performance trends are calling for base oils that have

- Higher VI to enable better fuel economy and low volatility
- Lower volatility for reduced oil consumption
- Practically zero sulphur
- Excellent oxidation stability
- High saturates content for improved additive response

Whilst these new standards are very good for the environment, they are creating significant challenges for lubricant manufacturers who must grapple with optimising lubricant formulations for new specifications whilst managing supply chain cost and complexity. New premium quality base oils will need to be added to the supply chain in order for blenders to meet the full range of new specifications for their Automotive Engine Oils (AEO).

This means increasing tankage to accommodate additional base oils or re-evaluating formulations across a blenders entire product line and identifying opportunities for reformulating with new premium base oils.

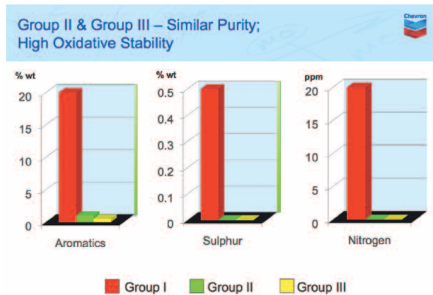
Base oil is the dominant ingredient in finished lubricants



Careful selection of base oil suppliers will help reduce potential supply chain complexity and cost. Given the complicated and costly process for qualifying lubricants, selecting base stocks from suppliers with large volumes and multiple plants helps minimise the need for expensive requalification testing with alternative base stocks. This also reduces tankage requirements. These challenges have brought a new level of scientific sharing between OEMs, lubricant manufacturers, additive companies and base oil suppliers to find solutions that optimise performance and meet market demands.

Meeting New Mid/Low SAPS Requirements – A Blending Challenge for Lubricant Manufacturers

Of particular concern, is how to optimise blending strategies for Automotive Engine Oils (AEO) in light of new specifications. Group I base stocks are high in aromatics, sulphur and nitrogen, all of which have a negative impact on lubricant performance. Historically, as the need for improved product quality increased, some combination of the additive treat rate and the amount of Group III were increased to compensate for the impurities/inefficiencies in Group I base stocks.



In response to the introduction of Euro V and VI emission regulations, OEMs have modified their engine designs and emission control systems to reduce the level of nitrogen oxides and particulates released into the atmosphere. One of the solutions was to install after treatment devices, such as diesel particulate filters (DPFs) and selective catalytic reduction units (SCRs).

Protecting the performance of these devices drove the need for new European specifications that restrict the levels of sulphated ash, phosphorous and sulphur (SAPS) in motor oils. In response to these tightening standards, new categories of “Mid and Low SAPS” engine oils have been designated.

Significantly, given the high amount of sulphur in Group I base oils, they cannot be used in AEO formulations designed for Mid or Low SAPS specifications. This creates a significant challenge for producers of 10W-XX and 15W-XX multigrade lubricants, which account for more than 85% of the European finished lubricant’s HDMO market. Group III alone has insufficient viscometrics to meet the performance requirements for heavier

motor oil grades and Group I has too much sulphur for the new specifications.

This is the crossroads for European lubricant manufacturers. The challenge lies in meeting the requirements for Mid and Low SAPS lubricants whilst providing the necessary performance for engines requiring 10W-XX and 15W-XX lubricants. This is particularly true for heavy-duty engines. Large diesel engines are subjected to demanding workloads. They typically operate at low speeds and very high torque. Their engines require lubricants that provide sufficient high temperature/high shear (HTHS) characteristics to insure adequate wear protection and maximise engine durability.

To meet this challenge European blenders are evaluating the range of base oils available and their impact on performance and supply chain economics.

Group	Sulphur, Wt %	Saturates	VI	Comments	
I	>0.03	and/or	<90	80-119	Insufficient for highest performance
II	≤0.03	and	≥90	80-119	Comparable purity Increasing VI
III	≤0.03	and	≥90	≥120	
IV	All Polyalpha Olefins (PAOs)				Synthetics – Traditionally Group IV
V	All Stock Not Included in Groups I-IV (Pale Oils and Non-PAO Synthetics)				Small volumes – some very high quality and some very low quality

Source: API 1500, Revision 2, October 2010

- Group II/III can approach PAO performance
 - Available in larger volumes
 - Lower costs

Alternative Base Oils

The ATIEL and API base oil classification system groups base oils based on their purity and VI. It was established to help marketers minimise re-testing costs when blending licensed engine oils with base oils from different manufacturing sources. The system uses physical and chemical parameters to divide all base stocks (oils) into five Groups – Groups I, II, III, IV and V.

Base stocks, even in the same ‘Group’, may differ widely in their molecular composition, and physical and chemical properties depending on the feedstock and processing parameters used by the refiner. Differences in base stock composition affect the performance of finished lubricants, consequently, base stocks are considered non-fungible in many lubricant formulations. This is particularly true in high performance

automotive engine oils. As a result, supply reliability of fungible base stocks should be a critical consideration in the early stages of new lubricant formulations.

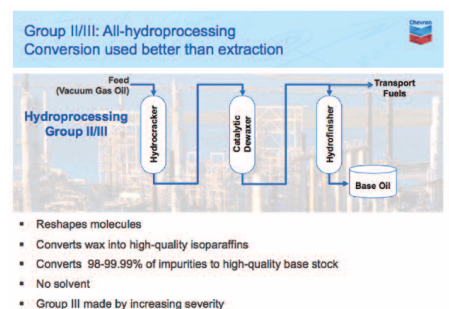
Where Automotive Lubricants go, Base Stock Characteristics go

Automotive lubricants demand more than half of all base oil production. Additionally, they have strict requirements for physical and chemical properties. So refiners, within the capabilities of their processing scheme, design the physical and chemical properties of their base oil production to meet the performance requirements of automotive lubricants.

Refiners can influence the characteristics of their base stocks by feed stock selection, processing severity and catalyst selection. But, by far, the most significant limiting factor on base oil quality is the manufacturing process used by the refiner. There are two general processing schemes for producing mineral oil base stocks. The older process, solvent dewaxing was developed in the 1920s and is used for producing Group I base stocks. The second, an all-hydroprocessing scheme Chevron introduced in 1993 uses isomerisation for dewaxing. It is used to make Group II/III base stocks.

Group I Base Stocks – Excellent for many industrial applications, but too much sulphur for tightening AEO specifications

Producing Group I base stocks starts with vacuum gas oil (VGO), one of the heavier streams coming out of the crude unit. Solvents are used to selectively remove 50-80% of the impurities. However, the treated base oils stream still has paraffins that need to be removed to produce usable base stocks.



The paraffins are removed by a dewaxing process that uses solvents taken to a low temperature, where the wax is precipitated out. The resulting Group I base stock has relatively high sulphur making it unsuitable for Mid and Low SAPS AEO specifications.

Group II/III Base Stocks – All-hydroprocessing technology

All-hydroprocessing for base oils starts with the same feed as a solvent plant. However, instead of using a solvent to remove undesirable compounds, the feed is processed in a high-pressure hydrocracker with catalysts that reshape the molecules, saturate the aromatic compounds and create high quality iso paraffins. In total, 98-99.9% of the impurities are converted to high quality base oils. Chevron invented this processing scheme in the 1990s and today more than two thirds of the world's premium base oil is produced using this upgrade path.

Group II/III: All-hydroprocessing Conversion used better than extraction



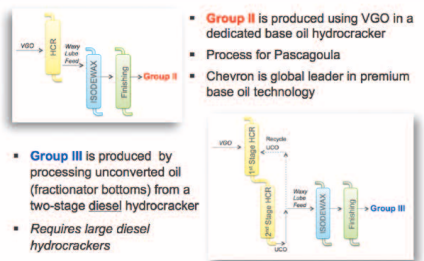
- Reshapes molecules
- Converts wax into high-quality isoparaffins
- Converts 98-99.99% of impurities to high-quality base stock
- No solvent
- Group III made by increasing severity

Whilst the same upgrading technology is used for producing Group II and Group III base stocks, the driver for which grade a refinery produces is the source of the feed - a large diesel hydrocracker vs a gasoline hydrocracker.

Group II is typically produced by processing VGO in a dedicated base oil hydrocracker in a gasoline refinery. Group III is primarily produced by processing unconverted oil (fractionator bottoms) from a two-stage diesel hydrocracker. Whilst any diesel hydrocracker can make some Group III feedstocks, they are most efficiently produced in large-scale diesel hydrocrackers.

Given the direct correlation between fuels production and base oil grade (Group II vs. Group III), regional base oil production capacity correlates significantly with regional fuels demand.

Group II and Group III similar processing schemes but from different feed based on fuel production



Regions with high diesel demand are more likely to have high Group III production, whilst gasoline producing regions favour Group II production.

The principal difference between Group II and Group III base stocks is VI. They are both premium base oils containing less than 10% aromatics and less than 300 ppm sulphur as defined by API publication 1509. They typically have about 1% aromatics or less and almost undetectable amounts of sulphur. As a result, these base oils have better oxidation stability, thermal stability, and cold flow properties than Group I base oils.

Group III+ GTL Base Stocks

The first large-scale GTL base oil plant started up in 2011. It uses the same hydro-isomerization process as that used to produce Group II and Group III base oils. Like its Group II and Group III counterparts, GTL base stocks have exceptional thermal and oxidative stability. What distinguishes them from other hydroprocessed base oils are their high VI of 135-145. Consequently, GTL base stocks are classified as Group III+, an unofficial API category that recognizes their higher VI than other Group III base stocks.

ISODEWAXING (Hydroisomerization) technology enables GTL base oils



- Same technology that created Group II and Group III base oils
- GTL base oils are unofficially designated Group III+

Whilst GTL base oils have had considerable coverage in the industry press, they have limited availability.

Group IV/V Base Stocks –PAOs, Synthetics and All Others

Polyalphaolefins (PAOs) have excellent performance properties and are well proven in many demanding formulations. However, they are a synthetic byproduct derived from processing crude oil. A complex manufacturing chain is required for their production.

Manufacturing PAO starts with an ethylene cracker making the simplest olefin (ethylene) from hydrocarbon feeds. The primary cracker feed is naphtha. Ethylene is selectively polymerized into linear alphaolefins (LAOs). The heart of the LAO production is C4, C6 (~16%), C8 (12-13%), and drops off to about 10% for C10 and 8% for C12. The lighter alphaolefins, C4-C8 cuts, are comonomers for plastics, whilst the C12-C16 cuts typically go into detergents and the very heavy ones -- >C24 go into specialty applications.

The C8, C10 and C12 LAO can be oligomerised into Polyalphaolefins (PAO). Most C8 goes to comonomer for plastics – only a little goes to PAO. PAO is primarily made from C10 LAO. Additionally, PAOs require a final hydrotreating step to fully saturate the double bonds. Given the competition for feedstock and complexity of the PAO production process, PAO supply will continue to be limited and relatively costly. As a result, its use will be confined to operating environments with exceptionally high or low temperatures, or circumstances requiring excessively long lubricant life - like space travel or wind turbines.

What is the role of new base oils entering the market? Synthetics & Re-refined base oils

- Traditional Synthetics** – Derived from chemical reactions – polyalphaolefins (PAO's), esters, etc.
- Limited supply
 - Used for extreme performance targets
 - Excessively high temperatures
 - Excessively low temperatures
 - Longer lubricant life is necessary



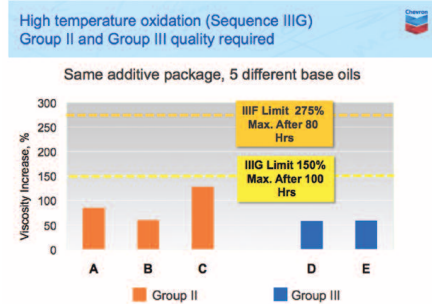
New boutique base oils entering the market, including those from vegetable oils, sugar cane, and re-refined base stocks, have a broad quality range. Whilst some of these base stocks have

excellent performance properties they are all constrained by limited production capacity. Consequently, they will be used in niche applications with limited volume demands.

Adequate and Reliable Supply is a Base Oil Prerequisite for Meeting New Mid/Low SAPS AEO Specifications

The challenge confronting lubricant marketers is how to capitalise on the range of base oils available to optimise formulations for changing specifications.

After reviewing the base oil alternatives for meeting new Mid and Low SAPS performance specifications, the optimal choice is Group II base oils. They have purity comparable to Group III base stocks plus the necessary viscosity for adequate wear protection in engines subjected to heavy duty work loads. Most importantly, they are now available in Europe in sufficiently large volumes from more than one supply source.

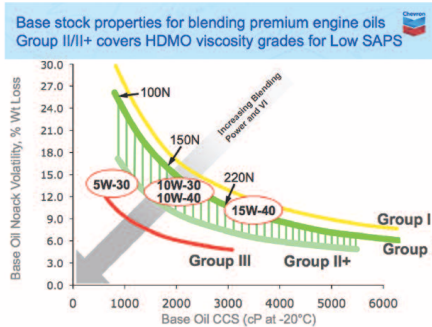


In practical reality, the question confronting European lubricant blenders who market a full range of automotive engine oils, is not whether they will integrate Group II base oils into their processing scheme, but when and how?

Optimising Blending With Available Supply Becomes the Next Challenge

Typically, lubricants use two base oils with different viscosity grades to achieve a desired viscosity level. New specifications may require the use of a third base stock as a 'correction fluid' to meet cold crank simulator and (CCS) and volatility (Noack) requirements.

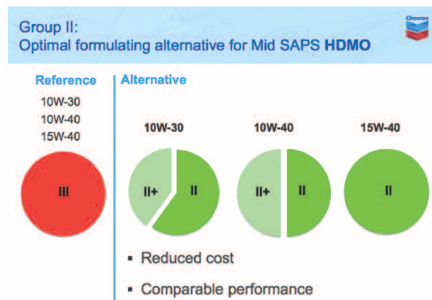
Blending chart plots showing base oil Noack volatility plotted against Cold Crank Simulator (CCS) - a measure of viscosity at low temperature - are an



effective and efficient way for identifying optimal base oil blends. If different ratios are blended you end up with a curve showing volatility at a given viscosity. Group II has a broad spectrum of performance that meets much of the blending requirements for 5W-XX or 10W-XX lubricants. The curves demonstrate increasing blending quality.

Group II/II+ Base Stocks Can Meet the Needs of the Majority of European Formulations

The European PCMO market is highly specialised with sub-segmented markets. These are defined by performance levels within different viscosity grades prescribed by industry and OEM specifications. Consequently key base oil property requirements vary considerably from one OEM's performance level to another. This has led to differing degrees of Group III content in mainline and premium automotive formulations and reflects the region's history of Group I and Group III base oil availability to the exclusion of Group II base oil.



Most of the automotive engine oil volume, both for heavy duty and passenger car segments, can be blended with the majority component being Group II and/or Group II+. In many cases, this blending strategy brings both cost and performance benefits.

Major formulators in Europe have been developing Group II blends for the last three years, plus all of the major additive companies have experience in North America optimising lubricant performance with Group II base oils in both industrial and engine oil applications.

Group II/II+ can meet European automotive performance specifications for all but the lightest grades such as extremely low volatility 5W-XX and 0W-XX grades.

As with any new product, formulators will need to determine the optimal viscometrics and volatility requirements for the base oil blend that is required for the specific additive system to be used. Through precise formulation work the level of Group III can be optimised, or in some cases, eliminated completely, leading to formulation cost savings without compromising performance.

Through optimisation with Group II base stocks, blenders may realise a reduction in additive treat rates for Group II blends versus Group I blends.

Formulating work completed with the major additive companies has shown that Group II/II+ base oils are an excellent alternative for producing 10W-40 and 5W-30 lubricants. 10W-40 PCMO formulations typically include between 20-50% Group III base oil with the remainder being Group I. Comparable performance can be achieved with an optimised blend of Group II and Group II+ base oils.

This formulating scheme eliminates the need for both more costly Group III and less pure Group I base oils. Similarly 5W-40 PCMO lubricants, which typically require 100% Group III, can be effectively formulated with a blend dominated by Group II+ with Group III used as a trim stock to meet performance requirements for a given specification.

For lubricant manufacturers, oxidation stability is a critical component of their formulating objectives. The better the lubricant's oxidative stability, the better the lubricant's ability to minimise deposits, sludge, and corrosive

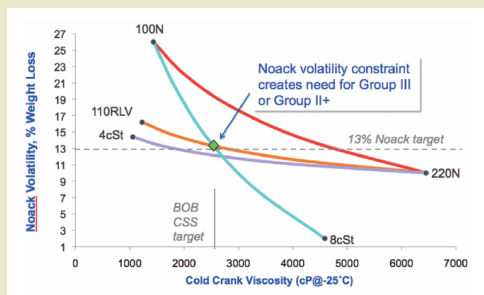
Graphic diagnostic tool identifies optimal blending ratios

By graphically displaying the performance range of base oil blends, one is able to identify the most efficient blend for meeting a desired performance objective. How it is done:

- Curves are created by blending two base stocks in varying ratios
- Target base oil blend viscosity and volatility is established by backing out contributions from additive and VM packages
- If curve lies below the target, the blend of the two base stocks is capable of meeting or exceeding the volatility and viscosity requirements
- In some cases, a correction fluid is required because only 2 blend components cannot meet either the CCS or the Noack volatility.

Example 1

Optimising the base oil blend for an E9 10W-40

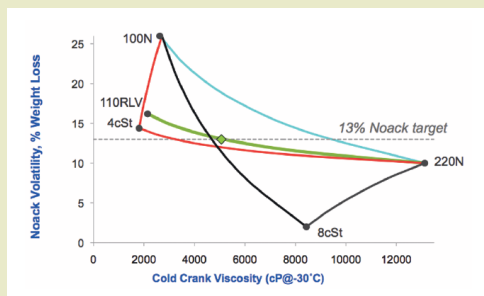


Blend component/ Blend case	Case 1 13% Noack	Case 2 13% Noack	Case 3 13% Noack
220N	46	49	2
100N		10	46
110RLV	54		
4cSt Group III		41	
8cSt Group III			52
CCS@-25°C	2530	2530	2530

To hit the indicated Base Oil Blend (BOB) target, an optimised blend would use only 220N and Chevron 110RLV (Group II+). Case 3, as a 'Dumbbell Blend,' is probably the weakest of the base oil blend alternatives. It contains a very high percentage of high volatility 100N oil and may have difficulty passing high temperature engine tests

Example 2

Identifying the preferred correction fluid for A3/B4, 5W-30

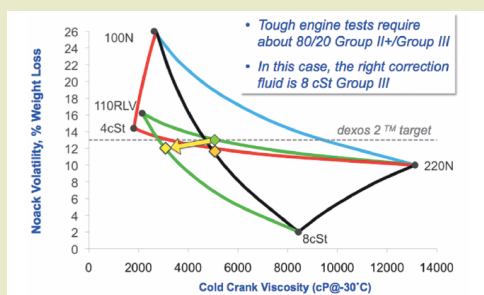


Blend component/ Blend case	Case 1 13% Noack	Case 2 13% Noack	Case 3 13% Noack
220N	51	53	10
100N		8	42
110RLV	49		
4cSt (Gp III)		39	
8cSt (Gp III)			48
CCS, cP@-30°C	5062	5062	5062

All 3 cases meet the same volatility and CCS requirements but have different formulating costs. However, if a lower Noack and CCS are required, the blending diagrams directionally show the preferred correction fluid. Again, Case 3 is a weak blend alternative.

Example 3

dexos™ 2 – 5W-30 PCMO base oil blend needs to have lower volatility and possibly CCS



Blend component/ Blend case	Case 1 12% Noack	Case 2 12% Noack and lower CCS	Case 3 12% Noack and lower CCS
Target on Chart	◆	◆	◆
220N	41		
100N			
110RLV	47	70	
4cSt (Gp III)			80
8cSt (Gp III)	12	30	20
CCS, cP@-30°C	5062	3075	2360

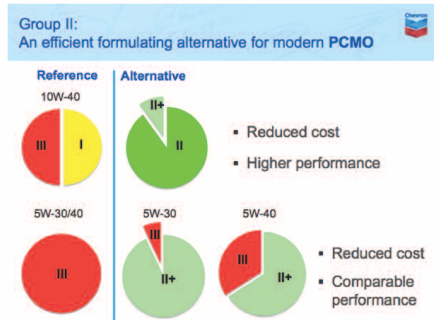
If just a lower Noack is required, the obvious correction fluid is 8 cSt Group III. However, if both a lower Noack and CCS are desired, the blending diagrams directionally show the preferred correction fluid is still 8cSt.

Lube-Tech

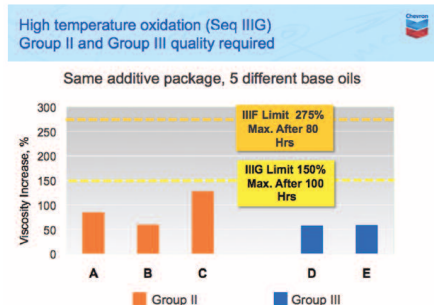
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byproducts in grease, engine oil and industrial oil applications. Additionally, lubricants with high oxidative stability are much less likely to undergo undesirable viscosity increase during the life of the oil.



The performance of five different lubricants blended with the same additive package, but alternative Group II and Group III base oils, were compared on the Sequence IIIIG test. It is a very tough test designed to simulate a vehicle pulling a heavy load across a hot desert, and is the cornerstone of the API GF-4/SM service category.



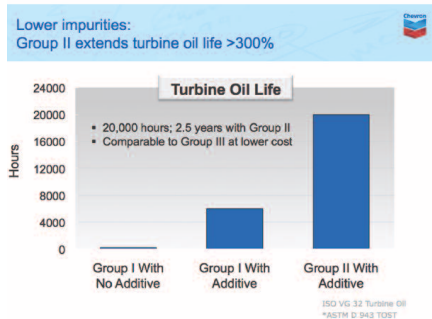
All of the formulations passed easily with one of the Group II blends performing comparably well with the Group III formulations.

Group II – An Excellent Alternative for Industrial Oils

The excellent oxidation stability of Group II base oils can be leveraged for significant performance improvement in industrial oils as well.

When Group II based turbine oils are subjected to a TOST test, Turbine Oil Stability Test (ASTM D946, D5846), there is substantially less viscosity increase in the oil than with Group I formulations. So much so, that the standard ASTM D 943 TOST test for turbine oils was

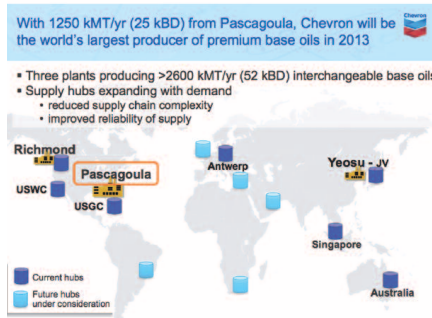
modified to accommodate the extended performance of the Group II base oils. By decreasing the sample withdrawal volume from the test oxidation cell by half, one can extend the maximum test run time from 10,000 to 20,000 hours. Thus, the Group II base oils extended turbine life by more than 300% to 2.5 years. This performance is comparable to Group III base oils at a lower total formulation cost.



New Chevron Pascagoula Plant Adding 25,000 Barrels per Day to Chevron's Global Supply Network

With the world demanding more environmentally sustainable behavior from its industries and transportation systems, Chevron committed to building a new 25 KBPD (1.25 Million TPA) premium base oil plant at its refinery in Pascagoula, Mississippi.

Chevron's refinery system will be producing consistent quality premium base oils from each of its refineries. Global availability will be augmented by a network of strategically located regional supply hubs. The Pascagoula plant is scheduled to come on line in late 2013. Its product slate was designed to meet the global quality and performance needs of both premium and mainline lubricant products. The majority of the production will be high quality Group II base stocks.



Chevron's premium base stocks can satisfy some of the most stringent lubrication applications as well as meet critical OEM specifications for both automotive engine oils as well as industrial oils.

Summary

As performance standards tighten, the impurities of Group I base stocks will make them unacceptable in many engine oil formulations. This is already evident in applications required to meet Mid and Low SAPs formulations in Europe.

The use of PAO and other boutique base oils will be confined to operating environments with exceptional performance demands coupled with low volume needs due to their limited production capacity.

As Europe moves into compliance with Euro VI emission standards, Group II base oils will become a critical component in the European market.

Group II/II+ base stocks have better viscometrics and volatility than Group I/III blends enabling formulaic optimisation. In some cases additive treat rate can be reduced whilst still meeting tough specifications for Mid and Low SAPs lubricant packages. Additionally formulating costs for current high SAPS specifications such as ACEA A3/B4, ACEA E4 can be lowered.

With the addition of the Pascagoula base oil capacity there will be an adequate supply of globally available Group II and Group II+ base oils with consistent quality.

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