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Burn is not the Only Way! Non-Energetic Derivatives as Route to Add Value to the Crude Oil

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INTRODUCTION AND CONTEXT

The current scenario present great challenges to the crude oil refining industry, prices volatility of raw material, pressure from society to reduce environmental impacts and refining margins increasingly lower. The newest threat to refiners is the reduction of the consumer market, in the last years became common, news about countries that intend to reduce or ban the production of vehicles powered by fossil fuels in the middle term, mainly in the European market. Despite the recent forecasts, the transportation fuels demand is still the main revenues driver to the downstream industry, as presented in Figure 1, based on data from Wood Mackenzie Company.

According to Figure 1, is expected a growing demand by petrochemicals while the transportation fuels tend to present falling consumption. Still according to Wood Mackenzie data, presented in Figure 2, due to the higher added value, the most integrated refiners tend to achieve higher refining margins than the conventional refiners which keep the operations focused on transportation fuels.

NCM = Net Cash Margins

The improvement in fuel efficiency, growing market of electric vehicles tends to decline the participation of transportation fuels in the global crude oil demand. New technologies like additive manufacturing (3D printing) have the potential to produce great impact to the transportation demands, leading to even more impact over the transportation fuels demand. Furthermore, the higher availability of lighter crude oils favors the oversupply of lighter derivatives that facilitate the production of petrochemicals against transportation fuels as well as the higher added value of petrochemicals in comparison with fuels.

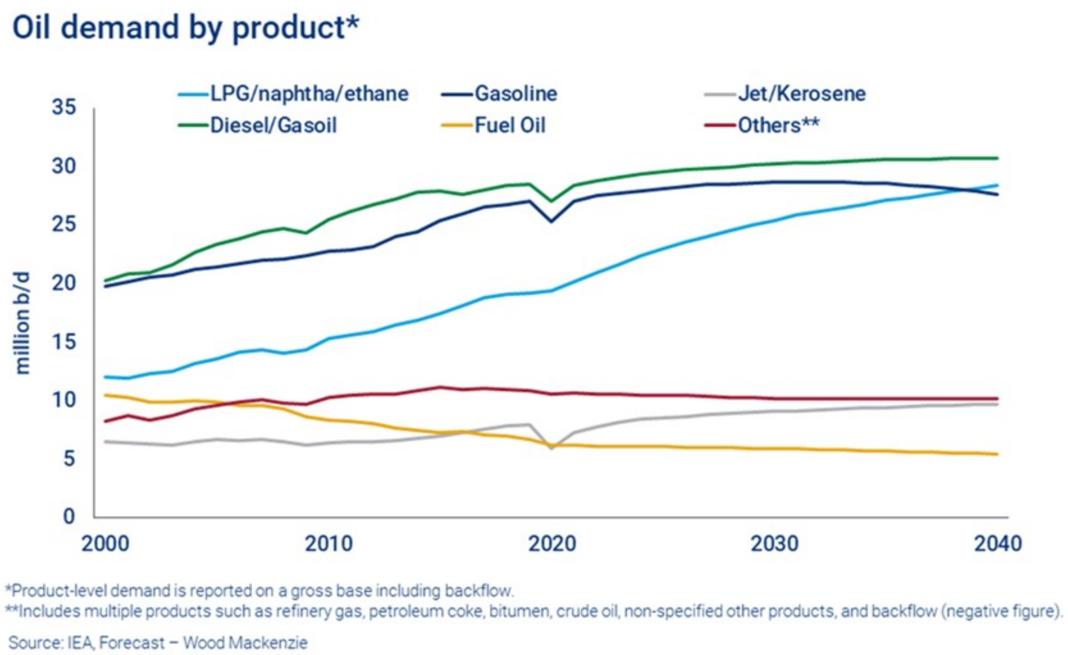
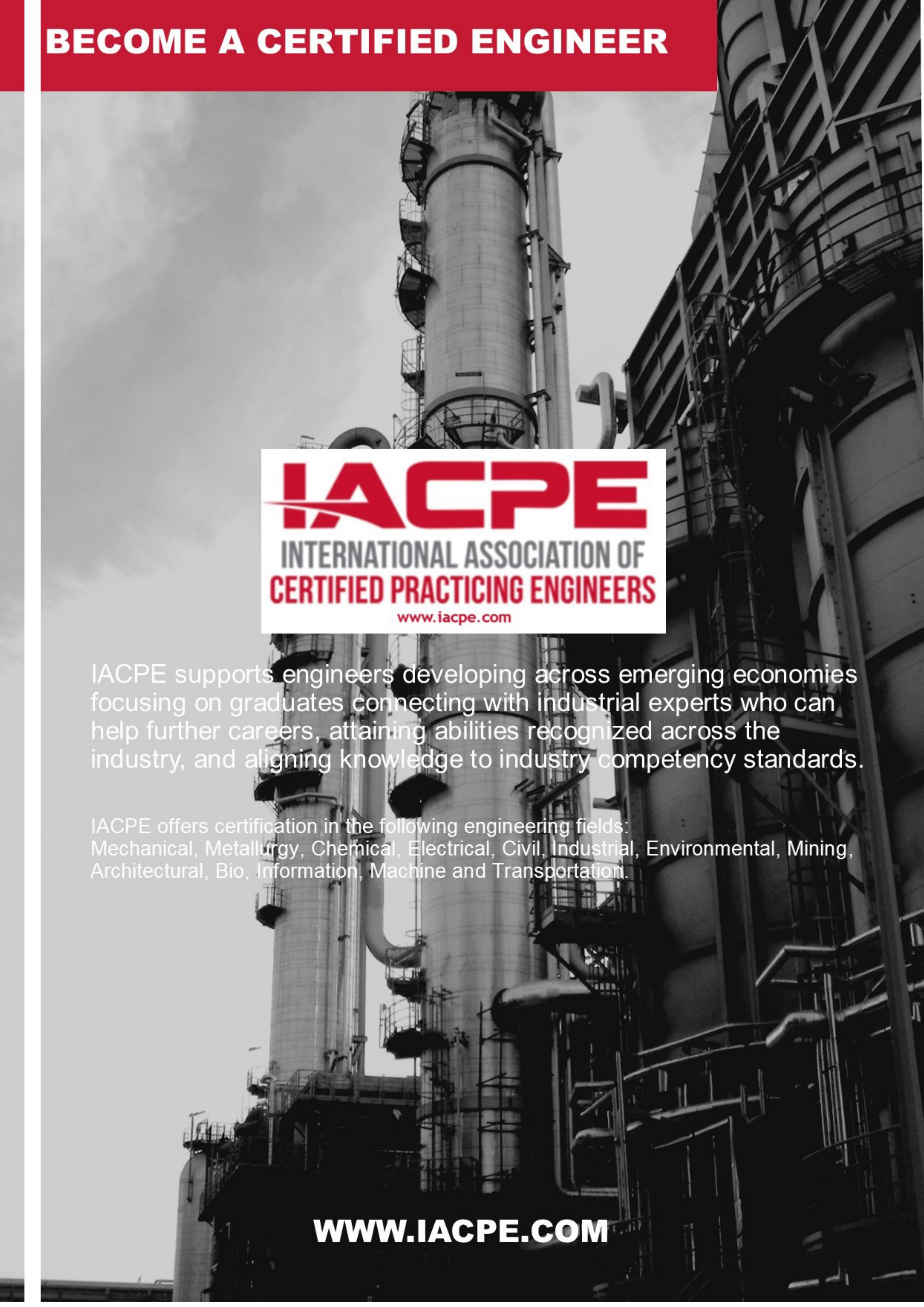


Figure 1 – Global Oil Demand by Derivative (Wood Mackenzie, 2020)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On the other hand, non-energetic derivatives like petrochemicals and lubricating presents a growing consumer market. According to trend analysts and recent forecasts, the lubricants market size was valued at USD 165 billion in 2022 and will grow by compound annual rates around 3,0 % and can reach a total value of USD 188 billion in 2027. Figure 3 presents the growing trend for lubricants market by consumer sector. The high added value of lubricants in comparison with the transportation fuels accompanied by the trend of reduction in transportation fuels demand indicates an attractive alternative to refiners with adequate refining hardware to improve his revenues and the competitiveness in the downstream market.

Like others crude oil derivatives, the economic and technology development have been required the production of lubricating oils with higher quality and performance, moreover with lower contaminants content. In his turn, petrochemicals also present a significant growth to the next years, as presented in Figure 4.

Just the olefins market will rise a total value of US$ 322 billion dollars in 2026 with a growing rate of 4,0 % in 2022 to 2027 period according to recent forecasts. Under this scenario, search for alternatives that ensure survival and sustainability of the refining industry became constant by refiners and technology developers. The maximization of non-energetic derivatives like lubricants and petrochemicals can offer a profitable alternative to refiners, according to the local market. Due to his similarities, better integration between refining and petrochemical production processes appears as an attractive alternative. Although the advantages, it’s important consider that the integration between refining and petrochemical assets increase the complexity, requires capital spending, and affect the interdependency of refineries and petrochemical plants, these facts need to be deeply studied and analyzed case by case.

HIGHER ADDED VALUE TO THE NAPHTHA – PETROCHEMICAL INTEGRATION CONCEPT

The focus of the closer integration between refining and petrochemical industries is to promote and seize the synergies existing opportunities between both downstream sectors to generate value to the whole crude oil production chain. Table 1 presents the main characteristics of the refining and petrochemical industry and the synergies potential.

As aforementioned, the petrochemical industry has been growing at considerably higher rates when compared with the transportation fuels market in the last years, additionally, represent a noblest destiny and less environmental aggressive to crude oil derivatives. The technological bases of the refining and petrochemical industries are similar which lead to possibilities of synergies capable to reduce operational costs and add value to derivatives produced in the refineries.

Figure 5 presents a block diagram that shows some integration possibilities between refining processes and the petrochemical industry.

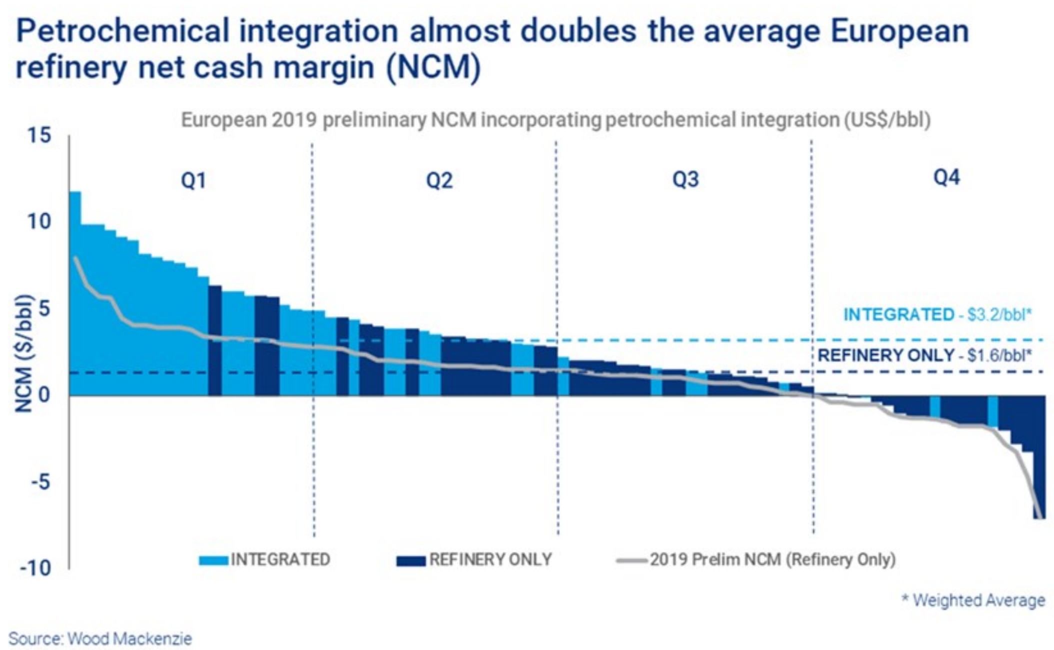

Figure 2 – Refining Margins to Integrated and Non-Integrated Refining Hardware (Wood Mackenzie, 2020)

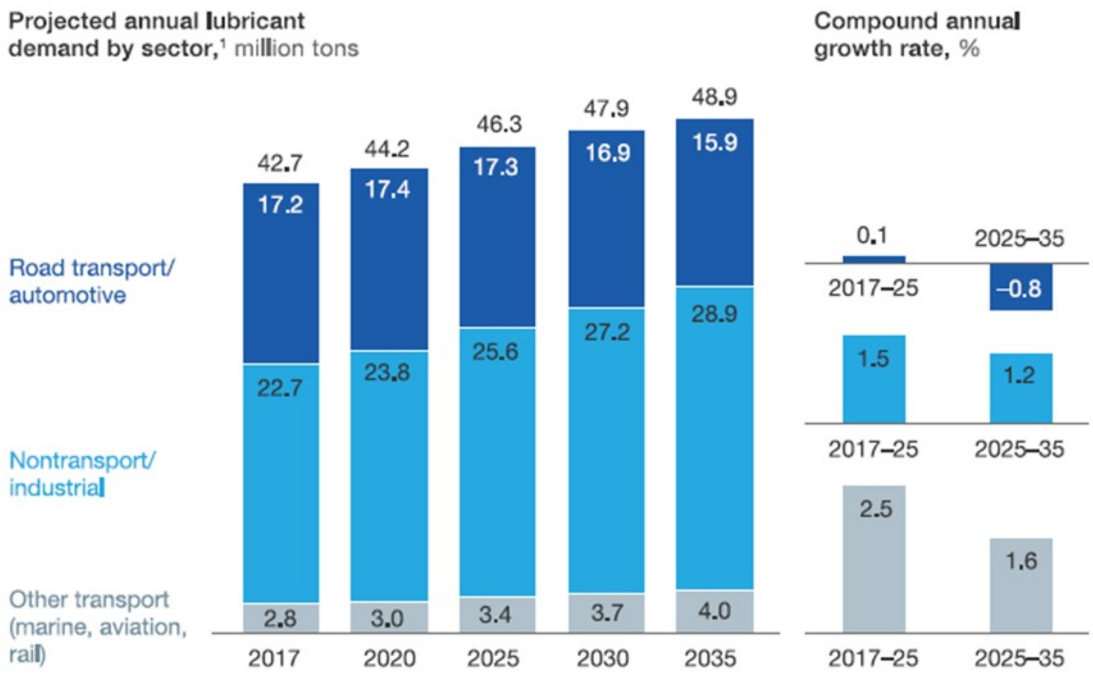

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Figure 3 – Growing Trend in the Demand by Lubricants (McKinsey & Company, 2018)

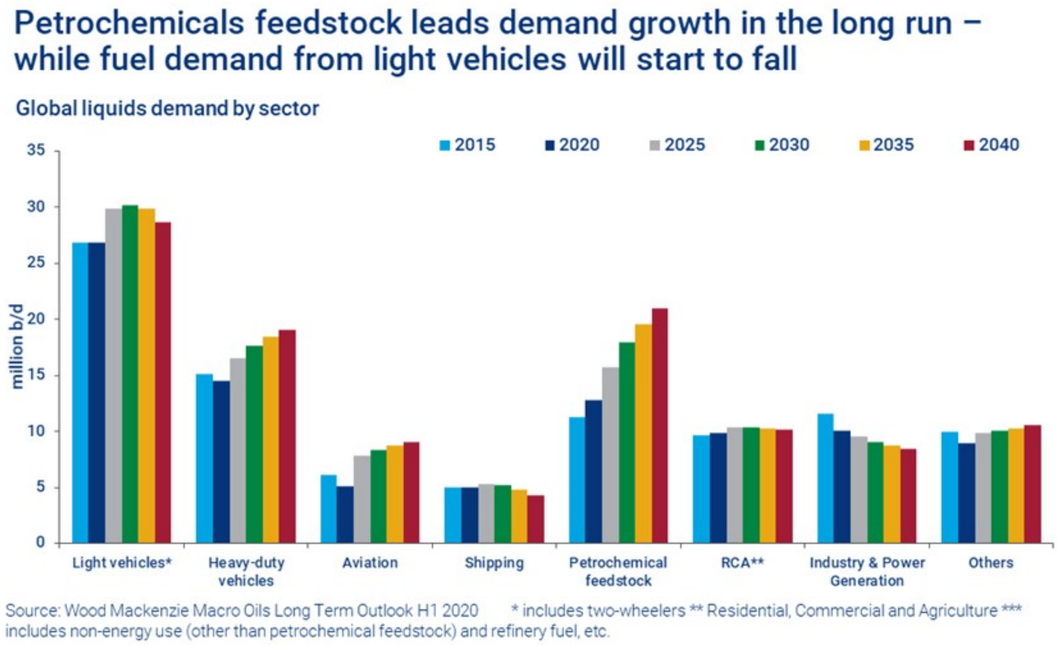

Figure 4 – Growing Trend in the Demand by Petrochemical Intermediates (Wood Mackenzie, 2020)

Table 1 – Refining and Petrochemical Industry Characteristics

Refining Industry	Petrochemical Industry
Large Feedstock Flexibility	Raw Material from Naphtha/NGL
High Capacities	Higher Operation Margins
Self Sufficient in Power/Steam	High Electricity Consumption
High Hydrogen Consumption	High Availability of Hydrogen
Streams with low added Value (Unsaturated Gases & C2)	Streams with Low Added Value (Heavy Aromatics, Pyrolysis Gasoline, C4's)
Strict Regulations (Benzene in Gasoline, etc.)	Strict Specifications (Hard Separation Processes)
Transportation Fuels Demand in Declining at Global Level	High Demand Products

Process streams considered with low added value to refiners like fuel gas (C2) are attractive raw materials to the petrochemical industry, as well as streams considered residual to petrochemical industries (butanes, pyrolisis gasoline, and heavy aromatics) can be applied to refiners to produce high quality transportation fuels, this can help the refining industry meet the environmental and quality regulations to derivatives.

The integration potential and the synergy among the processes rely on the refining scheme adopted by the refinery and the consumer market, process units as Fluid Catalytic Cracking (FCC) and Catalytic Reforming can be optimized to produce petrochemical intermediates to the detriment of streams that will be incorporated to fuels pool. In the case of FCC, installation of units dedicated to produce petrochemical intermediates, called petrochemical FCC, aims to reduce to the minimum the generation of streams to produce transportation fuels, however, the capital investment is high once the severity of the process requires the use of material with noblest metallurgical characteristics.

The IHS Markit Company proposed a classification of the petrochemical integration grades, as presented in Figure 6.

According to the classification proposed, the crude to chemicals refineries is considered the maximum level of petrochemical integration where the processed crude is totally converted into petrochemicals like ethylene, propylene, and BTX.

REACHING MAXIMUM ADDED VALUE - INTEGRATED REFINING SCHEMES

Historically, the refining industry growth was sustained and focused on transportation fuels, this can explain the profile of the traditional refining schemes. Nowadays, the downstream industry is facing with a trend of reduction in transportation fuels demand, followed by a growing demand by petrochemicals, this fact is the main driving force to promote the change of focus in downstream industry.

The growing market of petrochemicals have been led some refiners to look for a closer integration between refining and petrochemicals assets aiming to reach more adherence with the market demand, improve revenues, and reduce operation costs. To reach this goal, the refiners are implementing most integrated refining schemes as presented in Figure 7.

As presented in Figure 7, the integrated refining scheme rely on flexible refining technologies as catalytic reforming and fluid catalytic cracking (FCC) that are capable to reach the production of high-quality petrochemicals and transportation fuels, according to the market demand. A more integrated refining configuration allows the maximization of petrochemicals, raising the refining margins and ensures higher value addition to the processed crude oils. Another fundamental competitive advantage is the operational flexibility reached through the integrated refining configurations, allowing the processing of discounted and cheaper crude oils, raising even more the re-

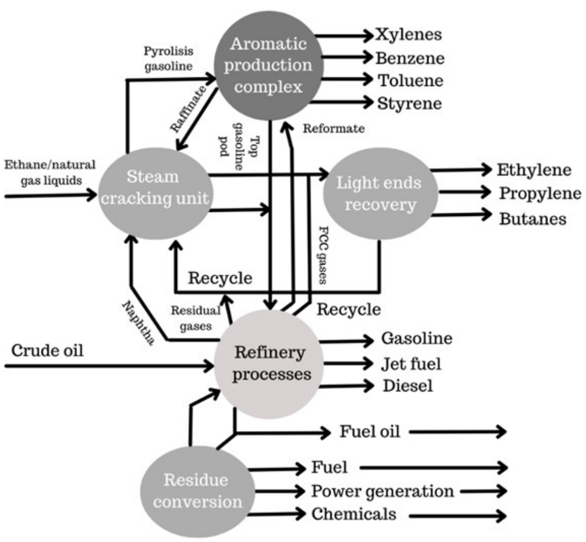

Figure 5 –Possible Synergies between Refining and Petrochemical Processes

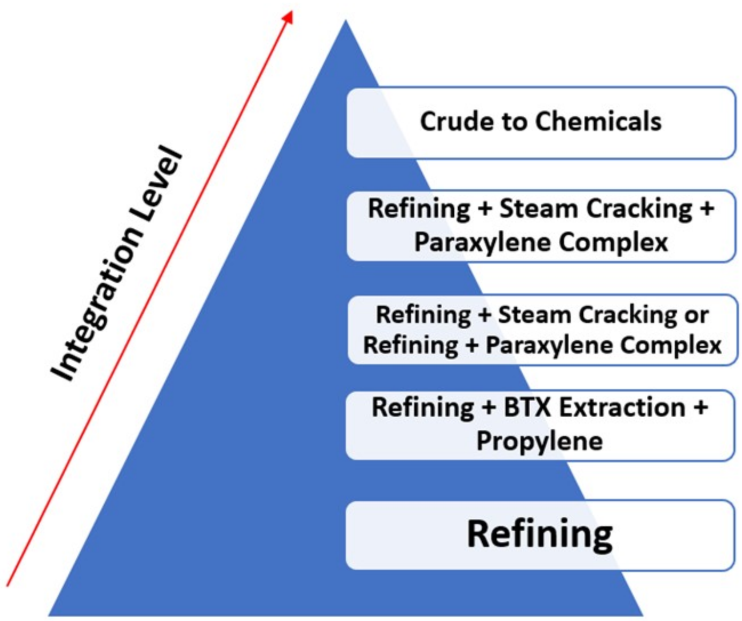

Figure 6 – Petrochemical Integration Levels (IHS Markit, 2018)

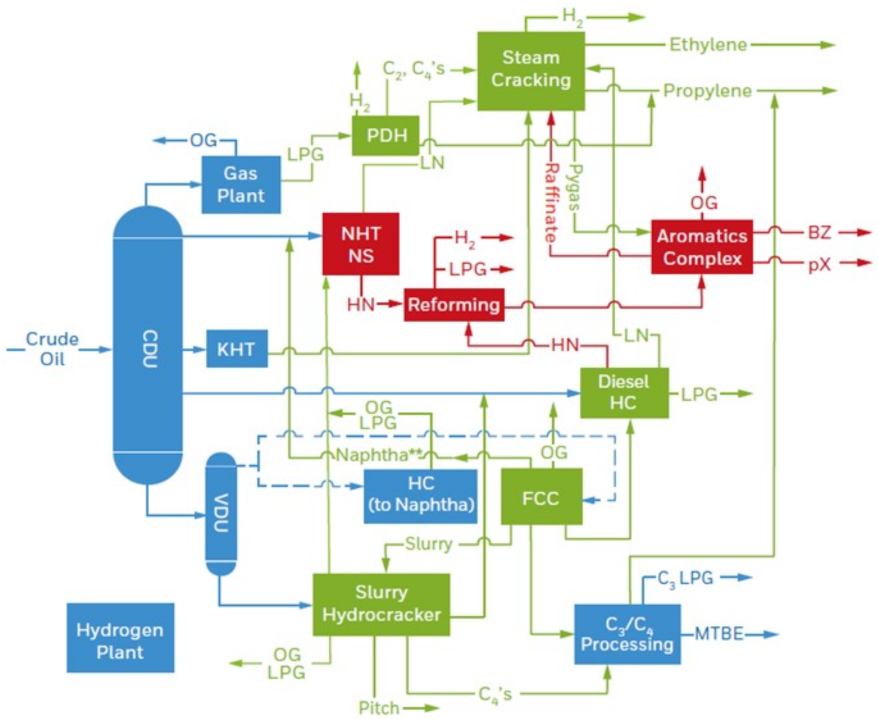

Figure 7 – Example of an Integrated Refining Focusing on Petrochemicals Scheme by UOP Company

THE CRUDE OIL TO CHEMICALS REFINING ASSETS

Due to the increasing market and higher added value as well as the trend of reduction in transportation fuels demand, some refiners and technology developers has dedicated his efforts to develop crude to chemicals refining assets. One of the big players that have been invested in this alternative is the Saudi Aramco Company, the concept is based on the direct conversion of crude oil to petrochemical intermediates as presented in Figure 8.

The process presented in Figure 8 is based on the quality of the crude oil and deep conversion technologies like High Severity or petrochemical FCC units and deep hydrocraking technologies. The processed crude oil is light with low residual carbon that is a common characteristic in the Middle East crude oils, the processing scheme involves deep catalytic conversion process aiming to reach maximum conversion to light olefins. In this refining configuration, the petrochemical FCC units have a key role to ensure high added value to the processed crude oil.

Some technology developers are dedicating his efforts to develop commercial crude to chemicals refineries. Figure 9 presents the concept of crude to chemicals refining scheme by Chevron Lummus Company.

Another crude to chemicals refining arrangements is proposed by Chevon Lummus Company, applying the synergy of residue upgrading strategies to maximize the petrochemical intermediates production, Figure 10 presents a crude to chemicals arrangement relying on delayed coking unit.

Another great refining technology developers like UOP, Shell Global Solutions, ExxonMobil, Axens, and others are developing crude to chemicals technologies, reinforcing that this is a trend in the downstream market. Figure 11 presents a highly integrated refining configuration capable to convert crude oil to petrochemicals developed by UOP Company.

As presented in Figure 13, the production focus change to the maximum adding value to the crude oil through the production of high added value petrochemical intermediates or chemicals to general purpose leading to a minimum production of fuels. As aforementioned, big players as Saudi Aramco Company have been made great investments in COC technologies aiming to achieve even more integrated refineries and petrochemical plants, raising considerably his competitiveness in the downstream market. The major technology licensors as Axens, UOP, Lummus, Shell, ExxonMobil, etc. has been applied resources to develop technologies capable to allow a closer integration in the downstream sector aiming to allow refiners extract the maximum added value from the processed crude oil, an increasing necessity in a scenario where the refining margins are

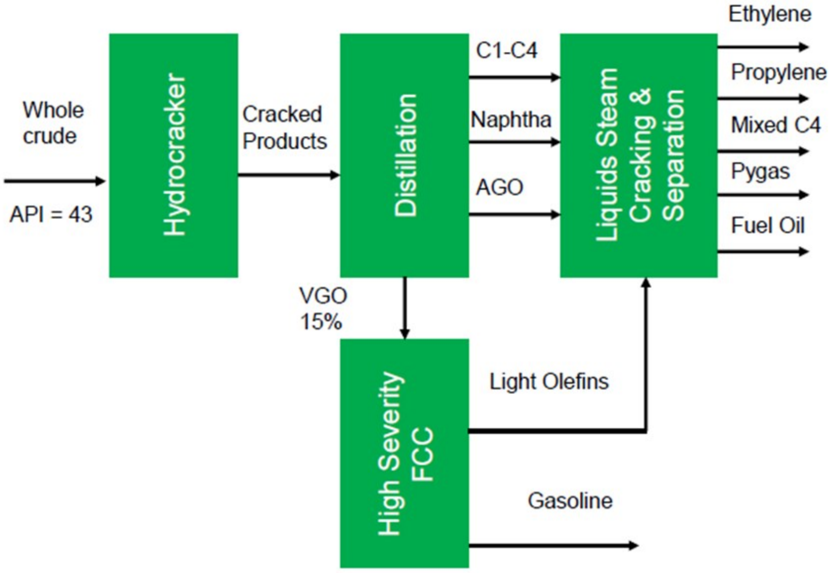

Figure 8 – Saudi Aramco Crude Oil to Chemicals Concept (IHS Markit, 2017)

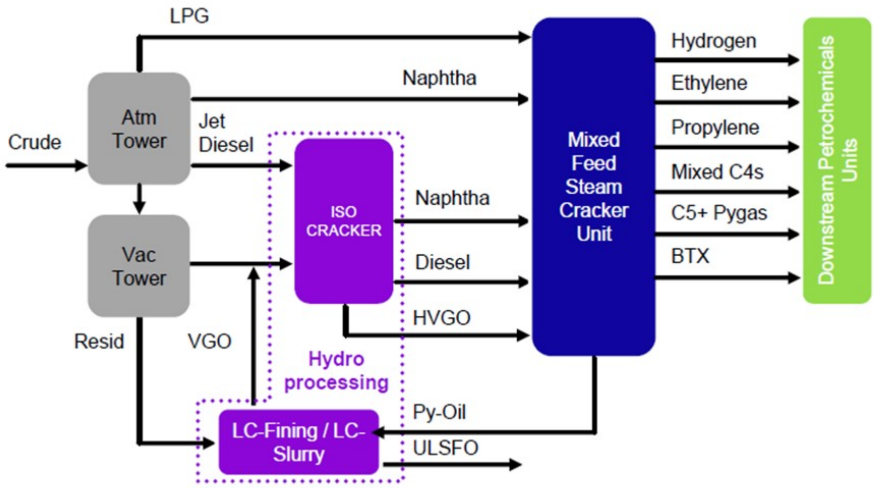

Figure 9 – Crude to Chemicals Concept by Chevron Lummus Company (Chevron Lummus Global Company, 2019)

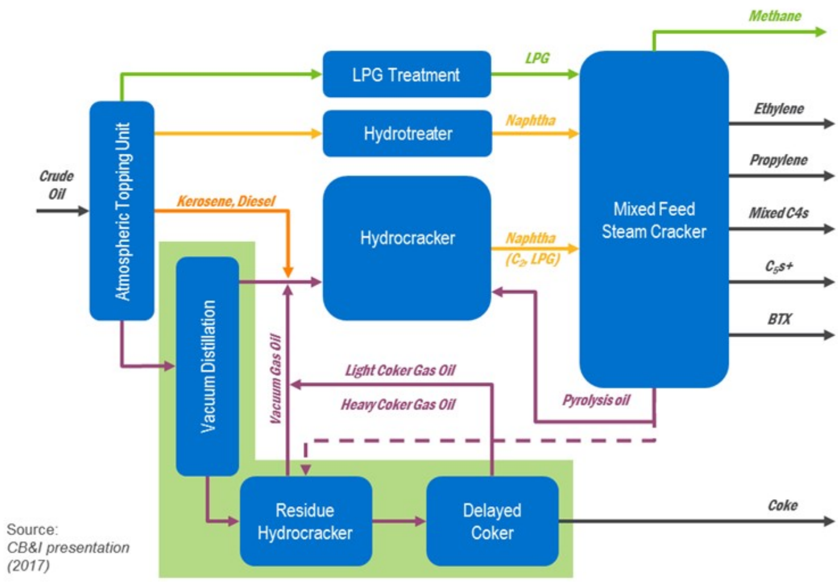

Figure 10 – Crude to Chemicals Concept by Chevron Lummus Company (Nexant Company, 2018)

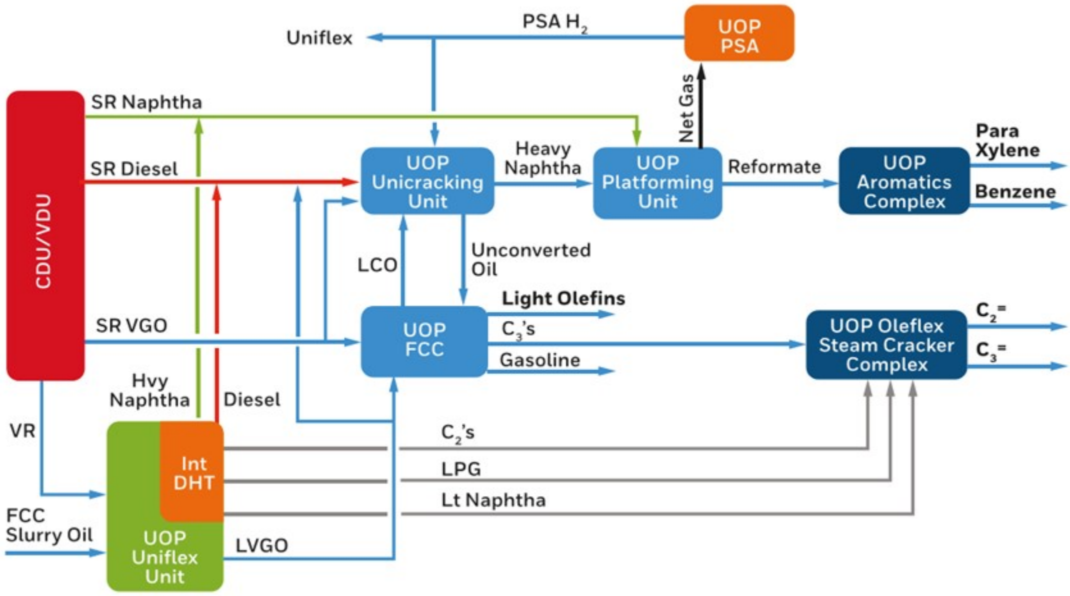

Figure 11 – Integrated Refining Configuration Based in Crude to Chemicals Concept by UOP Company.

As aforementioned, face the current trend of reduction in transportation fuels demand at the global level, the capacity of maximum adding value to crude oil can be a competitive differential to refiners. Due to the high capital investment needed for the implementation that allows the conventional refinery to achieve the maximization of chemicals, capital efficiency becomes also an extremely important factor in the current competitive scenario as well as the operational flexibility related to the processed crude oil slate.

THE LUBRICANT PRODUCTION ROUTES – ANOTHER PROFITABLE WAY TO ENSURE PARTICIPATION IN A GROWING MARKET

The first step in the lubricant production process is vacuum distillation of atmospheric residue obtained like bottom product in the atmospheric distillation processes. For vacuum distillation units dedicated to producing lubricating fractions the fractionating needs a better control than in the units dedicated to producing gasoils to fuels conversion, the objective is to avoid the thermal degradation and to control distillation curve of the side streams, a typical arrangement for vacuum distillation unit to produce lubricating fractions is presented in Figure 12. A secondary vacuum distillation column is necessary when is desired to separate the heavy neutral oil stream from vacuum residue.

In lubricating production units based on the solvent route the following steps are basically physical separation processes with the objective to remove from the process streams the components which can prejudice the desired properties of base oils, mainly the viscosity index, and chemical stability.

Figure 13 shows a block diagram corresponding to the process steps to produce base lubricating oils through solvent extraction route.

As aforementioned, in the vacuum distillation step, the fractionating quality obtained between the cuts is critical for these streams reach the quality requirements like flash point and viscosity. After vacuum distillation step the side cuts are pumped to aromatic extraction unit and the vacuum residue is sent to propane deasphalting unit.

The Propane deasphalting process seeks to remove from vacuum residue the heavier fractions which can be applied as lubricating oil. The Propane deasphalting units dedicated to producing lubricating oils apply pure propane like solvent because this solvent has higher selectivity to remove resins and asphaltenes from deasphalted oil.

In the aromatic extraction step, the process streams are put in contact with solvents selective to remove aromatics compounds, mainly polyaromatics. The main objective in remove these compounds is the fact that they have low viscosity index and low chemical stability, this is strongly undesired in lubricating oils. As the nitrogen and sulfur compounds are normally present in the polyaromatic structures, in this step a major part of sulfur and nitrogen content of the process stream is removed. The solvents normally applied in the aromatics extraction process is phenol, furfural, and N-methyl pyrrolidone.

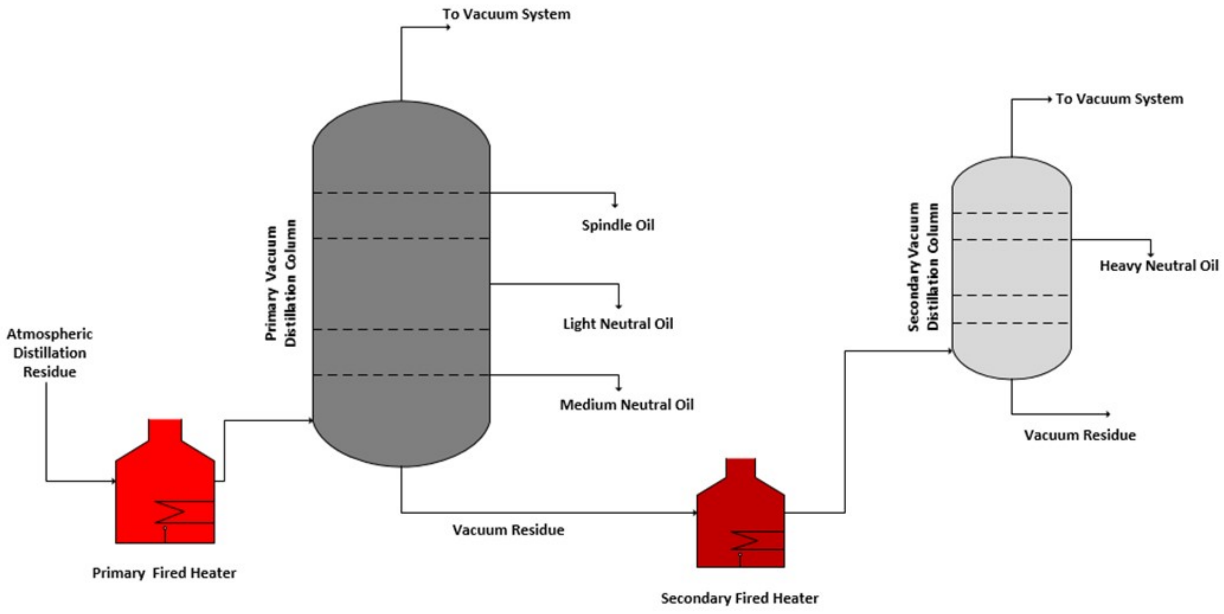

Figure 12 – Typical Arrangement for Vacuum Distillation Process to Lubricating Oil Production

The subsequent step is to remove the linear paraffins with high molecular weight through solvent extraction. This step is important because these compounds prejudice the lubricating oils flow at low temperatures, a typical solvent employed in the solvent dewaxing units is the Methyl-Isobutyl-Ketone (MIK), but some process plants apply toluene and/or methyl ethylketone for this purpose.

After paraffins removing, the lubricating oil is sent to the finishing process, in this step are removed heteroatom's compounds (oxygen, sulfur, and nitrogen), these compounds can give color and chemical instability for the lube oil, furthermore, are removed some remaining polyaromatic molecules. Some process plants with low investment and processing capacity apply a clay treatment in this step, however, modern plants and with higher processing capacity use mild hydrotreating units, this is especially important when the petroleum processed have higher contaminants content, in this case, the Clay bed saturates very quickly.

The paraffins removed from lubricating oils are treated to removing the oil excess in the unit called wax deoiling unit, in this step, the process stream is submitted to reduced temperatures to remove the low branched paraffins which have low melting point. Like the

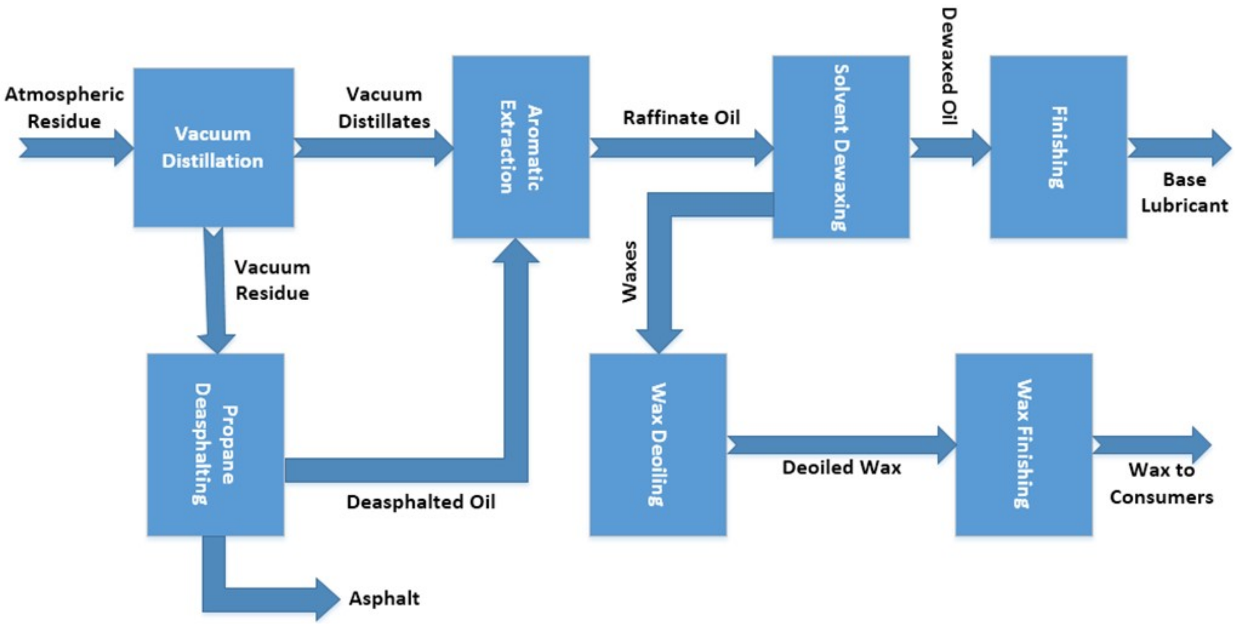

Figure 13 – Processing Scheme for Base Lubricating Oil Production through Solvent Route

lubricating oils, the subsequent step is a finishing process to remove heteroatoms (N,S,O) and to saturate polyaromatic compounds, in the paraffins case generally, is applied a hydrotreating process with sufficient severity to saturate the aromatic compounds that can allow to reaching the food grade in the final product. As cited earlier, the solvent route can produce group I lubricating oil, however, lube oils employed in severe work conditions (large temperature variation) need be had higher saturated compounds content and higher viscosity index, in this case, is necessary apply the hydro-refining route.

PRODUCING HIGH QUALITY LUBRICATING OILS – THE HYDROPROCESSING ROUTE

In the lubricating oil production by hydro-refining, the physical processes of the solvent route are substituted by catalytic processes, basically hydrotreating processes. Figure 15 shows a block diagram of the processing sequence to produce base lube oils through hydro-refining route.

In this case the fractionating in the vacuum distillation step has more flexibility than in the solvent route, once that the streams will be cracked in the hydrocracking unit, so another distillation step is necessary.

After the vacuum distillation and propane deasphalting steps, the process streams are sent to a hydrotreating unit, this step seeks to saturate polyaromatic compounds and remove contaminants like sulfur and mainly nitrogen which is a strong deactivation agent for the hydrocracking catalyst.

In the hydrocracking step, the feed stream is cracked under controlled conditions and chemical reactions like dehydrocyclization, and aromatics saturation occur which give to the process stream the adequate characteristics to the application as lubricants. The following step, hydroisomerization, seeks to promote isomerization of linear paraffins (which can reduce de viscosity index) producing branched paraffins.

After the hydroisomerization the process stream is pumped to hydrofinishing units to saturate remaining polyaromatic compounds and to remove heteroatoms, in the hydrofininshing step the water content in the lube oil is controlled to avoid turbidity in the final product.

In hydrotreating units dedicated to produce lubricant, one of the focus of the hydrotreating process is to reduce the concentration of long chain paraffin, to achieve this goal is applied a specific catalyst beds containing dewaxing catalysts (ZSM-5). One of the most known hydrodewaxing technology in the market is the MSDW™ process, commercialized by ExxonMobil Company. A basic process flow diagram for MSDW™ process is shown in Figure 16.

HDF = Hydrofininshing

Another available hydrodewaxing technology is the Isodewaxing™ process, developed by Lummus Company, this process is shown in Figure 17.

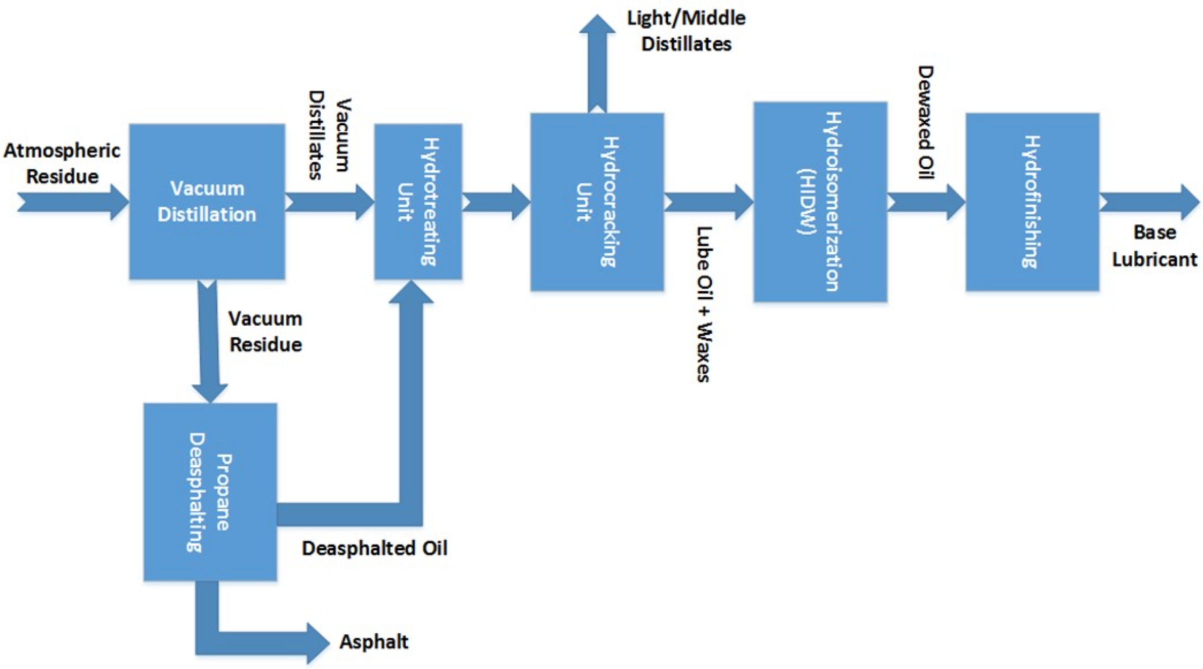

Figure 15 - Processing Scheme for Base Lubricating Oil Production through Hydrorefining Route

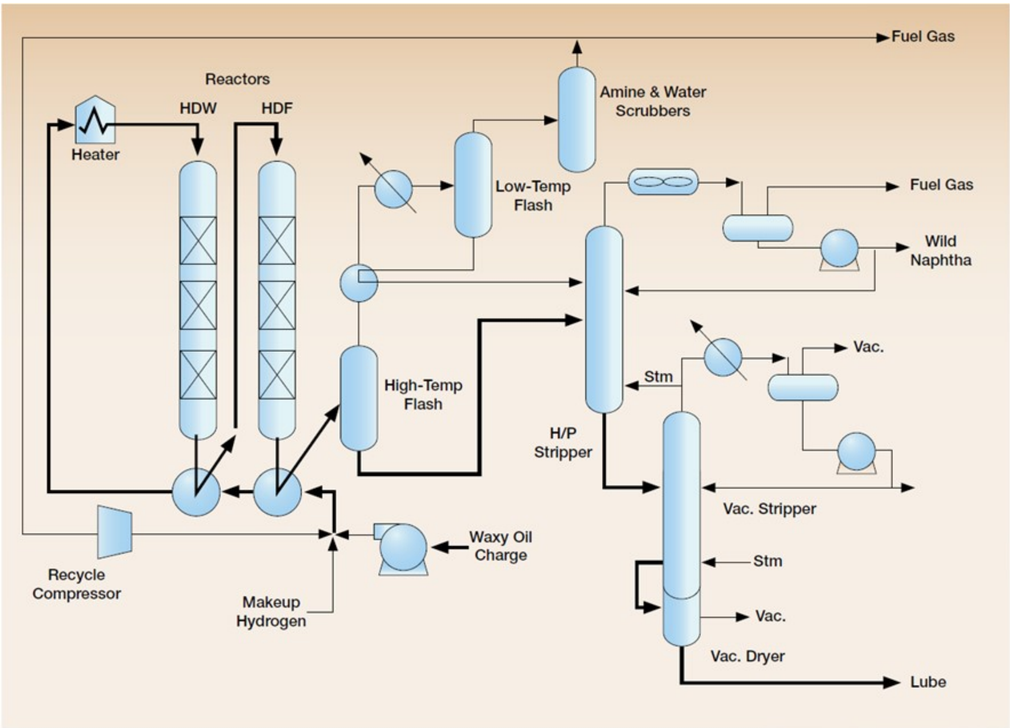

Figure 16 – Basic Process Flow Diagram for MSDW™ Dewaxing Technology by ExxonMobil Company (ExxonMobil Website).

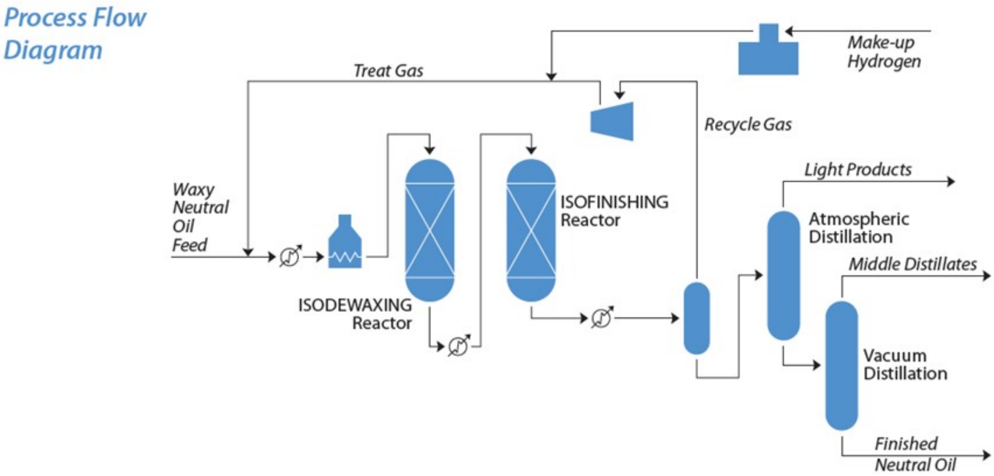

Figure 17 – Basic Process Flow Diagram for the Isodewaxing™ technology by Lummus Company.

At this point is important to quote that the main quality requirements of the lubricating oils are put under control through the following processes:

- Viscosity – The viscosity of the lubricating oil is controlled in the distillation step, managing the cuts in the crude distillation units or in the distillation columns after hydrocracking units;
- Viscosity Index (VI) – This variable is controlled in the hydrocracking step through the reduction in the aromatics content;
- Saturates – Another parameter that is adjusted in the hydrocracking step, through
- Pour Point – This quality requirement is controlled in the hydrodewaxing step, through the reduction of waxes content.

Despite the high capital spending involved in the hydroprocessing route, it's possible to achieve better quality, higher added value, and products with growing demand against the production of Group I lube that presents contraction demands. In this scenario, is expected which refiners relying on exclusively solvent routes, lose market share forcing revamps of the existing lubricating production units or the exit from the market.

SOLVENT ROUTE X HYDROREFINING ROUTE – KEEPING COMPETITIVE

As aforementioned, comparing the lubricant production routes can be observed that the hydro-refining route gives more flexibility in a relation of the petroleum to be processed. As the solvent route apply basically physical processes, is necessary to select crude oils with higher content of paraffins and low contaminants content (mainly nitrogen) to the processing, which can be a critical disadvantage in geopolitical instability scenario. The main disadvantage of the solvent route, when compared with the hydrorefining route, is that the solvent route can produce only Group I lubricating oil, this can limit his application to restricted consumer markets, which can reflect in the economic viability. Figure 18 presents a forecast to the market share evolution to different kinds of base oils in the market.

According to the data from Figure 18, is expected a significant reduction in the demand by Group I base oils, leading to a great competitive loss to refiners relying on base oil production exclusively through solvent routes.

Another solvent route disadvantage is the solvents applying which can cause environmental damage and needs specials security requirements during the processing, production of low value-added streams like aromatic extract is another disadvantage.

As advantages of the solvent route over the hydro-refining route can be cited lower capital investment and the fact that the solvent route produces paraffins which can be directed to the consumer market like products with higher added value.

Conclusion

As discussed above, the production of non-energetic derivatives can ensure high economic results to refiners once theses derivatives present higher added value and growing market. The synergy between refining and petrochemical processes raises the availability of raw material to petrochemical plants and makes the supply of energy to these processes more reliable at the same time ensures better refining margin to refiners due to the high added value of petrochemical intermediates when compared with transportation fuels. Another advantage is the reduction of risks of transportation fuels oversupply, facing the current scenario of demand reduction and restriction of fossil fuels. It's important to consider that integrated processes lead to higher operational complexity, however, given current and middle term scenarios to the refining industry, better integration between refining and petrochemical processes is fundamental to the economic sustainability of the downstream industry. Again, it's important to understand the transitive period faced by the downstream industry and maintain competitive operations with the current focus in transportation fuels while the transition to petrochemicals is prepared in a sustainable manner aiming to keep economic sustainability and competitiveness in the downstream market.

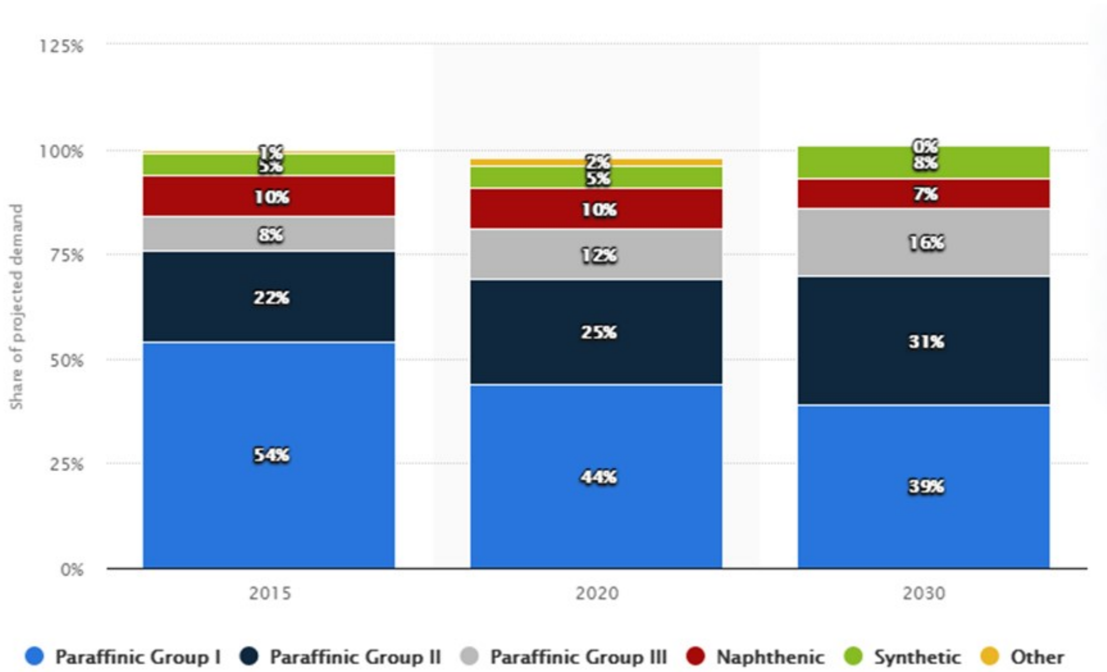

Figure 17 – Basic Process Flow Diagram for the Isodewaxing™ technology by Lummus Company.

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