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In This Issue

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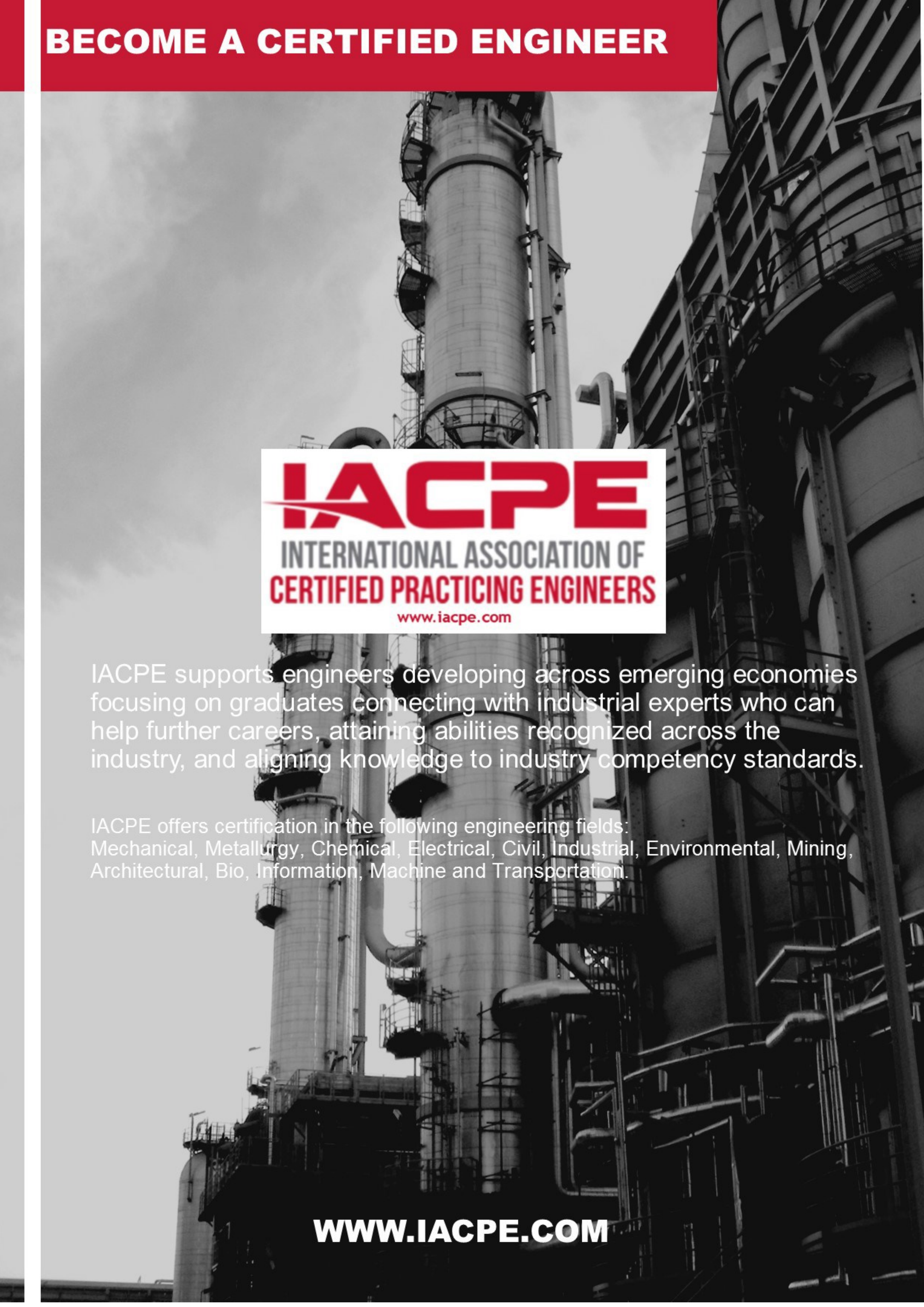
SPECIAL FEATURES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Advanced Process Control and Optimization for Oil Refining

Eng. Javier Marín

INTRODUCTION

After the removal of the restrictions imposed to stop the advance of the COVID-19 pandemic, the energy market has registered a faster-than-expected recovery, the demands for liquid fuels continue to increase in most countries, so it is imperative to increase inventories of distillates to supply the local and global demand for hydrocarbons at values close to those registered before the start of the pandemic. However, the projection for the consumption of liquid fuel is not as favorable as expected, according to the report “Short-Term Energy Outlook. July 2023” published by the U.S. Energy Information Administration EIA, consumption of liquid distillates will increase by only 1.8 million barrels per day (b/d) in 2023 and by 1.6 million b/d in 2024 Vs. 2.3 million b/d in 2022.

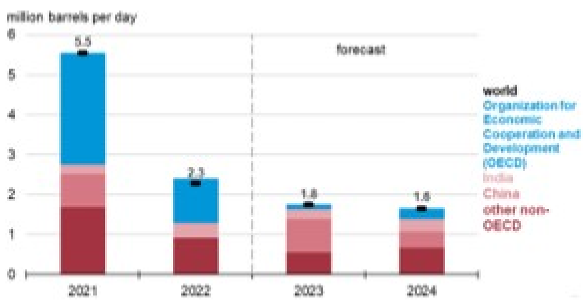

Figure 1. Annual change in world liquid fuels consumption (Data source: U.S. Energy Information Administration, Short-Term Energy Outlook. July 2023)

According to the report "Oil 2023 Analysis and Forecast to 2028" published by the International Energy Agency IEA, this trend of low consumption of liquid distillates will continue until at least 2028, due to increased production of biofuels and increased demand for electric cars that will possibly bring oil demand to a record low of 0.4 mb/d in the year 2028.

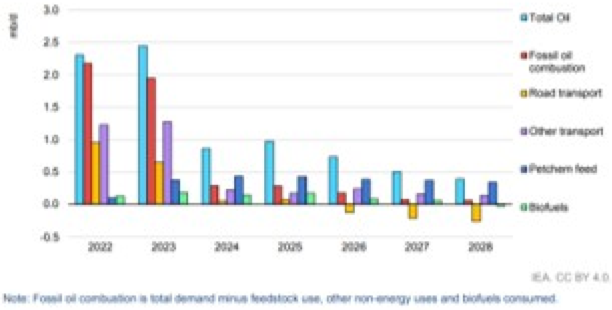

Figure 2. Annual oil demand growth, 2022-2028 (Data source: International Energy Agency IEA, Oil 2023-Analysis and forecast to 2028)

Given this not-very-encouraging situation for the liquid hydrocarbons sector, the use of software and mathematic tools for controlling and optimizing chemical processes should be a priority to maximize production and minimize energy consumption. Complex product disposition scenarios require an exhaustive analysis of the entire supply chain and the operation of the different process units to optimize the entire production line without compromising the quality of the products.

However, there are exceptions to the downward trend in distillate consumption, according to the report “Annual Energy Outlook 2022 Reference Case” published by the U.S. Energy Information Administration EIA, The US total consumption of petroleum and other liquids will increase in most years through 2050. But regardless of some local scenarios, downstream companies at a global level continue to promote automation/optimization projects, with advanced process control (APC), LP models, and real-time optimization (RTO) that allow increasing refining margins.

REFINING MARGINS

The objective of oil refining is to satisfy the demand for fuels, lube oil, and some other distillates, to generate a profit that allows covering costs. Therefore, the most important economic parameter of oil refining is the:

The refining margin: The difference between the value of the products obtained and the cost of the crude oil processed in the refinery, after deducting the variable costs.

OPPORTUNITIES TO IMPROVE REFINING MARGINS

The profitability of the refining business will always be affected by variations in the price of crude oil and distillates, and on many occasions, the only alternative to maintain a favorable refining margin is to minimize energy costs, avoid unscheduled plant shutdowns and maximize product performance. For this, there are various alternatives, techniques, and tools aimed at minimizing fuel consumption in furnaces and boilers, prolonging the equipment operation cycle (for example: minimizing fouling of heat exchangers), and maximizing the production of high-value distillates.

Many refineries use Linear Programming (LP) as their primary optimization technique, which allows operations to be mathematically optimized based on objectives and constraints. Through linear programming, highly complex refining processes can be modeled as a system of multiple equations, whose solution allows to optimally satisfy the business needs, maximize its objective function, maintain production within quality parameters, minimize costs, and meet market commitments. The success of linear programming (LP) in refineries is contingent on advanced knowledge of operations, constraints, and objectives, as well as high reliability of input data, adequate information processing, and successful disclosure of directions to the different levels of operation.

The second tool to improve the refining margin is the Advanced Process Control (APC) which is typically based on model-predictive control (MPC) technology and consists of empirical models with multiple inputs and multiple outputs that manipulate variables of the different units until finding an optimum operation point. The advanced process control is implemented to:

-Maximize process capacity.

-Reduce product off-spec.

-Minimize downtime.

-Optimize energy consumption.

The third optimization tool is the Real Time Optimizer RTO, a rigorous, large-scale model made up of multiple systems of differential-algebraic equations and thermodynamic equations that describe refining processes. This type of model acquires process and laboratory data through online connections to the DCS, runs simulations and data reconciliation, infers product quality and operating conditions to finally estimate the optimum operation point, and sends operating targets to one or many APC controllers.

Figure 3. Hierarchy of the Advanced Process Control and Optimization Tools

Even the oldest refineries have increased their level of automation and control, with the aim of optimizing their productive processes. The correct installation and maintenance of key instrumentation will be essential for the successful implementation of APC and RTO. Otherwise, refineries will face model convergence and tuning problems derived from misreading field values.

ROLE OF REAL-TIME OPTIMIZERS AND APC

Undoubtedly, implementing stand-alone multivariable controllers in refining units is a good alternative to obtain economic incentives. Regardless of the design of the refinery or the needs of the local market, any refinery is susceptible to catalyst deactivation phenomena, equipment fouling, and service supply failures, among others, to maintain the production rate, the APC controllers need to operate in sync with the directions of the Planning and Scheduling team and the goals of rigorous real-time models.

To successfully integrate the LP models with the optimization and control tools, it is necessary to send the different optimization vectors from the planning team to the lower levels and keep the effective communication of operational limits and optimization directions to supervisors/operators simultaneously and immediately. In addition, it is required that the optimization models can understand the existing limitations in the plant reflected in the

APC controller (for example, hydraulic limitations). Otherwise, the increase in the refining margin will be conditional on human intervention, not only on the advanced process control engineers who carry out the appropriate maintenance and tuning of models but also on operators and supervisors who allow APC controllers to operate with the necessary degrees of freedom and under the limits of controlled and manipulated variables appropriate to the design and planning.

Many industries in the downstream sector have opted for cross or hybrid planning schemes where logistics, operational and process objectives are combined to find the sweet spot of maximum performance and minimum expense. For this, the different units are linked through individual APC controllers coordinated by a real-time optimizer that estimates economic benefits and generates critical targets for cut-off temperatures in main separation towers, reaction temperatures, reflux flowrates, and pump-around flowrates.

The optimization of any refinery should consider three relevant aspects:

GENERAL REQUIREMENTS FOR ADVANCED APPLICATIONS:

Not all process units in a refinery require the implementation of APC, some effluent treatment plants or plants where several physical separation processes intervene without an adequate level of automation will be candidates for the implementation of highly complex control applications at the basic/supervisory control layer of the Distributed Control System (DCS). In the case of highly complex plants, with a large number of controlled and manipulated variables that end up forming a matrix of great magnitude and interconnection, with several disturbance variables and a high level of operational flexibility, it will be recommended the implementation of APC, which will allow the future implementation of an optimizer that synchronizes plans of the refinery with the plant, but it should be noted that in cases of control applications of high complexity in the DCS, the ability to align with the refinery planning will not necessarily be lost, it will only be required to make it clear which variables should be controlled and manipulated by the console operators.

CONTROLLER SIZE AND REAL-TIME OPTIMIZER:

For many refineries it is crucial to implement APC controllers with effective gain matrices that are easy to identify and maintain, one ideal premise for APC implementation should be to map the largest number of controlled variables by manipulating the necessary variables, with empirical models, identified under robust mathematical techniques. When trying to integrate APC with a real-time optimizer, the matrix of the different APC controllers must be replicated to the optimizer model, to contemplate for the real-time optimization, all the dynamic and hydraulic effects considered in the empirical models.

MISMATCHES BETWEEN APC AND LP:

If the objectives built into multivariable controllers are different from the objectives built into the LP, the plant will run at a different operating point from the one suggested by the LP or the schedule. If the constraints set in the APC controller differ from the constraints set in the LP model, the optimization in the control system will be incorrect.

REFINING MARGIN USING APC AND LP MODELS

A typical increase in refining margin capture by APC implementation is approximately \$0.3/b. An accurate LP model can improve the refining margin by \$0.5/b. The optimal operation of both technologies in a refinery with a small capacity of 100 -thousand-b/d would mean a capture of \$29 million per year.

OIL MARKET AND REFINING MARGIN

According to the report “Oil 2023 Analysis and Forecast to 2028” published by the International Energy Agency, gasoline consumption in the world will decrease by 0.3 mb/d in the coming years. The downstream companies should adapt their facilities, change unit operating conditions, and implement precise and updated control and optimization systems that allow maximizing the production of high-demand distillates vs. the production of gasoline.

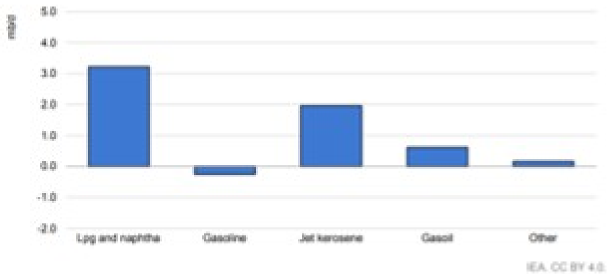

Figure 4. Global cumulative oil demand growth by fuel, 2022-2028 (Data source: International Energy Agency IEA, Oil 2023-Analysis and forecast to 2028)

Diesel is one of the distillates with the greatest optimization options through the development of blending systems for intermediate streams from the atmospheric distillation unit, FCC unit, Hydrocracker unit, Delayed coker unit and HDT unit. Diesel blend optimization models are typically implemented to maximize Diesel production while staying within specification on key properties (e.g distillation points, sulfur).

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Enhanced LP-CRS™

This position paper provides an overview of the Enhanced LP- CRS™ system developed by NGLTech and its potential to address the challenges of associated gas flaring in the oil and gas industry. The paper discusses the environmental impact of flaring and highlights the limitations of existing solutions. It presents the key features of the Enhanced LP-CRS™ system, emphasizing its commercial viability for low-pressure natural gas streams. The paper proposes a global marketing and commercialization strategy, focusing on partnerships, market penetration, demonstration projects, thought leadership, scalable manufacturing, and continuous research and development. The Enhanced LP-CRS™ system aligns with the vision of sustainable practices and environmental stewardship. By optimizing resource utilization and reducing emissions, it contributes to the industry's goals. Moreover, the high performance and low capital expenditure (capex) of the Enhanced LP-CRS™ system result in a short payback period, making emission reduction profitable for end-users rather than an additional cost.

The Enhanced LP-CRS™ system developed by NGLTech addresses the global challenge of reducing emissions and maximizing resource utilization in the oil and gas industry. It offers a commercially viable solution to extract valuable components from low-pressure natural gas, specifically targeting flare gas applications. The system's environmental and economic benefits, technological advancements, and potential for widespread adoption make it a promising solution for achieving sustainability goals.

INTRODUCTION

The global oil and gas (O&G) industry faces a significant challenge in reducing emissions and maximizing the utilization of valuable resources. Associated gas (AG) flaring is a prevalent practice that contributes to greenhouse gas (GHG) emissions, with alarming statistics from the World Bank's Global Gas Flaring Partnership (GGFR) highlighting its environmental impact. Malaysia, among other countries, also contributes to the high levels of AG flaring.

To address this urgent issue, NGLTech has developed the Enhanced LP-CRS™ system, an innovative technology specifically designed to extract valuable NGLs and oil condensates (C3+ components) from low-pressure natural gas streams, with a focus on flare gas applications. This system stands out as the only commercially viable solution optimized for NGL extraction from low- pressure natural gas.

This position paper provides a comprehensive overview of the Enhanced LP- CRS™ system and its potential to revolutionize emission reduction and resource monetization in the O&G industry. It highlights the environmental and economic benefits, showcases unique features and enhancements, and demonstrates alignment with industry objectives.

By examining the commercial potential of the Enhanced LP-CRS™ system, this paper unlocks opportunities for emission reduction and revenue generation. It emphasizes the urgency of the issue, showcases technological advancements, and presents a compelling case for widespread adoption.

Implementing the Enhanced LP-CRS™ system fosters sustainable practices, optimizes resource utilization, and contributes to global emission reduction efforts. This position paper serves as a foundation for industry stakeholders, policymakers, and investors to understand the potential impact and role of the Enhanced LP-CRS™ system in achieving sustainability goals of the O&G industry.

Position Statement

The Enhanced LP-CRS™ system represents a game-changing solution for the reduction of emissions and monetization of flare gas in the oil and gas industry. As virtually the only technology in the world that is both techno-commercially viable for the extraction of oil condensates from low-pressure natural gas streams and specifically tailored for flare gas applications, the Enhanced LP-CRS™ system offers unmatched performance, reliability, and operational advantages. By leveraging the Enhanced LP-CRS™ system, companies can significantly reduce emissions, optimize resource utilization, and unlock new revenue streams. This technology paves the way for sustainable practices and establishes a leadership position in the emission reduction and carbon capture space.

PROBLEM STATEMENT

Monetizing associated gas from oil producing facilities presents significant challenges due to the specific characteristics of the gas and the nature of oil production operations. The key issues surrounding associated gas flaring and the limitations of existing solutions are as follows:

- Low Pressure and High Impurities: Associated gas is typically low pressure and contains high levels of impurities, including significant water vapor content. Processing such gas for monetization requires substantial energy consumption and capital investment.

- Marginal Oil Production Facilities: Oil production facilities have become relatively marginal in size, often producing less than 30 MMscfd and typically short production life of 5 to 10 years. The combination of these issues further complicates the monetization of associated gas, exacerbating techno-economic challenges.

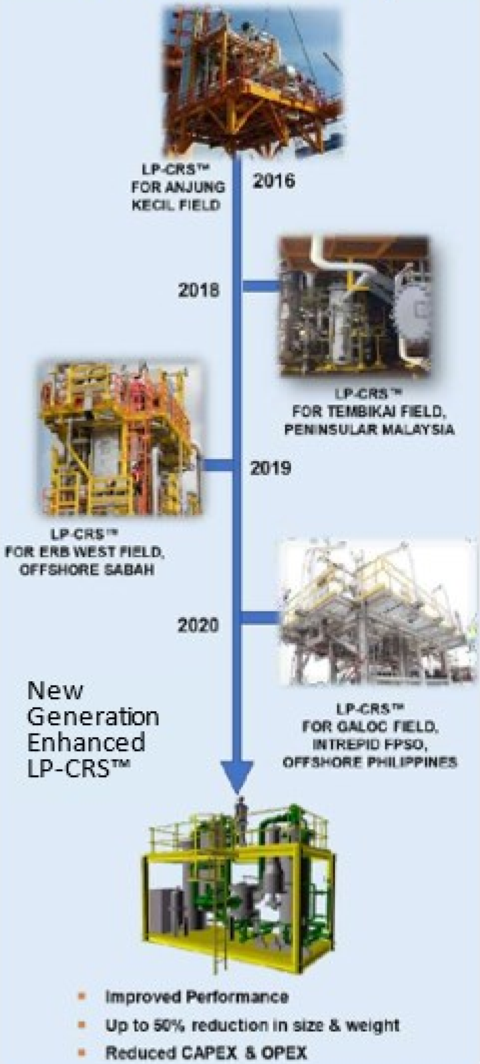
- Limited Solutions for Low Gas Production Rates: Existing gas monetization technologies face obstacles due to the short lifespan of oil-producing fields and the relatively low gas production rates. Justifying the high investments required for commercial viability becomes difficult.

- Cost-Prohibitive Market Solutions: While numerous gas monetization solutions exist, they often involve significant capital investments and long lead times for customized designs. This renders them commercially unviable for many facilities.

- Untapped Potential of C3+ Components: The low-pressure associated gas flared at oil producing facilities contains a high concentration of valuable C3+ components, such as NGLs, LPG, and oil condensates. However, the extraction and monetization of these components remain largely untapped.

Given these challenges and limitations, there is an urgent need for a commercially viable solution that efficiently and economically monetizes low-pressure associated gas while meeting the specific requirements of oil production facilities. The Enhanced LP-CRS™ system developed by NGLTech offers a unique and promising approach to overcome these obstacles. It enables the extraction and monetization of valuable C3+ components while simultaneously reducing flare gas emissions.

Figure 1:
LP-CRS™ Track Record & Development History



The Enhanced LP-CRS™ system, developed based on 8 years of operational experience, is an advanced solution for reducing flare gas emissions and extracting valuable resources. It offers enhanced performance, improved reliability, compact design, standardized units, and container-size footprint. It helps achieve sustainability goals and establish leadership in responsible energy production.

OVERVIEW

The Enhanced LP-CRS™ system represents a significant advancement in addressing the industry-wide challenge of flare gas emission reduction and monetization. Building on our extensive operational experience and lessons learned from deploying the LP-CRS™ system in multiple facilities, we have further refined and optimized the technology to create the Enhanced LP-CRS™ system. This enhanced version incorporates several key improvements, including:

1. Enhanced Performance: Achieves up to 40% reduction in GHG emissions from flaring and allows for the extraction of valuable NGLs, LPGs and/or oil condensates from the gas.

2. Improved Reliability and Operability: Ensures consistent and efficient operation under demanding conditions, providing a higher level of operational stability.

3. Compact and Lightweight Design: Reduced size and weight by up to 50%, facilitating transportation, installation, and integration into existing facilities.

4. Container-Size Footprint: Designed to fit within a standard 20-foot container, simplifying logistics and reducing deployment time.

5. Standardized Nominal Capacity Units: Offers four standardized units, enabling flexibility in operating conditions, high quality components, quick delivery and ability to be relocatable.

These enhancements position the Enhanced LP-CRS™ system as a game-changing solution for flare gas management, allowing companies to achieve sustainability goals, capitalize on valuable resources, and establish leadership in responsible energy production.

The LP-CRS™ system offers unparalleled performance by extracting NGLs from natural gas streams with low GHG emissions, without the need for compression or external refrigeration. Technological advancements, such as compact heat exchangers and a high-speed turbo-expander, ensure efficient NGL extraction and operational stability.

UNPARALLELED PERFORMANCE

The LP-CRS™ is designed to extract Natural Gas Liquids (NGLs) from natural gas streams ranging typically from 20 to 100 barrels/MMscf, with inlet gas pressures as low as 3 barg and a corresponding reduction of greenhouse gas (GHG) emissions by up to 40%. It achieves this without the need for inlet booster compression or external refrigeration nor gas dehydration thus making it a high-performance solution for NGL extraction that is also highly reliable and compact. Apart from the highly reliable turbo-expander, there are no other moving parts in the system, thus the high reliability and operability even under demanding conditions. Rigorous field trials and refinement have further enhanced the system's performance and operational stability.

TECHNOLOGICAL ADVANCEMENTS

The Enhanced LP-CRS™ system incorporates several technological advancements that enable efficient and effective NGL extraction. The system utilizes a combination of compact heat exchangers, separators, and a proprietary compact, high-speed turbo-expander, coupled with NGLTech's patented expansion cooling and evaporative cooling technology.

The combination of this enables deep chilling of the feed gas after pressure boost at the turbo-expander down to temperatures as low as

-40°C, allowing for the separation of heavy ends (C3+) from the NG stream that may be supplied at pressures as low as 3 barg. To inhibit the formation of hydrates, methanol is used as a Hydrates Inhibitor (HI) in the system. Importantly, the methanol is regenerated within the Enhanced LP-CRS™ package, significantly minimizing the need for methanol make-up and ensuring the sustainability of the process. The whole process is self-contained with no external utility requirements apart from nominal amounts of instrument power supply.

These technological advancements, including the proprietary cooling process, compact turbo-expander, and effective hydrate inhibition, are integral to the Enhanced LP-CRS™ system's exceptional performance and efficiency.

The Enhanced LP-CRS™ system by NGLTech offers standardized nominal capacity units, reducing size and weight by up to 50%. It fits into a standard container footprint, ensuring convenience, faster deployment, and easy relocation. Customization options are available for tailored solutions.

Table 1: Standardized Capacity

Model No.	LP-CRS-05	LP-CRS-10	LP-CRS-15	LP-CRS-20
Nominal Design Capacity	3 ~ 7 MMscfd	7 ~ 12 MMscfd	12 ~ 17 MMscfd	17 to 22 MMscfd
Skid Size (W, L, H)	2.3m, 5.3m, 5.0m	2.3m, 6.0m, 5.5m	2.3m, 7.0m, 5.8m	2.3m, 8.0m, 6.0m
Skid Weight (dry)	20,000 kg	25,000 kg	30,000 kg	40,000 kg

STANDARDIZED NOMINAL CAPACITY

In response to the industry's demand for efficient and adaptable solutions, NGLTech has achieved significant reductions in the size and weight of the Enhanced LP-CRS™ system, up to 50% compared to previous iterations.

The Enhanced LP-CRS™ system is specifically engineered to fit within a standard 20 or 40-foot container, depending on its capacity, offering a standardized container-size footprint. This standardized design ensures logistical convenience, reduces deployment time, and enables faster implementation of the technology across various facilities.

The combination of compact, standardized and container size design enables the system to be delivered within 5 months, easily transported and installed, eliminating the need for complex and time- consuming customization. Coupled with the fact that the system is designed for varying inlet flow conditions, this will also enable the units to be easily relocatable after the field production life expires.

Four standardized nominal capacity units for the Enhanced LP-CRS™ system are available and these units provide high quality components with consistent performance. Additionally, NGLTech provides customization options for clients with unique needs, offering tailored solutions to maximize the benefits of the Enhanced LP-CRS™ system in a variety of operational contexts.

APPLICATIONS

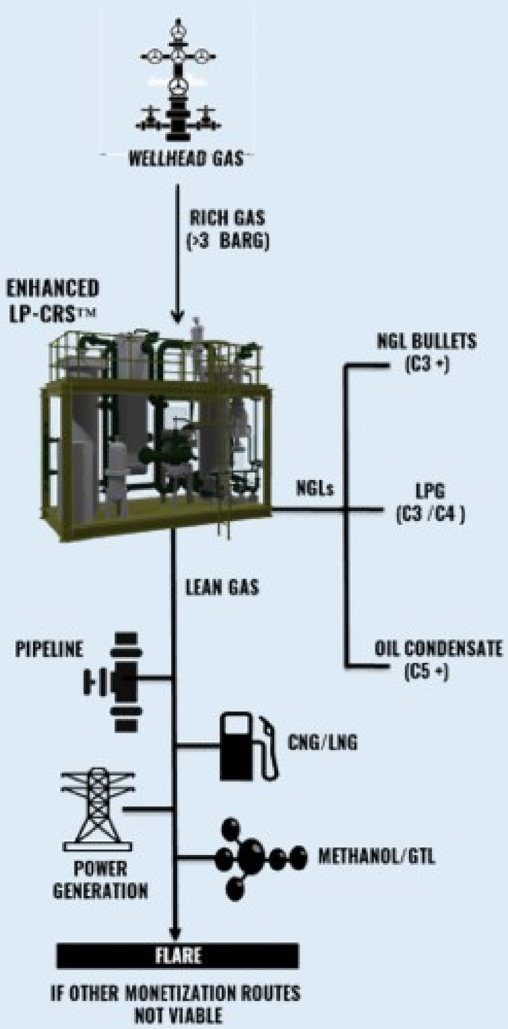
The Enhanced LP-CRS™ system offers versatile applications that address multiple challenges in the oil and gas industry. This cost- effective solution enables the monetization of flare gas by extracting valuable Natural Gas Liquids (NGLs) while simultaneously reducing greenhouse gas (GHG) emissions. The system can efficiently process raw gas to deliver lean dehydrated gas, which can be utilized as fuel gas, production of LNG, CNG or GTL or if no other alternatives are available, safely flared. Irrespective of whether the lean, dehydrated gas exiting the Enhanced LP-CRS™, is utilized or is flared, the resulting CO2 emissions is expected to reduce by up to 40%.

The removal of NGL and dehydration of gas using the Enhanced LP- CRS™ skid is essential for two reasons. First, dry lean gas (similar to typical methane natural gas) is necessary for power generation, CNG, LNG or methanol production. Specifically, natural gas- powered engines, used to drive generators run poorly on rich natural gas. Second, the value of the NGL is much higher than natural gas, and it simply makes good business sense to recover the liquids.

The extracted NGLs offer various possibilities for utilization. They can be co-mingled with the export crude oil stream, enhancing the volume and quality of the crude oil. Alternatively, the NGLs can be stored separately in LPG bullets, providing a valuable product for market distribution. Furthermore, the NGLs can be routed to a condensate stabilizing column, enabling condensate stabilization and extraction of LPG as separate products. This flexibility allows operators to choose the most suitable option based on their specific operational and market requirements.

In addition, the short delivery time of within 5 months for the standard units of the Enhanced LP-CRS™, enable quick reduction of emissions while increasing net revenue as an interim measure, while waiting for full-scale solution deployment which may entail a lead time of more than 2 years. By offering a range of applications, the Enhanced LP-CRS™ system empowers oil and gas facilities to optimize their operations, reduce emissions, and generate additional revenue streams.

Figure 1: Enhanced LP-CRS™ Applications



COMPETITION LANDSCAPE

While there are several technologies available in the market targeted for monetization of flare gas, virtually all are not practical for implementation at production sites at flare gas in the range of 3 MMscfd to 25 MMscfd. An impediment is the fact that oil production facilities in most locations generally have a short production life ranging from 3 to 10 years. The low production rates and low pressure coupled with short production life makes many of conventional technologies, like pipelines, power generation, LNG, CNG, GTL, etc. for monetizing the gas generally economically not viable. Table 2 presents some of the prominent solutions providers in the market.

As indicated in the tabulation, all the solutions mentioned above require relatively high CAPEX and require additional facilities for pressure boost, gas pre-treatment, power supply, among others. Particularly for offshore facilities, these solutions become prohibitive.

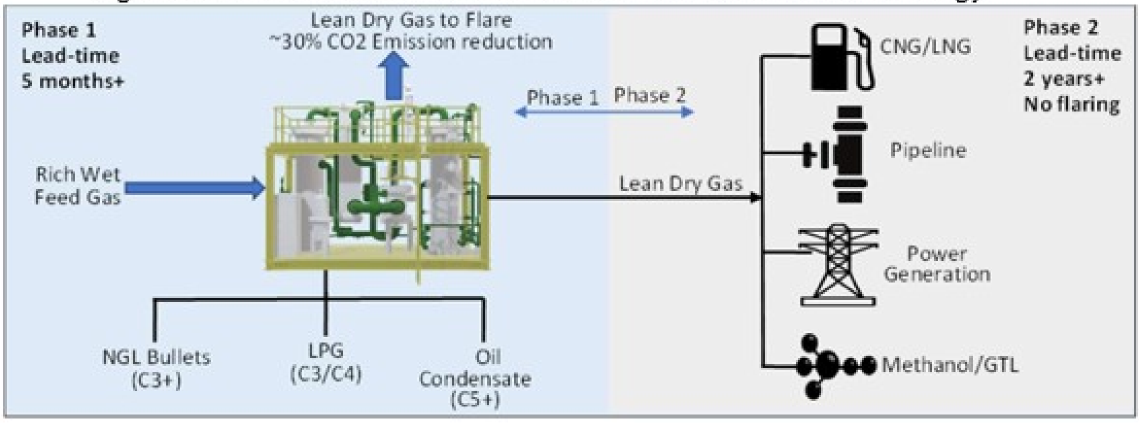
On the other hand, the Enhanced LP-CRS™ packages which come in four.

(4) nominal capacities are significantly smaller, lightweight and with lower capital cost. Even for facilities where the gas is to be monetized for power generation, CNG, LNG, CNG, pipelined, etc. the system is a cost-effective solution for pre-treatment. In addition, the short delivery time of within 5 months for the standard units of the Enhanced LP-CRS™, enable quick reduction of emissions and increasing net revenue as an interim measure, while waiting for full-scale solution deployment which may entail a lead time of more than 2 years.

Table 2: Competing Technologies

Company	*Merits/Demerits*
Aspen E.S. NGL Pro – NGL Extraction	*Requires Compression, power supply, high space, weight & CAPEX*
CleanSmart Membranes– NGL Extraction	*Requires Compression, Pre-treatment, power supply, high space, weight & CAPEX*
Expansion Energy VX Cycle – LNG production	*Requires Compression, Pre-treatment, power supply, high space, weight & CAPEX*
GTUIT – NGL Recovery	*Requires mechanical refrigeration &compression, power supply. high space, weight & CAPEX*
MTRI Membranes – NGL Recovery	*Requires Compression, Pre-treatment, power supply, high space, weight & CAPEX*
Nacelle Membranes – NGL Recovery	*Requires Compression, Pre-treatment, power supply, high space, weight & CAPEX*
Pioneer Energy Gas Processing with Refrigeration	*Requires Compression, Pre-treatment, power supply, high space, weight & CAPEX*

Figure 2: Phased Flare Gas Emission Reduction & Elimination Strategy



MARKET POTENTIAL—GLOBAL FLARING SCENARIO:

The global flaring of associated gas (AG) poses significant environmental and economic challenges. According to data from the World Bank's Global Gas Flaring Partnership (GGFR), AG flaring reached 139 billion cubic meters (bcm) in 2022, resulting in over 350 million tons of CO2-equivalent emissions annually. This extensive flaring activity takes place across approximately 7,000 production sites worldwide, highlighting the urgent need for an effective solution.

Despite global efforts to reduce flaring, gas flaring has remained consistently high, ranging from 140 to 150 bcm between 2010 and 2022. This data demonstrates the magnitude of the problem and emphasizes the potential impact of addressing it. Major flaring nations and their corresponding volumes of gas flared can be observed in Figure 4.

The market potential for the Enhanced LP-CRS™ system is substantial, driven by the increasing emphasis on emissions reduction and sustainable practices in the oil and gas industry. By enabling the extraction of valuable natural gas liquids (NGLs) from low-pressure natural gas streams, this technology not only reduces flaring and greenhouse gas emissions but also presents a significant revenue-generating opportunity.

BUSINESS CASE

The business case for the Enhanced LP-CRS™ system is exceptionally compelling, offering NGLTech a wide range of commercial technology aligns perfectly with industry trends and regulatory requirements, potentially making it a highly sought-after solution.

Figure 3: Historical Global Flaring and Oil Production

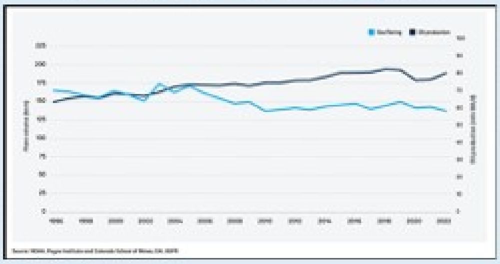
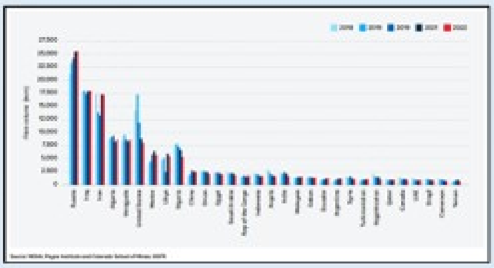


Figure 4: Major Flaring Nations



The global flaring of associated gas is a significant challenge. The Enhanced LP-CRS™ system offers compelling economic benefits, emission reduction, and vast market potential.

The scale of the market opportunity becomes evident when considering the number of production sites worldwide that flare significant amounts of associated gas. Based on data extracted from the World Bank's GGFR, there are approximately 7,000 production sites globally that flare AG, with around 850 production sites flaring more than 3 MMscfd, totaling 8.4 bscfd and with a mean AG flaring rate of 9.87 MMscfd.

Table 3: Business Case for Enhance LP-CRS™

Global Associated Gas (AG) Flaring	
Total number of sites	*7000*
Total daily AG flared	*11.3 bscfd*
Sites flaring more than 3 MMscfd AG	
Number of sites	*850*
Total daily AG flared	*8.4 bscfd*
Mean flaring rate per site	*9.87 MMscfd*
Average Cost of LP-CRS™ for each site	
Average cost of unit	*USD 3.5M*
Average installed cost	*USD 10.5M*
Benefit to end-user	
Average oil condensate extracted per day	*493.5 bopd*
Expected Revenue per year	*USD 12.6M*
Expected CO2 emission reduction	*71,400 tons/yr*
OPEX	*USD0.5mil/yr*
Carbon Tax Savings per year	*-*
Net Revenue per year	*USD 12.1M*

If the initial target for the global commercialization of the Enhanced LP-CRS™ system focuses on facilities flaring more than 3 MMscfd of AG (approximately 850 facilities), the business case becomes compelling. With an average cost estimate of USD 3.5 million (ex-works) and an estimated installed cost of USD 10.5 million for each system, the financial feasibility is evident.

The system's capability to extract an average of 493 barrels of oil condensate per day (bopd) from each production site unlocks incremental revenue of USD 12.1 million, assuming an oil price of USD 70 per barrel. Additionally, the system enables an average reduction of 71,400 tons per year in CO2 emissions, resulting in potential carbon tax savings.

The cumulative financial benefits realized with the installation of the Enhanced LP-CRS™ system are remarkable. The estimated payback period for the technology is approximately 11 months, highlighting its rapid return on investment. The total market potential for the Enhanced LP-CRS™ system is estimated at a staggering USD 2.98 billion, underscoring the vast commercial prospects waiting to be harnessed.

By capitalizing on this unparalleled market potential, NGLTech can position itself as a leader in emission reduction and carbon capture, simultaneously driving substantial financial gains. The Enhanced LP-CRS™ system's capability to deliver exceptional economic returns, reduce emissions, and create a sustainable

future establishes an unmatched business case that presents an irresistible proposition for global adoption.

CONCLUSION

The Enhanced LP-CRS™ system developed by NGLTech offers a promising solution to the challenges of associated gas flaring. By extracting valuable components from low-pressure natural gas streams, the system provides a commercially viable and environmentally friendly approach to monetizing flare gas. It addresses the limitations of existing solutions and presents an opportunity for emission reduction and revenue generation.

The system's high performance and low capex contribute to a short payback period, making emission reduction using the Enhanced LP-CRS™ system profitable for end-users. This economic advantage further incentivizes the adoption of technology and promotes sustainable practices within the oil and gas industry.

In conclusion, the Enhanced LP-CRS™ system has the potential to contribute to emission reduction and resource monetization in the oil and gas industry. Its implementation aligns with sustainability goals, promoting responsible practices, optimizing resource utilization, and offering economic benefits for end-users.

The Enhanced LP-CRS™ system offers a promising solution to associated gas flaring challenges, enabling profitable emission reduction and revenue generation. Its high performance, low capex, and comprehensive marketing strategy position it as a leader in sustainable practices within the industry.

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Some Common Questions on Centrifugal Compressors

Jayanthi Vijay Sarathy

The following article covers attending to some questions related to centrifugal compressors.

LIFE CYCLE COSTS

Most compressor purchasers look at price first, but the lowest capex cost is often the highest cost when you include energy and maintenance cost. How can clients be best helped to understand the life cycle cost and the cost of quality?

The total lifecycle cost of a compressor package comprises of both CAPEX and OPEX costs. As part of CAPEX, the expenses cover manufacturing, transportation, installation & commissioning costs, which is a one-time affair. However, OPEX costs are a variable which involves spare parts and consumables (such as lube oil & nitrogen for sealing), costs due to shipping delays, annual maintenance, associated labour costs, power consumed for operations & costs associated with production loss and equipment failure. OPEX costs can also vary when there are production/ process changes or brownfield expansion/ developments, which puts the operational flexibility and reliability of the turbomachinery under question, and if they can deliver the same performance as before.

Considering a natural gas facility can run over 25 to 30 years, turbomachinery suppliers can focus on coordinating with the client on the benefits and savings accrued in investing better during the design phase as part of CAPEX. Even with a relatively higher cost of CAPEX investments, it allows clients to significantly save on OPEX in the long run.

MONITORING COMPRESSOR PERFORMANCE

In recent years, plant operators look towards outsourcing their compressor monitoring services to third party service providers. Both SaaS and PaaS as part of Industrial IoT / Digital transformation is expected to increase multifold in the next few years primarily focusing on increasing power savings, extended turbomachinery life, operational efficiency, reducing compressor stall and surge avoidance. However, to support AI/ML based solutions, data gathering using improved sensor quality & embedded systems would be a prerequisite.

Compressor performance & monitoring depends on a mix of both hardware and software capabilities and more importantly, how accurate and reliable the signal measurements are to perform diagnostics. For reliable readings, much starts with the design stage where, the location of the instrumentation on the piping and equipment matters as well as how good the support structures and civil foundation is laid. Process instrumentation often suffer from vibrational disturbances & any radio/electromagnetic interference (depending on whether digital or analog) thereby generating noise in the signals. Therefore, sampling frequency & signal integrity needs to be maintained to generate high quality data for any further post processing using software methods. In the author's opinion, AI/ML cannot be used to compensate for poor design and hardware performance.

COMPRESSOR FOUNDATIONS

What are some best practices for centrifugal compressor foundations?

A common issue with compressor operations is resonance which is caused when the operating forced frequencies become equal to the natural frequency. This can be captured in a Campbell diagram. Compressor startup and shutdown are two events, where the possibility of vibrations is the highest as the speed is ramped up or ramped down. The aim of the foundation design must be to transfer the static and dynamic loads uniformly from the baseplate to the grouting and down into the concrete foundation.

API 686 is a design standard that provides guidelines on foundation design. A part of the solution comes from increasing the weight of the concrete foundation by at least up to 3 to 5 times the weight of the total equipment laid on the foundation. The concrete mix should be poured into a neat and clean excavation with zero formed side faces. Typically, increasing the width and length of the foundation is better choice instead of an increase in depth, so as to uniformly distribute the weight of the total equipment. For a design less than 50% of the allowable static load, soil bearing methods can help avoid shear failure.

The foundation needs to be a unified system which has a concrete footing laid on the soil base. Upon which lies a concrete pad and grouting. Jack bolts and anchors are placed through the grouting and concrete pad upon which the compressor I-beam base plate is installed with vibration dampeners. Therefore, to avoid any cracking of the grouting & concrete, which can result in the anchoring getting dislodged, the material quality should be high & cured sufficiently. Cracking of the foundation can also occur when there are no expansion joints since concrete can expand and contract due to temperature changes. Additionally, the shoulder spacing of the grouting must not be excessive to prevent any edge lifting which can cause the grouting to crack.

Grouting is also susceptible to degradation due to oil leakages. Hence provisions such as a drip pan must be provided to avoid any lube oil or seal oil leaking into the crevices of the grouting. The primary purpose of anchor bolts is to prevent any upward movement of the concrete by providing tensile strength. Earlier designs of anchor bolts were a “J” or an “L” shape. But in recent years, the anchor bolting is sunk deeper into the foundation with rounded plates.

COMPRESSOR LUBRICATION

What are some best practices of lubrication in centrifugal compressors?

A lube oil system is a closed loop system consisting of a lube oil reservoir, two oil pumps (running + auxiliary) with their respective lube oil coolers, followed by oil filters, before the lube oil is fed to the compressor bearings and returned to the lube oil reservoir. A common issue is the accumulation of debris, to form a sludge that settles down at the bottom of the lube oil reservoir. Therefore, the base of the reservoir must be sloped to ensure easy drainage. Any dissolved gases in the reservoir lube oil can get degassed for which a vent valve must be provided. Temperature sensors & liquid level gauges must be placed for constant monitoring and prevent overheating during peak operating cycles. The entire contents in the reservoir are circulated typically between 8 to 12 times/hr.

To attend to cold/winter/ startup conditions, where the lube oil viscosity needs to be regulated, a heating coil can be installed in the reservoir with temperature control. Relief valves and check valves need to be installed appropriately to prevent any backflow and prevent any over pressurization. A key parameter is, to maintain the oil pressure which is fed to the bearings. To do so, a bypass line with a pressure control valve from the oil reservoir to the compressor bearings is installed. This ensures any excess flow of lube oil is routed back to the lube oil reservoir. Additionally, a pressure switch is installed at the lube oil pump discharge which upon activation due to low discharge pressure, causes the auxiliary pump to start. However, in the event where despite the auxiliary pump running, if the oil pressure is insufficient, the compressor train needs to shut down.

A typical range of ISO viscosity grades of lube oils used is between 32 to 46. They must have resistance to oxidation as per ASTM D943, a flash point of more than 2000C as per ASTM D92 and should provide more than 5000 hours of operation. Lube oils must also provide resistance to foaming, volatility at high temperatures that can cause reservoir depletion, any corrosion & repel water if it enters the lube oil system.

SMALL BORE PIPING

Small bore piping on compressor discharges have seen many failures. What are some best practices for small bore piping on compressor discharge?

A chief cause for small bore piping to fail is due to mainline piping vibrations. Locations in the mainline which are near piping elements like flow meters, bends, and Tee-bends experience turbulent flow. This causes noise and vibrations which is transmitted to the small-bore piping. Depending on the phase at which these issues are addressed, certain measures can be taken.

During the design phase a Finite Element Analysis (FEA) study can be conducted to check for stress concentration points. The small-bore piping can then be shifted accordingly to locations which have low stress concentration. Alternatively, small bore piping can be welded instead of using threaded connections with higher piping schedule during the design stage.

In case of existing facilities, bracing or supports can be provided to minimize any movement. U-bolts are often used but suffer from lateral movement and need to be used in pairs and spaced sufficiently. Alternatively, strapped clamping with a liner material can also be placed to hold the small-bore piping. A key factor to be considered is the stiffness of the restraint, whereby higher stiffness offers more restraint. Using external supports to would be effective provided the distance between the small-bore piping and external support is short. If no external supports are present, then the small-bore line can be strapped back to the main line.

COMPRESSOR SEALS

What are some best practices in centrifugal compressor seals?

For applications up to about 200 bara pressure, dry gas seals can be considered, but for higher discharge pressures, seal oil systems are preferable. Additionally, a temperature limit of 1800C to 2000C exists for dry gas seals due to the O-ring temperature limitations. Traditionally oil type seals were in vogue, but with time, newer designs incorporated dry gas seals. Dry gas seals offer the advantage of using the process gas itself to provide compressor sealing and thus doing away with the need for seal oil infrastructure. If the centrifugal compressor in question is eligible for retrofitting, oil seals upon reaching its end of useful life can be replaced with dry gas seals which offer better economic advantages, improved efficiency, reliability, and reduced fugitive emissions.

Seal oil systems suffer from process gas diffusing into the seal oil and thereby requires degassing equipment to reuse the seal oil. This represents maintenance, a monetary and inventory loss in the long run. Water content affects the quality of seal oil and causes wear & tear due to drag and deterioration in the sealing ability. During compressor depressurization after a shutdown, chances exist for any debris to escape through the seal and seal sleeve. Additionally, any additives in seal oil tends to precipitate out if the operating temperatures exceed stipulated temperature limits.

To prevent any contamination between seal oil and process gas, nitrogen can be used as a barrier. The pressure differential used to maintain any process gas from mixing with the seal oil is around 3 bar pressure for non-sour applications and can go upto 5 bar for sour gas applications. If the buffer gas pressure exceeds ~5 bar differential pressure, the reverse can happen, i.e., where buffer gas (nitrogen) is ingested into the compressor casing. In such a situation the process gas exported to the client through the gas pipeline would not meet the client's gas purchasing specification.

SEAL OIL SYSTEM

Seal Oil Systems in centrifugal compressors are outdated. Aren’t Dry Gas Seals (DGS) the new norm?

For applications up to about 200 barg pressure, dry gas seals can be considered, but for higher discharge pressures, seal oil systems are preferable. Additionally, a temperature limit of 2000C to 2500C exists for DGS due to the O-ring temperature limitations. However, some of the chief causes of DGS failure are,

1. Dirty Gas – The sealing space between the stationery and rotating surfaces is of the order of 2 to 5 microns. When the sealing gas supplied contains fine debris, you are setting up the seals for failure due to clogging and subsequent wear & tear.

2. Reverse Rotation of Impellers – During a centrifugal compressor shutdown, chances still exist for any reverse rotation of the impellers, if the check valve at the compressor discharge fails causing reversal in process gas leakages. When the dry gas seals are designed for unidirectional rotation, you can take it for granted the seals will wear out faster than expected.

3. Reverse Pressurization – The dry gas seal from the compressor exits to a low-pressure flare (or also a cold flare). With the sealing gas flowing into a common header to join other stream from multiple sources, the possibility of back pressure acting on the sealing system exists, thereby initiating a compressor trip.

4. Depressurization post shutdown – This is far more detrimental especially when the sealing gas contains any sour compounds

such as H_2S and CO_2 or ingress of air. Any contamination of the sealing gas with process gas can cause the mixture to act as a poison to the catalyst bed downstream (if any).

5. In case any moisture or condensable vapours are present, then either we could potentially see liquid condensation or hydrate formation, during a compressor depressurization.

6. O-rings are elastomers & any rapid depressurization can cause the process gas along with hydrates/condensables / H_2S / CO_2 to diffuse/ permeate into the O-rings, causing degradation & deformation.

7. Traditionally oil type seals were in vogue, but with time, newer compressor designs incorporated dry gas seals since the 1990s. But there are legacy compressors which even to this day, still run on seal oil systems.

Therefore, the engineer needs to go on a case-to-case basis, to see what kind of process gas, process conditions & the kind of plant operations, the turbomachinery has to deal with. Also, not all legacy centrifugal compressors can be retrofitted with dry gas seals.

ANTI-SURGE VALVE

What are some the key elements in sizing an Antisurge Valve for a Centrifugal Compressor?

The surge curve is defined as the Surge Limit Line [SLL] and an operating margin is provided [e.g., 10% on flow rate] which is called the surge control line [SCL]. To ensure process safety & avoid mechanical damage, the anti-surge valve (ASV) must be large enough to recycle flow sufficiently. An undersized valve would fail to provide enough recycle flow to keep the compressor operating point away from SCL and SLL. Whereas over sizing the ASV leads to excess gas recycling that can drive the compressor into the choke flow region. Oversized valves also create difficulties in tuning the controllers due to large controller gain values and limited stroke.

To size the anti-surge valve (ASV), the philosophy employed should consider, operating the compressor on the right-hand side of the SCL while also ensuring the operating point does not cross the choke flow line. Towards this, the recycle flow rates across the ASV can be taken to be 1.8 to 2.2 times the surge flow rate.

Traditionally ASVs have linear opening characteristics, though sometimes equal percentage characteristics can be incorporated into the linear trend. Quick opening characteristics are not preferred due to poor throttling characteristics while Equal percentage valves suffer from slow opening during the early travel period. The stroking time of the valve should be ideally less than 2 sec with less than 0.4 sec time delay and no overshoot. The actuator response time must be less than 100 msec and the noise limit is ~85 dBA. The maximum noise level allowed is 110 dBA.

Anti-surge valves are Fail-open [FO] type and should provide stable throttling. Fluid velocities should be less than 0.3 Mach to avoid piping damage and valve rattling. The anti-surge valve can be operated pneumatically or by solenoid action. For valve sizes greater than 16”, a motor operated valve can be used to effectuate the fast-opening requirements. Although the current module provides a methodology to size an ASV which is suitable during Concept/Basic Engineering stage, a compressor dynamic simulation shall be performed with the actual plant layout based on detailed design to verify if the ASV can cater to preventing a surge during start-up & shutdown scenarios.

The final ASV size must be verified in concurrence with the turbomachinery vendor, valve manufacturer, if the ASV can cater to the surge control philosophy employed, slope of the performance curves & polytropic efficiency maps at the choke points.

UNCERTAINTIES IN MEASUREMENTS

How much do uncertainties in measurements affect the surge control system?

Pressure, temperature, and flowrate are the three parameters that go into the anti-surge algorithm. Any uncertainties in these measurements can either overestimate or underestimate the surge protection margins. Underestimating the uncertainties is more detrimental, as it could prevent the anti-surge controller from having sufficient time to respond. Say the flow measuring orifice is near a piping bend, it can create turbulence which causes improper recording of the process parameters.

As per GMRC Guidelines, Ver. 4.3, the In-Practice achievable uncertainties for measured test parameters, suggests the following typical values, 0.3% to 2.0% (full scale) for pressure, 0.30C to 4.00C for temperature, 1% to 3% for flow (clean gas) and 0.2% to 3.0% for density, enthalpy, and isentropic coefficient. Flow measurement uncertainty is affected by installation errors such as insufficient straight run length for fully developed flow, DP meters causing bias errors in flow measurement and pulsating flow in the piping. For accurate pressure measurements, the location of the pressure transmitters must follow ASME PTC 10 standards. For temperature transmitters, apart from incorrect positioning and calibration errors, insufficient insulation causes heat transfer from the piping wall to the temperature probes and hence also needs to meet ASME PTC 10 standards, to reduce uncertainties in temperature measurements.

In case of DP transmitters on the restriction orifice, high static line pressures (> 69 bara) affect the DP measurements and hence need to be calibrated for higher static pressures. DP transmitters also suffer from damping which needs to be minimized for faster response. DP transmitters also have sampling lines which are susceptible to liquid entrapment and hence need to be aligned horizontally to drain any liquids for accurate measurements.

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Petrochemicals x Transportation Fuels: Which will Drive the Strategic Planning of the Downstream Players for Next Years?

Dr. Marcio Wagner da Silva

INTRODUCTION AND CONTEXT

In 1979 Michel Porter wrote the revolutionary article in Harvard Business Review "How Competitive Forces Shapes Strategy", where introduced the concept of the five competitive forces. Through an analysis of these forces in a determined business the players can analyses their competitive positioning while is possible to define some strategies to achieve better competitive positioning.

According to the Michel Porter article, there are five competitive forces that define the competitive positioning of a player in a determined market:

- The supplier power – How is the bargain power of the supplier in relation to the consumers?
- The costumer power – How is the flexibility and alternatives of the customer in relation to your services and products?
- Substitute products and services – There are substitute products or services capable of easily substituting the products/ services currently offered?
- The threat of new entrants – How difficult is for a new entrant to join the market?
- Rivalry between the existing players - How aggressively the players are competing in the market?

Figure 1 presents the relation of the five competitive forces for a determined market.

According to the positioning of a player in relation of each one of the competitive forces, the players can define their strategies to improve the competitive positioning reinforcing the point considered the weakness.

The current scenario presents great challenges to the crude oil refining industry, prices volatility of raw material, pressure from

Figure 1 – The Five Competitive Forces (PORTER, M., 1979)

society to reduce environmental impacts and refining margins increasingly lower. The drastic reduction of sulfur content in the final product, lead refiners to look for alternatives to reduce the sulfur content in the intermediate streams, in this business environment it's possible to imagine how the Porter's competitive forces to the downstream industry.

THE PORTER'S COMPETITIVE FORCES IN THE DOWNSTREAM INDUSTRY

Considering the shown in Figure 1, it's possible to analyze the five competitive forces listed by Michael Porter to the downstream industry.

- Bargain power of Suppliers – The main supplier of the downstream industry is the crude oil producers, normally the refiners have low bargain power because the crude oil price is defined by a several factors, but refiners relying on flexible refining hardware can face advantages once are capable to processing heavier and discounted crudes that present lower costs. In other words, adequate bottom barrel conversion capacity can offer a significant competitive advantage to the refiners. Over the years some companies have developed integrated operations to minimize the exposition of the variation of crude oil prices. Regarding the other suppliers, normally the refiners are considered great costumers and these suppliers tends to present low bargain power, in normal conditions, they do not represent a great threat, in this case, the most integrated players can get competitive advantage. The operational efficiency is another fundamental characteristic, refiners capable to reduce the operating costs can acquire more resilience face to the variations of crude oil prices, the operating costs reduction is especially related with energy efficiency of the refining hardware, once more than 60 % of the operating costs are related to energy consumption.

- Bargain power of buyers – The costumers have low bargain power in the downstream industry once is still difficult to found energy sources in quantity and quality capable to substitute the crude oil derivatives, of course, in markets with high quantity of players, the competitiveness can offer alternatives to the costumers, but it's difficult to achieve great gap of prices in a commodity market. Despite this, the public opinion over the downstream industry is increasingly important and have potential to change the energy market, an example is the growing trend of energy transition efforts demanded by the society, requiring a transition to low carbon energy sources.

- Threat of new entrants – Due to the high capital requirements, it's hard to face the new entrant threat in the downstream industry, but this threat can always be considered mainly due to government interventions and the attractiveness of the local markets.

- Rivalry among existing competitors – This is a great concern in the downstream industry, the great number of players and the standardization of the products create great pressure over the refining margins, to overcome this the refiners have look for improve their operational efficiency, but it's normally quickly followed by the other players, reducing the profitability in the market.

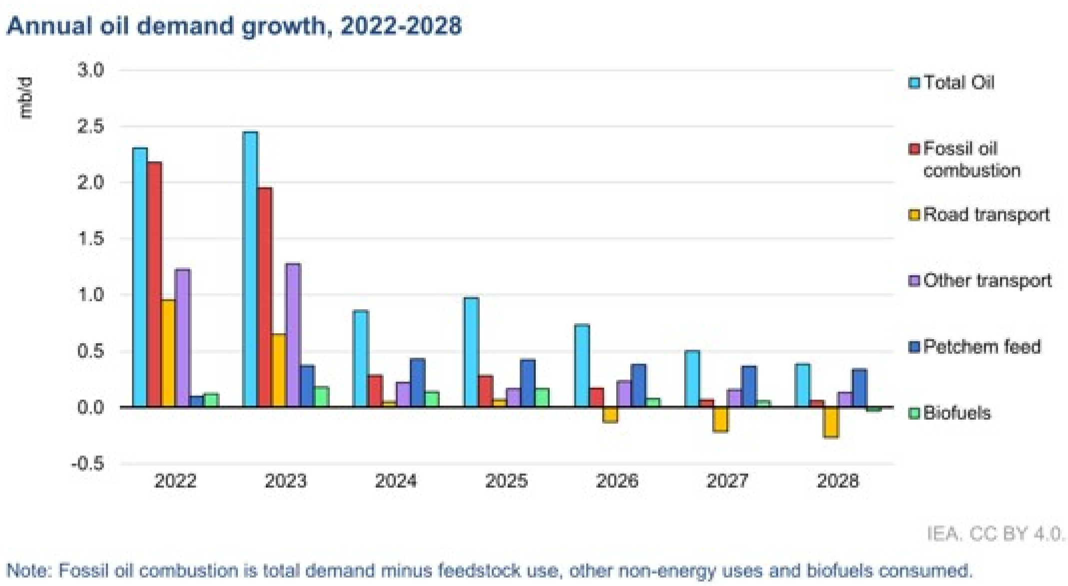

Figure 2 – Forecast for Petrochemical Feedstock/Transportation Fuels Demand for Next Years (IEA, 2023)

- Threat of substitute products and services – Nowadays, this is the great threat to the players of the downstream industry. 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 2, based on data from International Energy Agency (IEA).

According to Figure 2, the transportation fuels demand represents close to five times the demand by petrochemicals as well as a focus on transportation fuels of the current refining hardware. Despite these data, is observed a strong trend of reduction in transportation fuels demand followed by a growing market of petrochemicals. Still according to IEA data, presented in Figure 3, is expected a relevant growth in the petrochemical's participation in the global oil demand.

The improvement in fuel efficiency, growing market of electric vehicles tends to decline the participation of transportation fuels in the global crude oil demand. Figure 4 presents the growth of electric vehicles in the last years in the global market.

Further the electrification of the automobiles, new technologies like additive manufacturing (3D printing) has the potential to produce great impact to the transportation demands, leading to even more impact over the transportation fuels demand the growing trend of vehicles sharing services like Uber has great potential to destroy demand in the downstream industry. Another threat is the growing participation of renewable raw material in the crude oil refineries, in a response of the society requirement to energy transition efforts. In the last months some important players have announced the conversion of some crude oil refineries into renewable processing plants while other players and technology developers announce the production of diesel and jet fuel applying co-processing of crude oil and renewable raw material like HVGO in some refineries around the world.

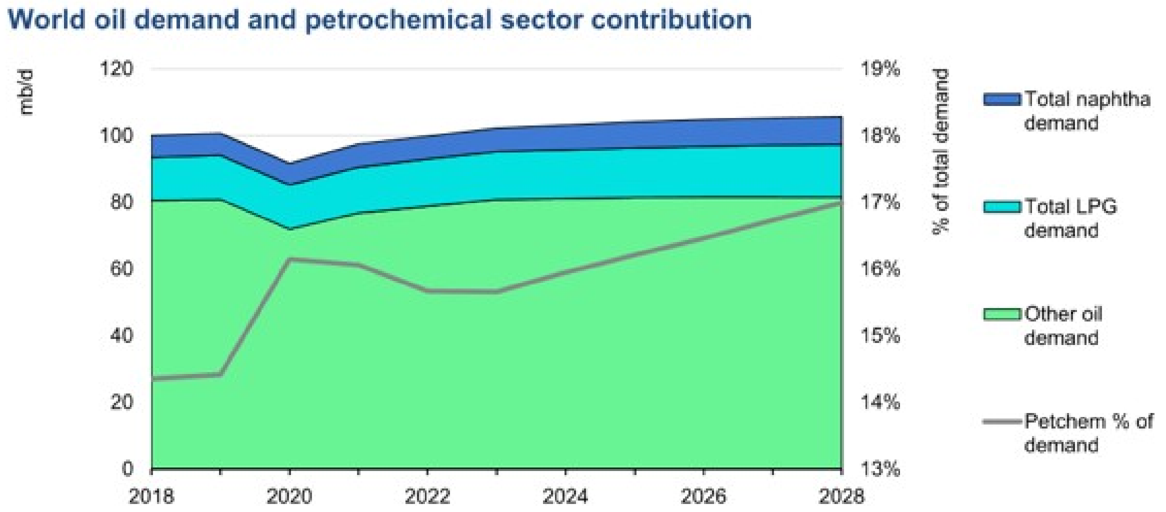

Figure 3 – Change in the Profile of Global Crude Oil Demand (IEA, 2023)

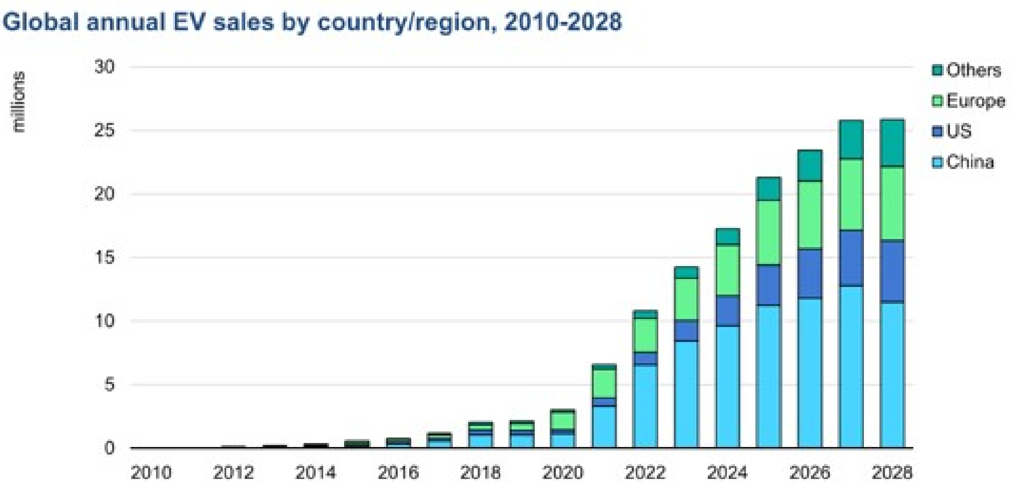

Figure 4 – Growth of the Electric Vehicles Fleet over the Years (Global EVs Outlook 2023, IEA)

Another deep change in the downstream sector that reinforces the necessity of high conversion refining hardware is the IMO 2020. Restrictive regulations like IMO 2020 raised, even more, the pressure over refiners with low bottom barrel conversion capacity once requires higher capacity to add value to residual streams, especially related to sulfur content that was reduced from 3,5 % (in mass) to 0,5 %. Refiners with easy access to low sulfur crude oils present relative competitive advantage in this scenario, these players can rely on relatively low-cost residue upgrading technologies to produce the new marine fuel oil (Bunker) as carbon rejection technologies (Solvent Deasphalting, Delayed Coking, etc.), but they are the minority in the market. The most part of the players need to look for sources of low sulfur crudes, which present higher cost putting under pressure his refining margins or look for deep bottom barrel conversion technologies to ensure more value addition to processed crude oils and avoid to loss competitiveness in the downstream market. For these refiners, deepest residue upgrading like hydrocracking technologies can offer great operational flexibility, despite the high capital spending. In this scenario, with necessity to higher value addition to bottom barrel stream and growing market of petrochemicals, refiners with adequate bottom barrel conversion capacity can achieve great competitive advantage in the downstream industry.

Based on the description above it's possible to apply the article published by W. Chan Kim and Renée Mauborge called "Blue Ocean Strategy" in Harvard Business Review, to classify the competitive markets in the downstream industry. In this article the authors define the conventional market as a red ocean where the players tend to compete in the existing market focusing on defeat competitors through the exploration of existing demand, leading to low differentiation and low profitability. The blue ocean is characterized by look for space in non-explored (or few explored markets), creating and developing new demands and reaching differentiation, this model can be applied (with some specificities once is a commodity market) to the downstream industry, considering the traditional transportation fuels refineries and the petrochemical sector.

Due his characteristics, the transportation fuels market can be imagined like the red ocean, where the margins tend to be low and under high competition between the players with low differentiation capacity. On the other side the petrochemicals sector can be faced like the blue ocean where few players are able to meet

the market in competitive conditions, higher refining margins, and significant differentiation in relation to refiners dedicated to transportation fuels market. Figure 5 presents the basic concept of blue ocean strategy in comparison with the traditional red ocean where the players fight to market share with low margins.

As presented above, the market forecasts indicates that the refiners able to maximize petrochemicals against transportation fuels can achieve highlighted economic performance in short term, in this sense, the crude oil to chemicals technologies can offer even more competitive advantage to the refiners with capacity of capital investment.

Can be difficult to some people to understand the term "differentiation" in the downstream

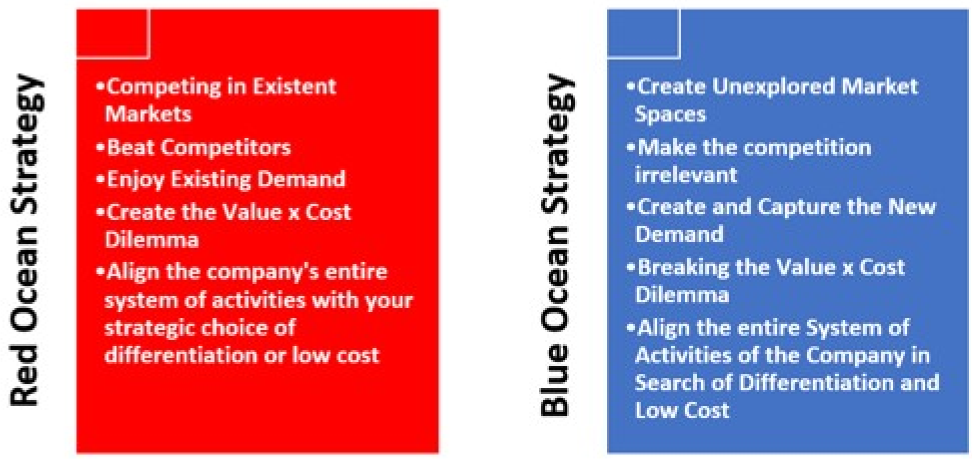

Figure 5 – Differences between Blue and Red Ocean Strategies (KIM & MAUBORGNE, 2004)

industry once this is a market that deal with commodities, but the differentiation here is related to the capacity to reach more added value to the processed crude oil and as presented above, nowadays this is translated in the capacity to maximize the petrochemicals yield, creating differentiation between integrated and non-integrated players.

CHANGING THE FOCUS – MORE PETROCHEMICALS AND LESS FUELS

In this business environment it's possible to adapt the Anssoff Matrix to considering the contraction profile of transportation fuels market to analyze the available alternatives to the downstream players, the Anssof Matrix is presented in Figure 6.

In Figure 6 the current position of downstream players is focused on transportation fuels demand that presents a contraction profile as aforementioned. In this scenario there are three alternatives to the players:

1 – Look for new clients – This alternative seems attractive at first look, but the stricter regulations and trend of reduction in the consumption create great pressure over the consumption of fossil fuels. The major consumers of transportation fuels are still the in development economies like Brazil, Mexico, and India but the most efficient engines and substitute technologies like hybrid and electric vehicles tends to reduce the market growth even in these countries;

2 – Offer a new Value Addition – Face the reduction in transportation fuels, an attractive strategy to the downstream sector is to offer a new proposed value to the market through higher value addition to the processed crude oils as well as needed materials to the society with lower environmental footprint than fossil fuels. The petrochemical intermediates have higher added value to refiners and growing demand as data, the substitution of steel is some engineering materials is an interesting way to ensure market to petrochemicals in short term, in this sense, the refiners can change the production focus from transportation fuels to petrochemicals, especially in markets like Asia and Europe where the falling in transportation fuels demand is most significant. Beyond the petrochemicals, the capacity to add value to bottom barrels streams appears like a competitive advantage.

3 – New Clients and New Value Addition – Strategically, this alternative seems the right way to follow, mainly to refiners with the most complex refining hardware. Through the promotion of closer integration with petrochemical sector, the refiners not only offer a higher proposed value to the clients and society but can reach a new range of costumers capable to ensure higher added value to the processed crude oils and lower operational costs through available synergies between refining and petrochemical assets.

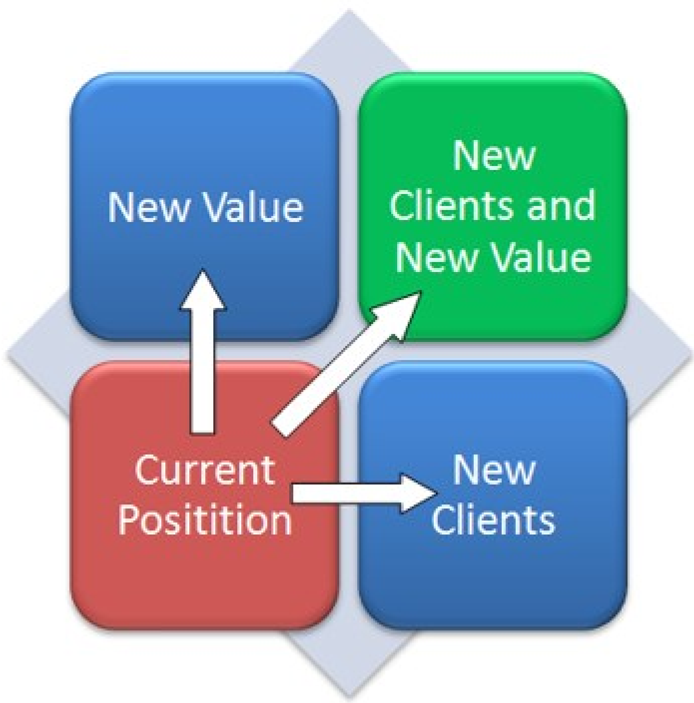

Figure 6 – Adapted Ansoff Matrix to an in Contraction Market (Based on ROGERS, 2016)

Another strategic planning model which can be applied to the current scenario of the downstream industry is the PESTEL model. This theory applies six fundamental factors which influence the strategy of any business, these factors are:

- Political – The growing pressure to minimize the environmental footprint of the energetic matrix is leading the governments raise the pressure over the downstream players to reduce their carbon intensity, this is translated into an increasingly hostile scenario to the fossil fuels.
- Economic – The higher added value of petrochemicals in comparison with transportation fuels as well as their higher potential of circularity are important drivers to consider in the strategic planning of the downstream players. The question here is the capital intensity required to make the change of a refining asset from transportation fuels to petrochemicals.
- Social – The impact of the energy industry in the communities is high, considering the higher circularity of the petrochemicals against the fuels and the higher economic returns it's possible to imagine a better social benefits for the society considering the change of the production focus in the downstream sector from fuels to petrochemicals or non-energetic derivatives like lubricants depending on the local policies of the consumer market.
- Technological – The refining and petrochemical industries are well technologically developed, and the commercial technologies are totally able to allow closer integration between refining and petrochemical assets. The challenge here is related to the production of green hydrogen in large scale to minimize the carbon intensity of the downstream sector.
- Environmental – Again, the environmental factor favors the petrochemical sector due the higher potential of circularity than the transportation fuels.
- Legal – We are seeing a growing pressure over the downstream players to reduce the carbon intensity of their operations which is translated to stricter regulations, this factor overlaps with the political factor which favors the adoption of petrochemicals against fuels as production focus.

A simplified analysis based on the PESTEL model can indicate the favorability of changing the production focus from fossil fuels to petrochemicals, this is summarized in Figure 7.

At this point it's important to explain that the energy transition is an incremental and not disruptive process. The change in the production focus from fuels to petrochemicals is not a easy task and the capital requirement is a barrier among the downstream players, our point of view is that the players with capital power and inserted in more economic developed markets will change quickly from fuels to petrochemicals while the players with less access to capital and based in in developing economies will keep their focus in transportation fuels.

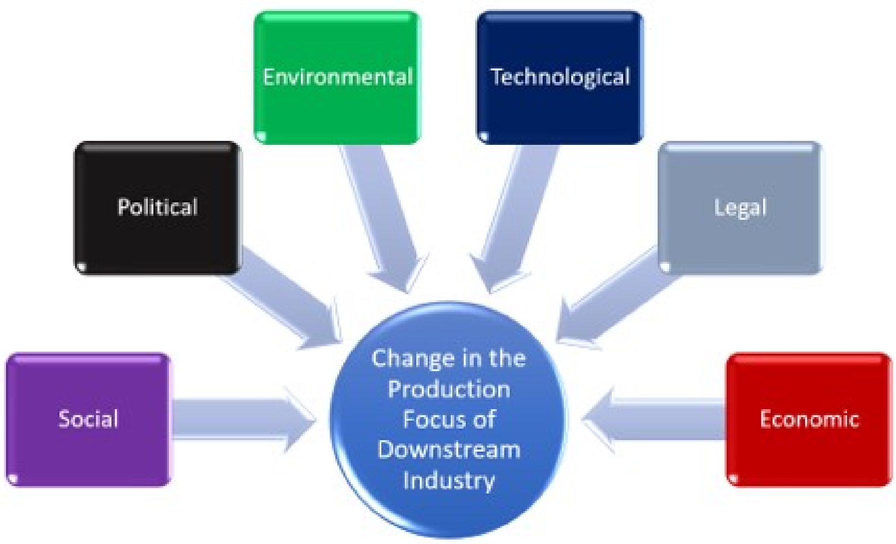

Figure 7 – PESTEL analysis for the Change in the Production Focus of the Downstream Players

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

PETROCHEMICAL AND REFINING INTEGRATION AS DIFFERENTIATION STRATEGY

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 leads to possibilities of synergies capable of reducing operational costs and add value to derivatives produced in the refineries.

Figure 8 presents a block diagram that shows some integration possibilities between refining processes and the petrochemical industry.

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, pyrolysis 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

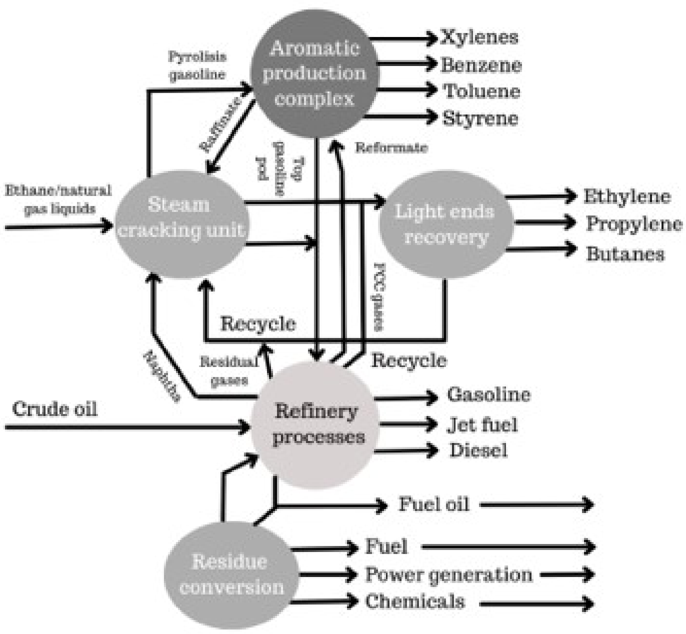

Figure 8 – Synergies between Refining and Petrochemical Processes

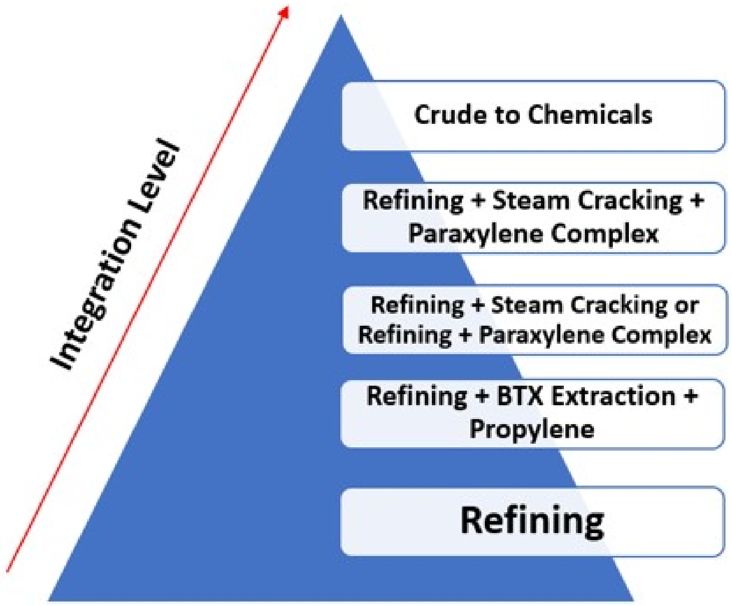

Figure 9 – Petrochemical Integration Levels (IHS Markit, 2018)

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 9.

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

CRUDE OIL TO CHEMICALS STRATEGY

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 10.

The process presented in Figure 10 is based on the quality of the crude oil and deep conversion technologies like High Severity or petrochemical FCC units and deep hydrocracking technologies. The processed crude oil is light with low residual carbon that is a common characteristic in 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. An example of FCC technology developed to maximize the production of petrochemical intermediates is the PetroFCC™ process by UOP Company, this process combines a petrochemical FCC and separation processes optimized to produce raw materials to the petrochemical process plants, as presented in Figure 11. Other available technologies are the HS-FCC™ process commercialized by Axens Company, and INDMAX™ process licensed by Lummus Company.

To petrochemical FCC units, the reaction temperature reaches 600 oC and higher catalyst circulation rate raises the gases production, which requires a scaling up of gas separation section. The higher thermal demand makes it advantageous to operate the catalyst regenerator in total combustion mode leading to the necessity of installation a catalyst cooler system.

The installation of petrochemical catalytic cracking units requires a deep economic study considering the high capital investment and higher operational costs; however, some forecasts indicate growth of 4,0 % per year to the market of petrochemical intermediates until 2025. In this scenario can be attractive the capital investment aiming to raise the market share in the petrochemical sector, allowing then a favorable competitive positioning to the refiner, through the maximization of petrochemical intermediates. Figure 12 presents a block diagram showing a case study demonstrating how the petrochemical FCC unit, in this case the INDMAX™ technology by Lummus Company, can maximize the yield of petrochemicals in the refining hardware.

In refining hardware with conventional FCC units, further than the higher temperature and catalyst circulation rates, it's possible to apply the addition of catalysts additives like the zeolitic material ZSM-5 that can raise the olefins yield close to 9,0% in some cases when compared with the original catalyst. This alternative raises the operational costs, however, as aforementioned can be economically attractive considering the petrochemical market forecasts.

Installation of catalyst cooler system raises the process unit profitability through the total conversion enhancement and selectivity to noblest products as propylene and naphtha against gases and coke production. The catalyst cooler is necessary when the unit is designed to operate under total combustion mode due to the higher heat release rate as presented below.

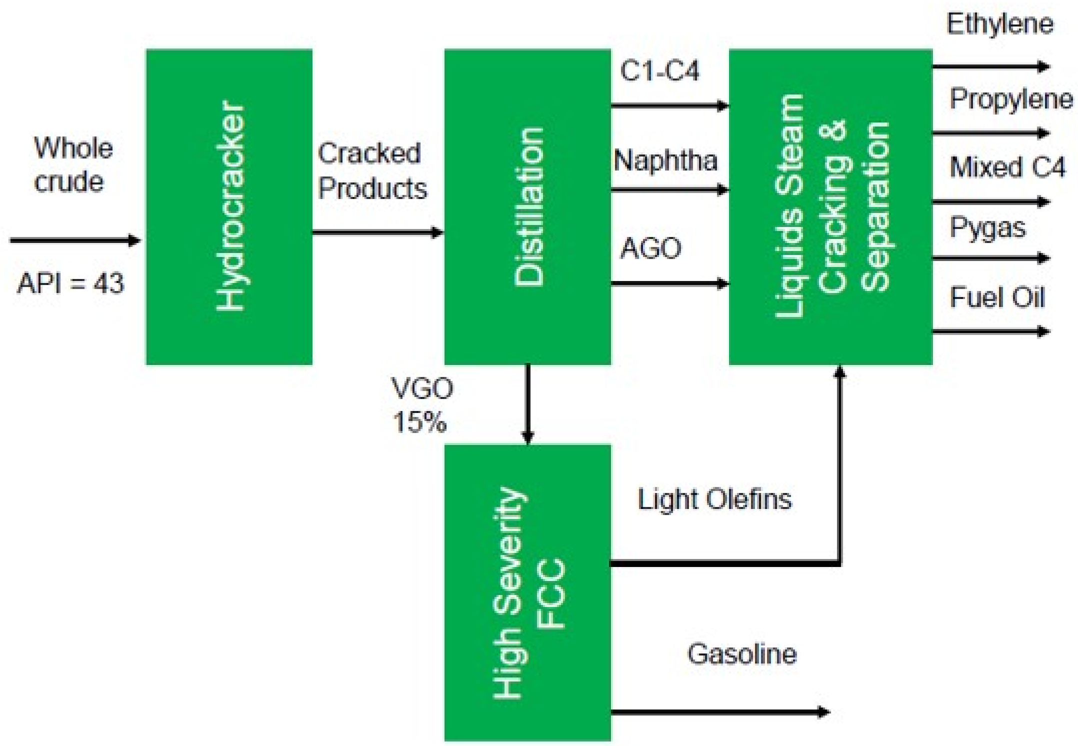

Figure 10 – Saudi Aramco Crude Oil to Chemicals Concept (IHS Markit, 2017)

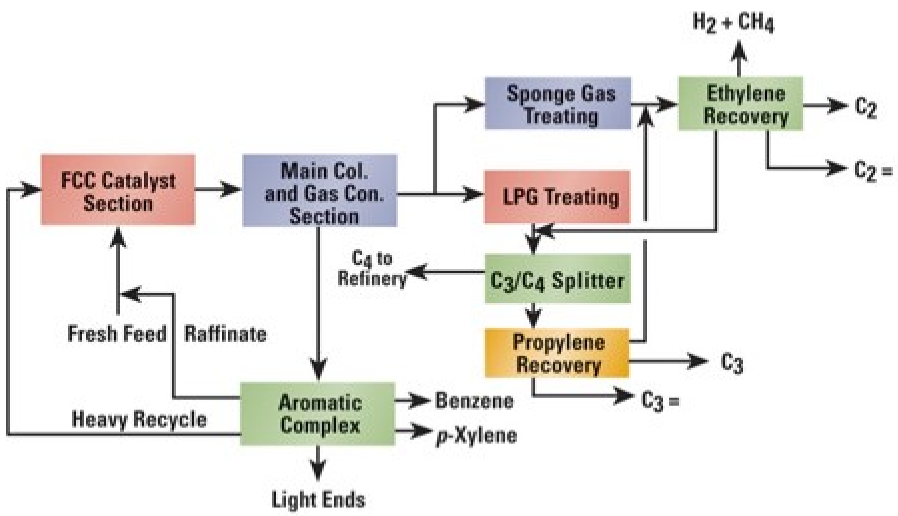

Figure 11 – PetroFCC™ Process Technology by UOP Company.

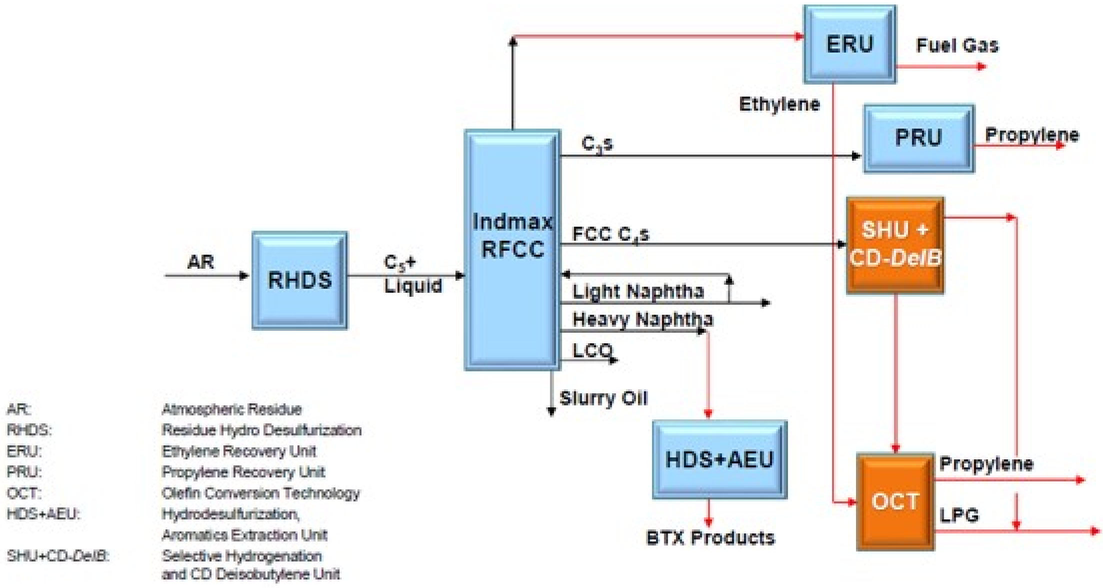

Figure 12 – Olefins Maximization in the Refining Hardware with INDMAX™ FCC Technology by Chevron Lummus Global Company (SANIN, A.K., 2017)

$C + ½ O_2 \rightarrow CO$ (Partial Combustion) $\Delta H = -27$ kcal/mol

$C + O_2 \rightarrow CO_2$ (Total Combustion) $\Delta H = -94$ kcal/mol

In this case, the temperature of the regeneration vessel can reach values close to 760 oC, leading to higher risks of catalyst damage which is minimized through catalyst cooler installation. The option by the total combustion mode needs to consider the refinery thermal balance, once, in this case, will not the possibility to produce steam in the CO boiler, furthermore, the higher temperature in the regenerator requires materials with noblest metallurgy, this significantly raises the installation costs of these units which can be prohibitive to some refiners with restricted capital access.

Another key refining technology to crude oil to chemicals refineries is the hydrocraking units. Despite the high performance, the fixed bed hydrocracking technologies can be not economically effective to treat crude oils directly cue to the possibility of short operating lifecycle. Technologies that use ebullated bed reactors and continuum catalyst replacement allow higher campaign period and higher conversion rates, among these technologies the most known are the H-Oil and Hyvahl™ technologies developed by Axens Company, the LC-Fining Process by Chevron-Lummus, and the Hycon™ process by Shell Global Solutions. These reactors operate at temperatures above 450 oC and pressures until 250 bar.

An improvement in relation of ebullated bed technologies is the slurry phase reactors, which can achieve conversions higher than 95 %. In this case, the main available technologies are the HDH™ process (Hydrocracking-Distillation-Hydrotreatment), developed by PDVSA-Intevep, VEBA-Combicracking Process (VCC)™ commercialized by KBR Company, the EST™ process (Eni Slurry Technology) developed by Italian state oil company ENI, and the Uniflex™ technology developed by UOP Company. Figure 13 presents a basic process flow diagram for the VCC™ technology by KBR Company.

In the slurry phase hydrocracking units, the catalysts in injected with the feedstock and activated in situ while the reactions are carried out in slurry phase reactors, minimizing the reactivation issue, and ensuring higher conversions and operating lifecycle. Figure 14 presents a basic process flow diagram for the Uniflex™ slurry hydrocracking technology by UOP Company.

Other commercial technologies to slurry hydrocracking process are the LC-Slurry™ technology developed by Chevron Lummus Company and the Microcat-RC™ process by Exxon Mobil Company.

For this side, the Steam cracking process has a fundamental role in the petrochemical industry, nowadays the most part of light olefins light ethylene and propylene is produced through steam cracking route. Steam cracking consists of a thermal cracking process that can use gas or naphtha to produce olefins.

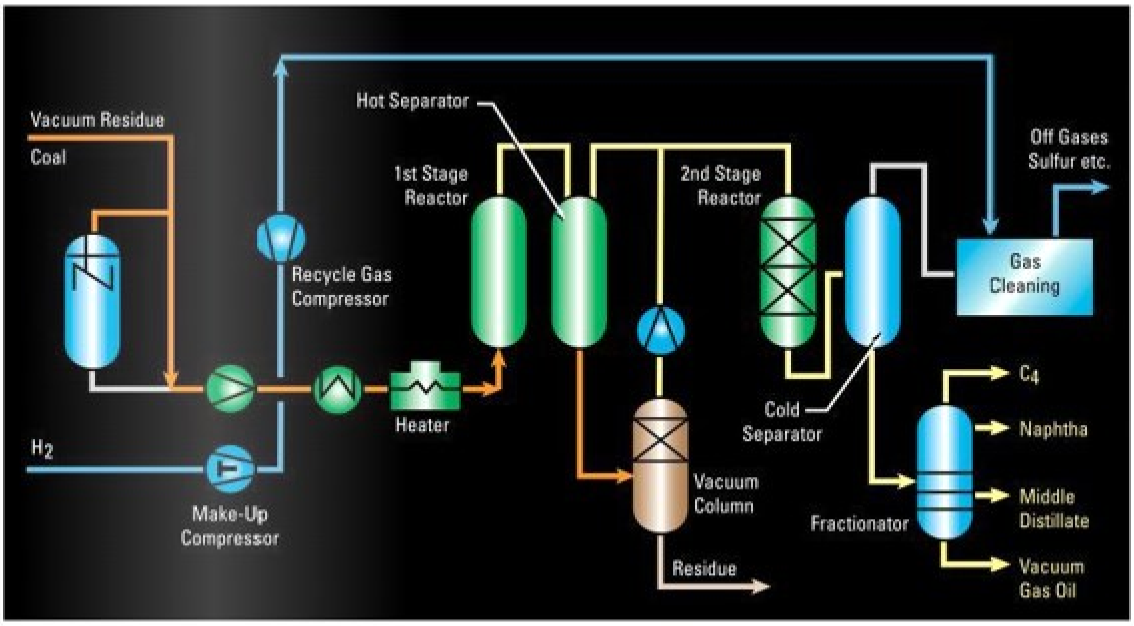

Figure 13 – Basic Process Arrangement for VCC™ Slurry Hydrocracking by KBR Company (KBR Company, 2019)

The naphtha to steam cracking is composed basically of straight run naphtha from crude oil distillation units, normally to meet the requirements as petrochemical naphtha the stream needs to present high paraffin content (higher than 66 %).

Due to his relevance, great technology developers have dedicated their efforts to improve the steam cracking technologies over the years, especially related to the steam cracking furnaces. Companies like Stone & Webster, Lummus, KBR, Linde, and Technip develop technologies to steam cracking process. One of the most known steam cracking technologies is the SRT™ process (Short Residence Time), developed by Lummus Company, that alternative as feedstock to steam crackers.

applies a reduce residence time to minimize the coking process and ensure higher operational lifecycle. Another commercial technology dedicated to optimizing the yield of ethylene is the SCORE™ technology developed by KBR and ExxonMobil Companies which combines a selective steam cracking furnace with high performance olefins recovery section.

The cracking reactions occur in the furnace tubes, the main concern and limitation to operating lifecycle of steam cracking units is the coke formation in the furnace tubes. The reactions carry out under high temperatures, between 500 oC to 700 oC according to the characteristics of the feed. For heavier feeds like gas oil, is applied lower temperature

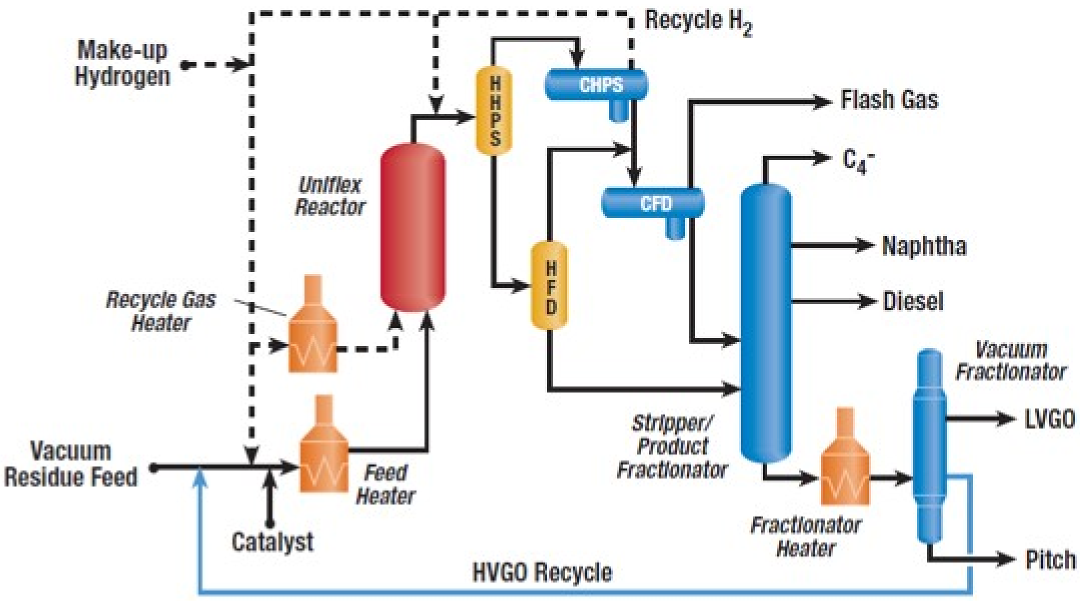

Figure 14 – Process Flow Diagram for Uniflex™ Slurry Phase Hydrocracking Technology by UOP Company (UOP Company, 2019).

aiming to minimize the coke formation, the combination of high temperatures and low residence time are the main characteristic of the steam cracking process. Despite be possible to operate with naphtha, nowadays the steam cracking operators have chosen to operate with ethane or LPG against naphtha due to the competitive prices related to the new sources of NGL (Natural Gas Liquid), despite this trend over the last years, in markets where is observed a gasoline surplus, naphtha can still an attractive alternative as feedstock to steam crackers.

According to some forecasts, the demand for propylene will rise from 130 million metric tons in 2020 to around 190 million metric tons in 2030. Facing the increasingly light feed to refineries and steam cracking units which tends to favor the ethylene production in detriment of propylene, the propylene demand tends to be supplied by on-purpose propylene production routes like propane dehydrogenation, methanol to olefins (MTO), and olefins metathesis.

As quoted above, some technology developers are dedicating their efforts to develop commercial crude to chemicals refineries. Figure 15 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 16 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 17 presents a highly integrated refining configuration capable of converting crude oil to petrochemicals developed by UOP Company.

As presented in Figure 17, the production focus changes 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 under pressure.

Figure 18 presents a comparison between the petrochemicals yields of traditional refineries, a benchmark integrated refinery and Hengli crude to chemicals complex, according to data from IHS market.

Analyzing Figure 18 it's possible to note the higher added value reached in crude to chemicals refineries when compared even with highly integrated refineries. Based on data from 2019 the total capital investments

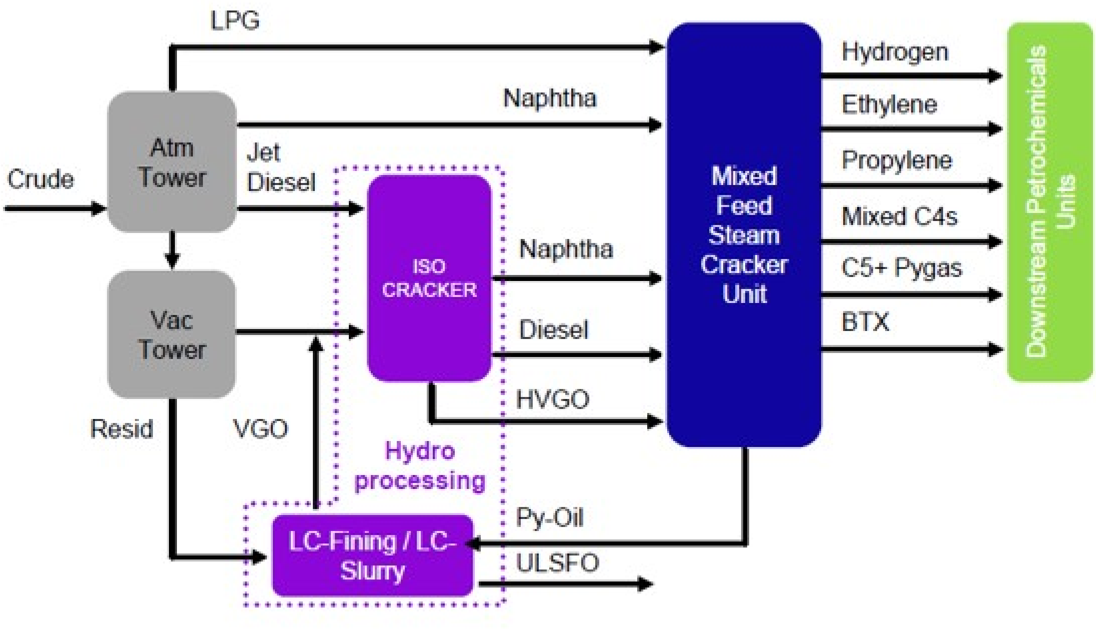

Figure 15 – Crude to Chemicals Concept by Chevron Lummus Company (Chevron Lummus Global Company, 2019)

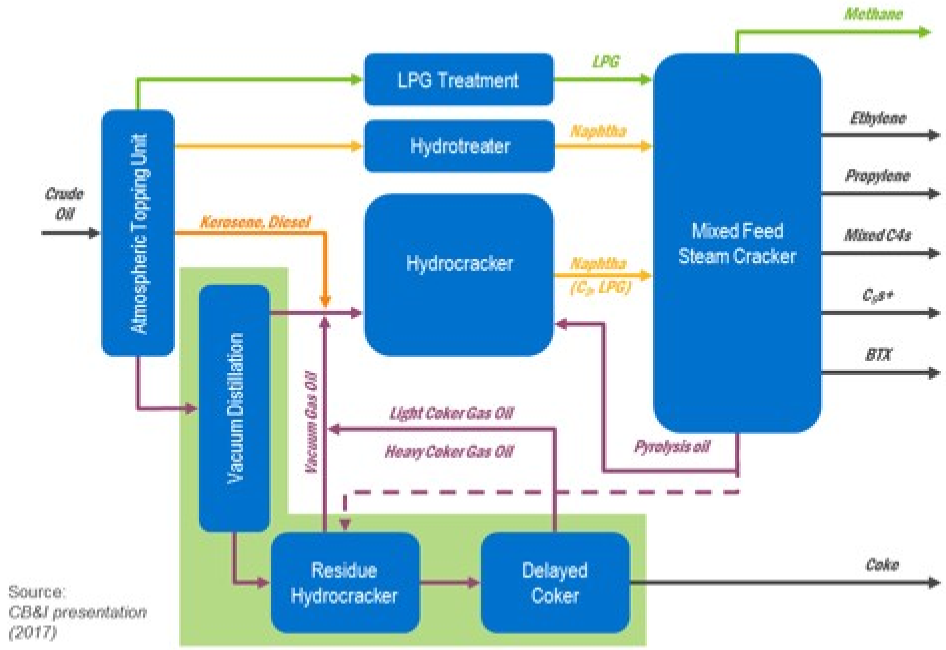

Figure 16 – Crude to Chemicals Concept by Chevron Lummus Company (Nexant Company, 2018)

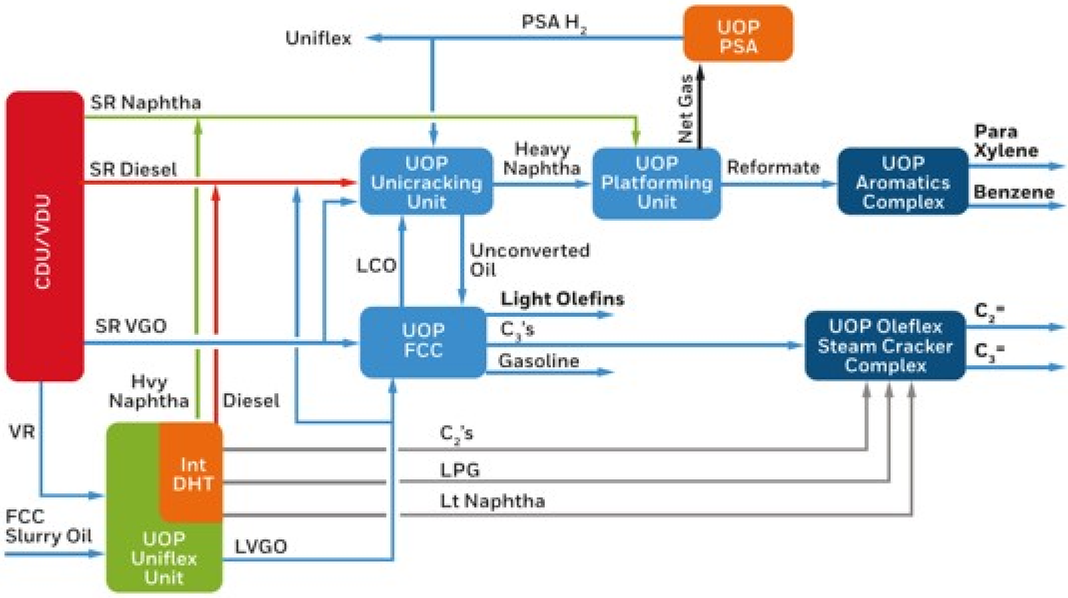

Figure 17 – Integrated Refining Configuration Based in Crude to Chemicals Concept by UOP Company.

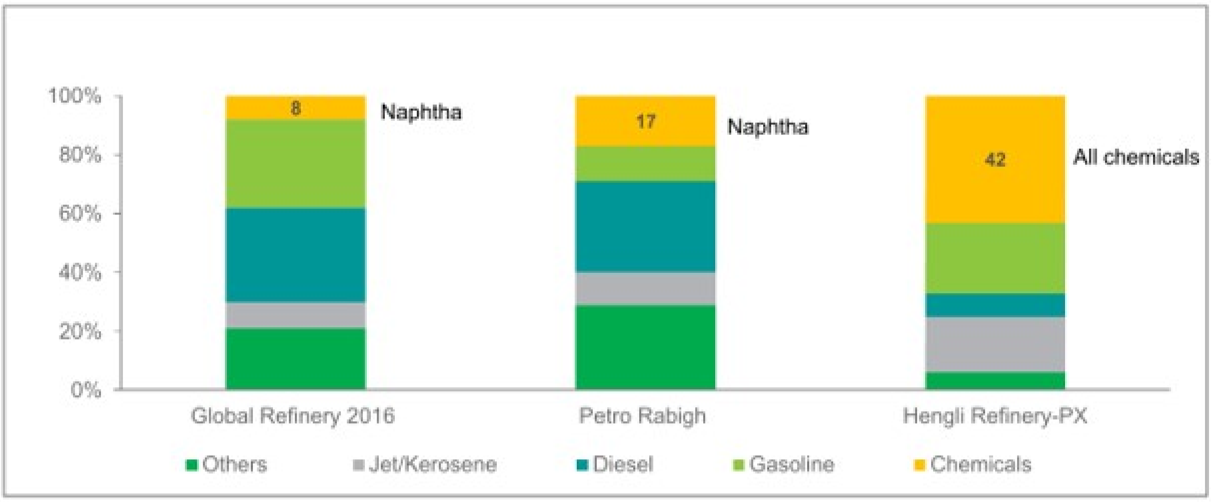

Figure 18 – Petrochemicals Yield Comparison (IHS Markit, 2018)

in crude to chemicals refineries is 300 billion US dollars and 64 % of this investment was made by Asian players, to reinforce this trend Figure 19 present a comparison between the relation of crude oil distillation capacity and the integrated refinery capacity for each continent.

Figure 19 shows that the Asian players have a superior integration capacity of their refining assets in comparison with another continents, as mentioned above, this can be translated in a significant competitive advantage to the Asian players and a great potential o competitive imbalance of the downstream market considering the recent forecasts which indicates growing demand for petrochemicals. Furthermore, it's possible to see the power of the China in the Asian and global downstream market. Another interesting point of Figure 19 is the positioning of the Middle East market which presents great potential of competitiveness of the petrochemical integration due to the high capital availability and access to light and high added crude oil. Recently, the SATORP Company (A Joint Venture between Saudi Aramco and Total Energies Companies), announces an investment of USD 11 billion in the Amiral crude to chemicals complex in Saudi Arabia.

As aforementioned, facing 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.

INTEGRATED REFINING HARDWARE – SYNERGY OF PETROCHEMICALS MAXIMIZATION AND RESIDUE UPGRADING

As aforementioned the residue upgrading units are capable to improve the quality of bottom barrel streams, the main advantage of the integration between residue upgrading and petrochemical units like steam cracking is the higher availability of feeds with better crackability characteristics.

Bottom barrel streams tend to concentrate aromatics and polyaromatics compounds that present uneconomically performance in steam cracking units due the high yield of fuel oil that presents low added value, furthermore, the aromatics tends to suffer condensation reaction in the steam cracking furnaces, leading to high rates of coke deposition that reduces the operation lifecycle and raises the operating costs. In this case deep conversion units like hydrocracking can offer higher operational flexibility.

Once cracking potential is better to paraffinic molecules, and the hydrocracking technologies can improve the H/C in the molecules converting low added value bottom streams like vacuum gasoil to high quality naphtha, kerosene, and diesel the synergy between hydrocracking and steam cracking units, for example, can improve the yield of petrochemical intermediates in the refining hardware, an example of highly integrated refining configuration relying on hydrocracking is presented

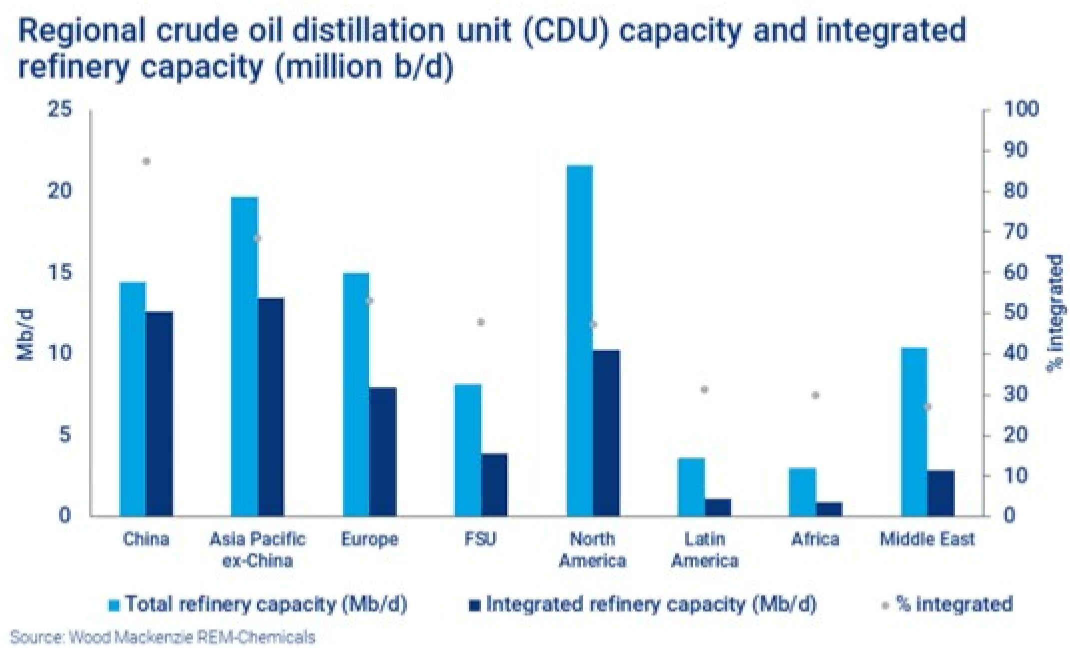

Figure 19 – Crude Oil Distillation Capacity and Integrated Refinery Capacity for Each Continent (Wood Mackenzie, 2023)

Considering the recent trend of reduction in transportation fuels demand followed by the growth of petrochemicals market makes the presence of hydrocracking units in the refining hardware raise the availability of high-quality intermediate streams capable to be converted into petrochemicals, an attractive way to maximize the value addition to processed crude oil in the refining hardware. As presented in Figure 20, the synergy between carbon rejection and hydrogen addition technologies like FCC and hydrocracking units can offer an attractive alternative, sometimes the hydrocracking and FCC technologies are faced by competitors technologies in the refining hardware due to the similarities of feed streams that are processed in these units. In some refining schemes, the mild hydrocracking units can be applied as pretreatment step to FCC units, especially to bottom barrel streams with high metals content that are severe poison to FCC catalysts, furthermore the mild hydrocracking process can reduce the residual carbon to FCC feed, raising the performance of FCC unit and improving the yield of light products like naphtha, LPG, and olefins.

Considering the great flexibility of deep hydrocracking technologies that are capable to convert feed stream varying from gas oils to residue, an attractive alternative to improve the bottom barrel conversion capacity is to process in the hydrocracking units the uncracked residue in FCC unit aiming to improve the yield of high added value derivatives in the refining hardware, mainly middle distillates like diesel and kerosene.

CONCLUSION

Nowadays, is still difficult to imagine the global energetic matrix free of fossil transportation fuels, especially in developing economies. Despite this fact, recent forecasts, growing demand by petrochemicals, and the pressure to minimize the environmental impact produced by fossil fuels creates a positive scenario and acts as main driving force to closer integration between refining and petrochemical assets, in the extreme scenario the zero fuels refineries tend to grow in the middle term, especially in developed economies.

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. The development of crude to chemicals technologies reinforces the necessity of closer integration of refining and petrochemical assets by the brownfield refineries aiming to face the new market that tends to be focused on petrochemicals against transportation

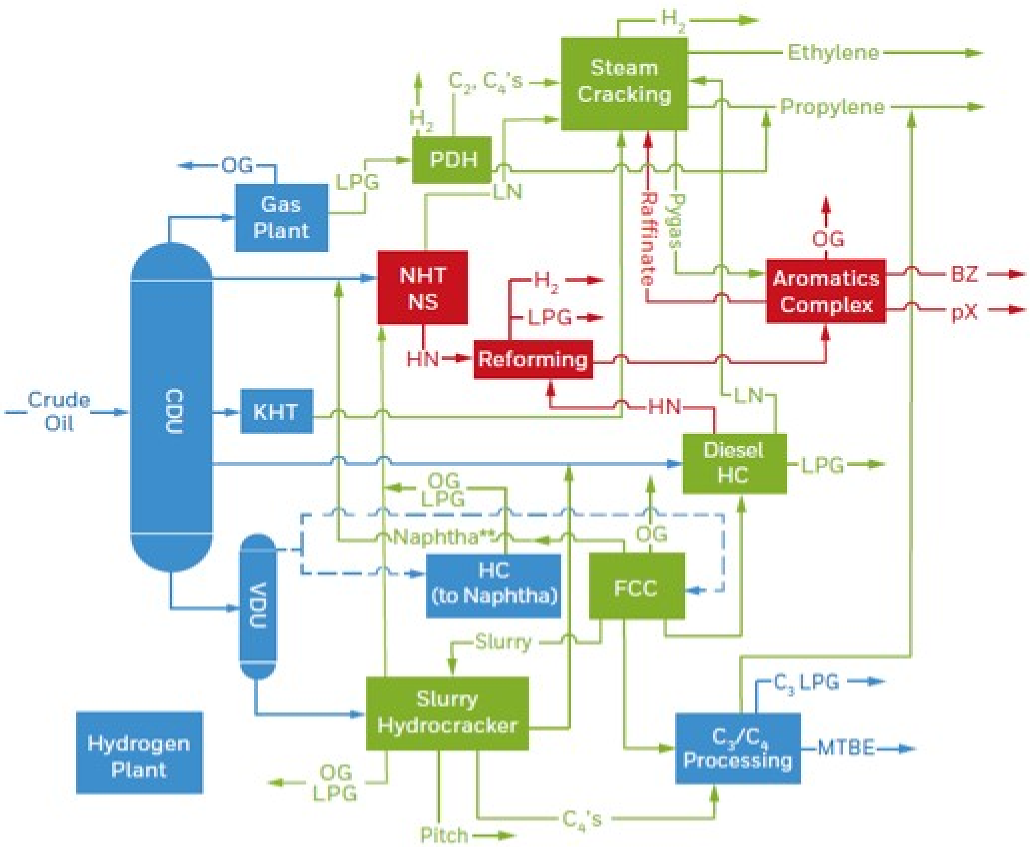

Figure 20 – Integrated Refining Scheme Relying on Residue Upgrading and Petrochemical Maximization Technologies (UOP, 2019)

fuels, it's important to note the competitive advantage of the refiners from Middle East that have easy access to light crude oils which can be easily applied in crude to chemicals refineries. As presented above, crude oil to chemicals refineries is based on deep conversion processes that requires high capital spending, this fact can put under pressure the refiners with restrict access of capital, again reinforcing the necessity to look for close integration with petrochemical sector aiming to achieve competitiveness.

In the extreme side of the petrochemical integration trend, there are the zero fuels refineries, as quoted above, it's still difficult to imagine the downstream market without transportation fuels, but it seems a serious trend and the players of the downstream sector need to consider the focus change in his strategic plans like opportunity and threat.

Despite the benefits of petrochemical integration, it's fundamental to take in mind the necessity to reach a circular economy in the downstream industry, to achieve this goal, the chemical recycling of plastics is essential. As presented above, there are promising technologies which can ensure the closing of the sustainability cycle of the petrochemical industry.

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Design and Revamp Guidelines for Palm Oil Stripper Columns

Karl Kolmetz

INTRODUCTION

The palm oil industry has emerged as one of the vital manufacturing sectors in the world. Further, it has gradually become the most abundant traded vegetable oil in the world, owing to the growing demand.

Palm oil processing refers to the extraction and refining of palm oil from the fruit of the oil palm tree (Elaeis guineensis). Palm oil is widely used in various industries, including food, cosmetics, and biofuel production.

The crude palm oil is gathered from the mesocarp (seed) of the palm oil. However, the crude palm oil that has been extracted contains unwanted impurities and requires a purification process to partially or eliminate them to produce edible oils, mainly cooking oil.

In the current scenario, palm oil is widely used in tropical countries in Southeast Asia, Africa, and parts of Brazil for cooking purposes. Further, due to its low costs and oxidative stability, palm oil has grown popular in these regions.

As mentioned before, crude palm oil that is extracted contains impurities that require a purification process to improve the quality, physical appearance, oxidative stability, and other properties. The impurities are removed at a processing plant, and thus, it is essential to ensure that the plant is modern and equipped with advanced technologies to make the process efficient.

The palm oil processing process typically involves the following steps:

Harvesting

Sterilization

Threshing

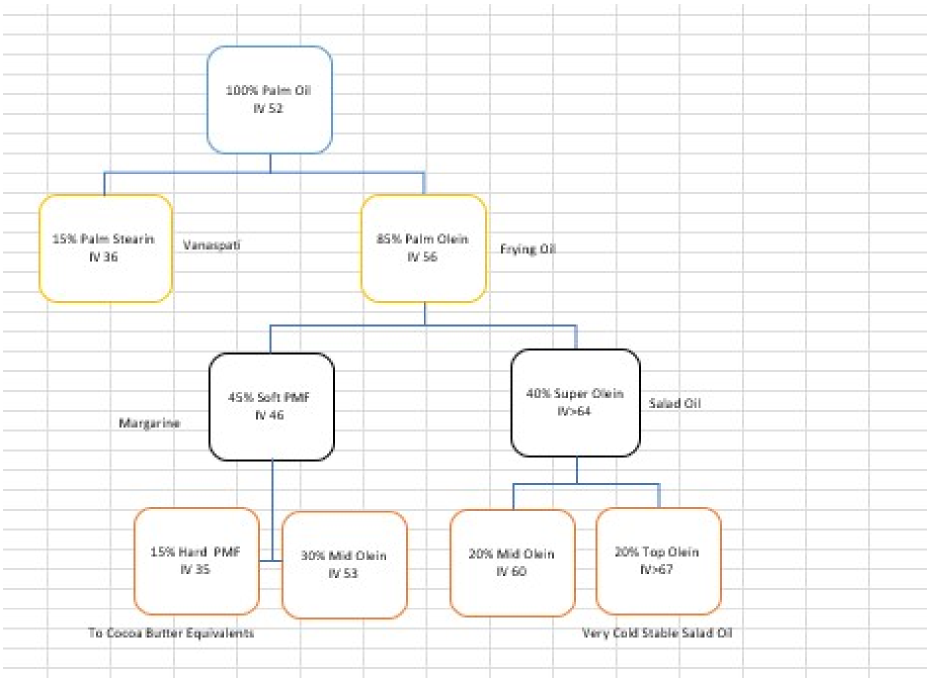
Digestion

Extraction of oil

Clarification

Refining – Physical and Chemical

Fractionation



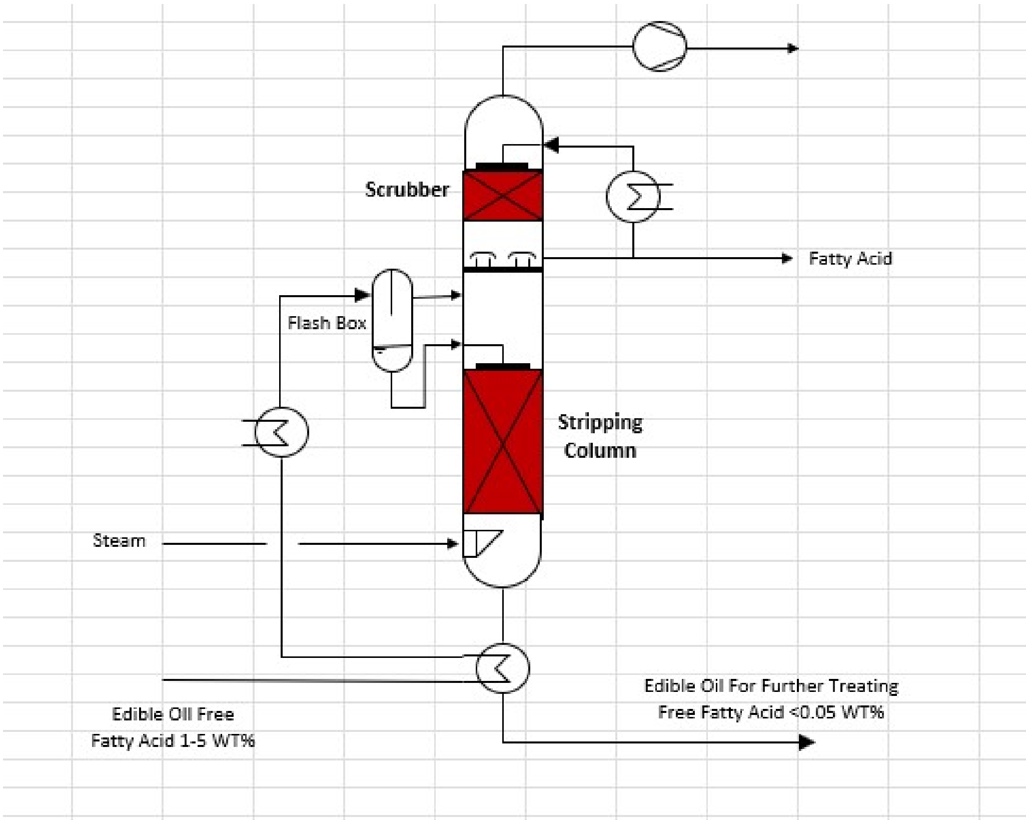
FRACTIONATION

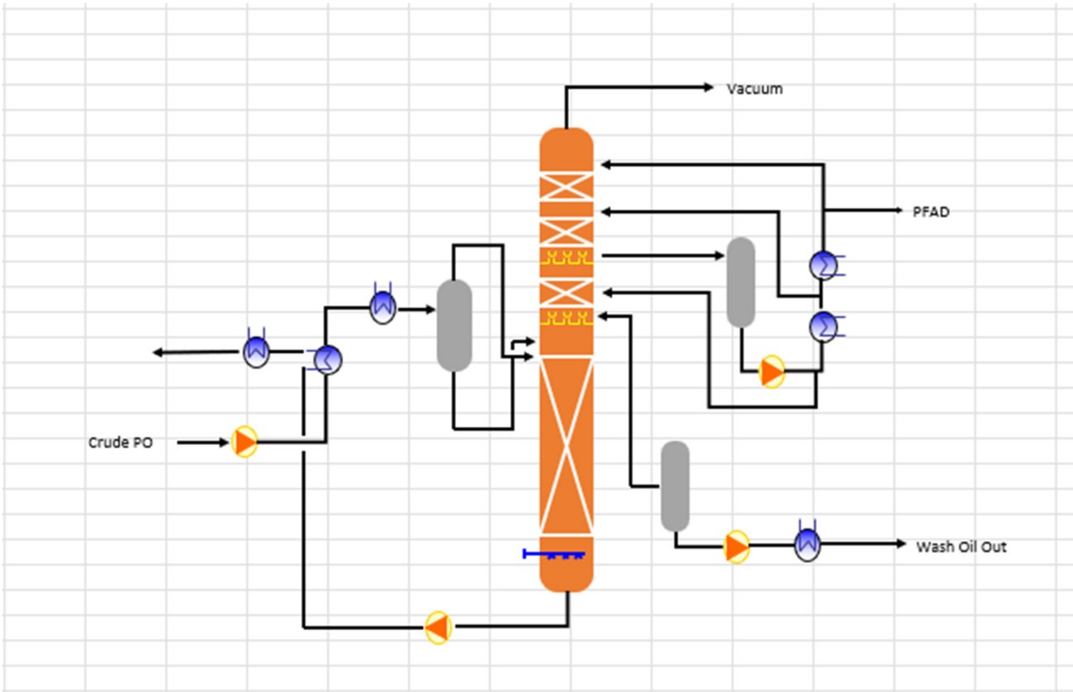
Fractionation is a process that can be employed to separate the palm oil into different fractions, such as palm olein (liquid fraction) and palm stearin (solid fraction). This process is used to obtain oils with specific melting points and different applications.

After processing, the palm oil is usually stored and transported in bulk for various uses in the food industry, such as cooking oil, margarine, and processed foods. It is also used in the production of personal care products, soaps, and biodiesel.

PALM OIL STRIPPER

The Palm Oil Stripper is one of the first fractionation columns in the palm oil process. The Palm Oil Stripper is typically one or two columns. For a single column, the bottoms section is called the stripper and the top section is called the scrubbing section. Preheated, hot crude palm oil is entering the stripper column, which is equipped with structured packing and operated at very low pressure, where the FFA are stripped off by introducing stripping steam in the bottom. Some processes have the palm oil stripper as part of the deodorization system.





For a single column the top section is called the scrubbing section. The scrubbing section can be one to three beds. The scrubbing section is typically structured packing of KLM 250X EC style. The EC (Enhanced Capacity) is 2nd Generation Structured Packing.

If the column has two stripping section beds, the top bed height of 1.3 meters with 1.3 mbar pressure drop. The higher-pressure drop is due to the pump around the bed which has higher flow parameters. The middle bed height is approximately 1.6 meters with 0.6 mbar pressure drop. Total tower pressure drop may be in the range of 4 to 6 mbar. A typical column diameter is one to two meters.

The stripping section is structured packing of KLM 250Y EC style with a bed height of four to 6 meters. The 6-meter bed might have approximately 3.92 mbar pressure drop.

Typical metallurgy is SS 304, SS 316 and SS 316L. Typical stripping steam ratio is 0.20 kg/hr for each MTPD. Free Fatty Acid (FFA) in the feed is about 5% wt and FFA out is about 0.05% wt. Typically, about one stage per meter and packing pressure drop about 1 mbar per meter except for the pump around sections. Typically, design with about 20% safety factors.

Some Palm Oil Strippers may be more complex with an extra draw from the column.

Steps of a Column Revamp

1. Determine Current Capacity and Limitations

The first step of a revamp is to understand your current capacity and limitations. One way to determine your current capacity and limitations is a high load test. You develop a test and measure all the relevant data. Determine what is the current capacity and limitations. Limitations might include packing, heat exchangers, or pumps.

2. Develop a simulation matching current data

From the high load test data, a simulation is developed for the complete system including heat exchangers and pumps. The simulation should match the field data. KLM is happy to assist in your simulation.

3. Review the equipment.

<u>Heat Exchangers</u>

Heat exchangers are rarely optimized or designed well because they are awarded to the low bidder. Then the operating unit pays for the low unit performance in heat exchanged

and run length. Equipment should be bid on a cost and performance matrix.

When a performance matrix is utilized, the lowest bidder rarely wins the heat exchanger bidding. For many units heat exchangers set the run time between maintenance outages. With today's high energy cost heat exchanger is a larger focus. KLM can assist with a better design and supply of heat exchangers.

<u>Pumps</u>

Pumps again are awarded to the lowest bidder. Typical low-cost pump efficiency might be 80% where newer pumps are above 90% - this is a large energy saving. If you need to replace a pump do not replace it with a low efficiency pump. KLM can assist with a high efficiency pump.

Packing

Structured Packing has performed well in Palm Oil Strippers. Distillation of Oleochemicals requires attention to the following key features:

- High Vacuum
- Low pressure drop
- Low bottom temperature
- Minimum holdup
- Short residence time

There is a trade off in structured packing between capacity and fractionation ability. Early columns were designed with KLM 450Y which has higher fractionation capacity, but lower capacity ability. Most newer columns are designed with KLM 250Y EC (Enhanced Capacity - 2nd Generation Structured Packing) which has less fractionation ability but higher capacity.

From the High load test, we can develop vapor and liquid flows. We can then calculate tower hydraulic loads. KLM is happy to assist in developing hydraulic profiles and hydraulic capacity.

To increase fractional ability

If your tower diameter is not the limiting case from the hydraulic profile, we can increase your style of packing to increase your fractioning ability. If you had KLM 250Y before, we could consider KLM 300Y, or KLM 350Y for better fractionation. If you had KLM 350Y before, we could consider KLM 400Y or KLM 450Y for better fractionation.

To increase capacity

If your tower diameter is the limiting case from the hydraulic profile and your fractionation ability is good, we could slightly decrease your style of packing to increase your capacity. If you had KLM 250X before we could consider KLM 200X. If you had KLM 350Y before we could consider KLM 300Y or KLM 250Y.

If you had KLM 250Y before we could consider KLM 250Y EC for increased capacity. The KLM 250Y and KLM 250Y EC has roughly the same efficiency but the KLM 250Y EC has about 25% to 40% more capacity.

Here are some average Number of Theoretical Stage Per Meter (NTSM) and Height of Equivalent Theoretical Plate (HETP). These numbers are based on low pressure of about 1 bar, low relative volatility, and good vapor / liquid distribution – see next section on distributors.

DISTRIBUTORS

For Packing systems, every designer will mention that the packing only works as well as the distributor, and then they normally provide a not optimized distributor. Normal industry standard distributors average about 90 to 92% distribution quality. Below 90% is considered poor and 94% is achievable.

For structured packing, the top two layers distribute the liquid. If each layer is 300mm and you have a 3-meter bed, you have lost efficiency in the top two layers (600mm) which is 20% of the bed height. Remember, higher efficiency will save energy and reduce energy costs.

For random packing, the packing will mix the liquid some, but not like the structured packing. It is more important to have an optimized distributor for random packing to increase efficiency and reduce energy.

KLM optimizes distributor design to gain as much distribution as possible, to improve the packing efficiency, reduce energy costs and save money. With energy in USA at USD $4.00 MMBtu and in Asia at 15.00 MMBtu, it does not take much energy saving to be real money.

Palm Oil has a viscosity challenge – make sure you have an optimized distributor for your Palm Oil Application.

COST OF QUALITY

There are hundreds of Random Packing Suppliers, some at very low cost. KLM only buys from Quality Suppliers that we have vetted.

Suppose you are buying random packing and

Style	NTSM	HETP
KLM 200 Y	2	20 Inches (508 mm)
KLM 250 Y	2.5	16 inches (406 mm)
KLM 350 Y	3.33	11 inches (279 mm)
KLM 500 Y	4	9.75 Inches (248 mm)

thickness is 0.30 mm. Low-cost vendor provides you with a thickness of 0.28, which is difficult to measure. His raw material cost is 6.66% percent lower. If you have a large bed height, the crush strength of the thinner packing is lower and the bottom of the bed may be crushed, leading to a higher pressure drop.

Suppose you are buying random packing and the size is 25 mm. Low-cost vendor provides you packing of 27mm, which is difficult to measure. Packing is sold in 1-meter bags. The bags should be full and weighted, make sure the bags are weighted. Again, His raw material cost is 3 to 5% percent lower by using less metal.

We know that larger packing size gives more capacity, but less efficiency. If your energy cost is low this should not have a large effect, but most companies do not have low energy cost.

With energy in US at USD $4.00 MMBtu and in Asia at 15.00 MMBtu, it does not take much energy saving to be real money. There may be a good reason someone's packing is lower cost – and it may not actually save you money.

CONCLUSIONS

Palm Oil Stripper Columns are typically the first fractionation column in palm oil processing. There are many types and styles of Palm Oil Strippers. There are opportunities to revamp these towers. Revamps, when possible, should increase capacity and reduce energy. This can be accomplished with the proper design of heat exchangers, pumps, and distillation equipment. KLM would be happy to work with your team.

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THE VIEW FROM ROCK BOTTOM

Ron Cormier

Welcome to the September edition of *The View from Rock Bottom*. Hopefully you may recall from last month's edition of *TVfRB*, this author's mention of moving to cooler climes due to severe summer heat and changing climate effects in Central Texas. While our move was with mixed blessings on parting with the lauded Rock Bottom Ranch after many years, I am happy to report that the mission is now accomplished, having relocated down to the high elevation of Lake Chapala's north shore in Mexico. To experience daily and to enjoy the most beautiful scenery and weather ever, is a true luxury. Fable has it that the north shore of Lake Chapala in Jalisco, Mexico has the world's second-best climate after Quito, Ecuador. Here in Ajijic, Jalisco we are equal to the elevation of Denver, Colorado at nearly 5200 feet above sea level, and are located on the same latitude as Honolulu, Hawaii. Simply gorgeous most of the year; I highly recommend the area.

Since becoming a resident in Mexico, one cannot help but notice the high degree of commercial development apparent in the country. So much so, that Mexico has replaced China as the USA's largest trading partner. If you happen to visit a Costco parking lot at capacity in Mexico, especially on the weekend (not to mention overflowing shopping carts), you will most likely witness proof of Mexico's exploding middle class. This trend is no small feat, a huge global value uplift addition, plus an increased quality of life for Mexicans across the country.

Both Mexico and China are two of the United States' most significant trading partners. Trade relations with both countries have certainly evolved over the years. However, this sophistication has been strained in part by the Russia/Ukraine War and associated geopolitical alliances. More opaque relations between (and trade flow effected by) Russia, China, and North Korea have strained net global trade. Accordingly, The United States is at present, heavily courting India to help assure their evolving alignment with the west, with the goal avoiding communist rule in India.

<u>China Mexico Trade Overall:</u>

China:

- Trade Volume: China has been a major trading partner of the U.S. for several decades. It has been one of the largest sources of U.S. imports, supplying a wide range of products, including electronics, machinery, textiles, and consumer goods.
- Trade Imbalance: The trade relationship with China has often been characterized by a trade imbalance, with the U.S. importing more goods from China than it exports to the country. This trade deficit has been a subject of much economic and political discussion among the developed nations.
- Tariffs and Trade Tensions: Trade tensions between the U.S. and China escalated between 2017 through the present, led to the imposition of tariffs on various goods by both countries. These trade disputes have impacted several industries and global markets.

Mexico:

- Trade Volume: Mexico is also a significant trading partner of the U.S., sharing a long physical border and a complex trade relationship. Trade between the U.S. and Mexico includes a wide range of goods, including automobiles, machinery, electronics, and agricultural products.
- Integrated Supply Chains: The U.S. and Mexico have deeply integrated supply chains, particularly in industries like automotive manufacturing. Many U.S. companies have production facilities in Mexico, taking advantage of lower labor costs and proximity to the U.S. market.
- USMCA Agreement: The United States-Mexico-Canada Agreement (USMCA), which replaced NAFTA (North American Free Trade Agreement), governs trade relations between these countries. The USMCA aims to modernize trade rules and address various issues related to trade and labor.

Both China and Mexico play crucial roles in the U.S. trade landscape, but their trade relationships have distinct characteristics and challenges. Trade effects can change due to shifts in economic conditions, trade policies, and global events, as demonstrated by the changes in both U.S.'s largest trading partner over time. Significantly shorter supply chains to and from Mexico cannot be denied, versus an additional thirty-day deep sea transit and transit cost for goods traded between the Far East and the Americas.

Automobiles:

China's share of exports into the U.S. reached its lowest level this year since 2006, according to data released Sept. 6 by the U.S. Government. In its place now is Mexico, which has emerged as the new go-to for imported goods as the U.S. decreases its reliance on Chinese goods, a shift driven primarily by increasing investment from the U.S. auto industry.

Since 2021, GM, Kia Motors (including Hyundai/Genesis), VW, Ford, and BMW have all made electric vehicle investments in Mexico, Bloomberg reported. In May, Tesla announced at its annual shareholder presentation that it was building in an auto factory for Monterey, Mexico.

In our business, we have historically treated autos as a bellwether for the health of hydrocarbons-based products manufacturing. Modern vehicles are assemblies loaded with plastics, rubber, heat exchange fluids, lubricants, batteries, fuel, coatings, and other reactive chemical products/durable goods.

Chemicals & Fuels:

China:

- Chemicals Trade: China exports a wide range of chemicals to the U.S., including industrial chemicals, plastics, and specialty chemicals. These chemicals are used in various industries, such as manufacturing, electronics, and agriculture.
- Fuels Trade: China also exports petroleum and petroleum products to the U.S. While the U.S. is a major producer of oil and gas, it still imports some petroleum products, and China can be one of the sources.
- Trade Tensions: Trade tensions between the U.S. and China, especially post-2017, have led to fluctuations in the chemicals and fuels trade. Tariffs and trade disputes can impact the prices and availability of these products.

Mexico:

- Chemicals Trade: Mexico exports various chemicals to the U.S., including petrochemicals, plastics, and pharmaceuticals. The proximity of Mexico to the U.S. and integrated supply chains makes it a crucial, high-value source for chemicals.
- Fuels Trade: Mexico is a significant supplier of crude oil and petroleum products to the U.S. The two countries have a strong energy trade relationship, with the U.S. importing Mexican crude oil for refining. Much of bulk liquid exports from the U.S. gulf coast sail to Mexico, as a more economical alternative vs the significant capex required for renewed/additive refining in Mexico.
- USMCA Impact: The United States-Mexico-Canada Agreement (USMCA) governs trade relations in this sector. It includes provisions related to the energy sector, which can influence the trade of fuels between these countries.

Both China and Mexico play essential roles in supplying chemicals and fuels to the United States, contributing to the country's industrial and energy needs. Mexico has historically been an important trader of oil and fuels with the United States.

Here's an overview of the oil and fuels trade relationship between Mexico and the USA:

- Crude Oil Imports: Mexico has been one of the largest sources of crude oil imports for the United States. The U.S. imports Mexican crude oil primarily for refining purposes. The proximity of Mexico to the U.S. Gulf Coast refineries makes it a convenient source of crude oil.
- Petroleum Products: In addition to crude oil, Mexico also exports various petroleum products, such as gasoline, diesel fuel, and natural gas liquids, to the United States. These products are crucial for meeting the energy needs of the U.S. market, though Mexico's crude oil and refined products positively affect the USMCA balance.
- Trade Agreements: The trade in oil and fuels between the U.S. and Mexico is influenced by trade agreements such as the USMCA. This agreement includes provisions related to the energy sector, which can impact on the trade relationship.
- Market Dynamics: The oil and fuels trade between the two countries can be influenced by market dynamics, including fluctuations in oil prices, changes in energy policies, and supply and demand factors. Ratable availability throughout North America better portends via balanced supply of oil and fuels, many times covering for unplanned operations capacity problems in the refining sector.

Overall, Mexico's role as a trader of oil and fuels with the United States is significant and has a substantial impact on both countries' energy markets and economies. This trade relationship is subject to various factors. These include economic conditions, energy policies, international agreements, and even marine traffic conditions in Houston, Corpus Christi, New Orleans, Pascagoula, and Monterey.

In Summary

Both China and Mexico play significant roles in the U.S. automobile (as a proxy for durable goods), and hydrocarbons industry, albeit in different ways. China is a source of vehicle imports and components, while Mexico is a manufacturing and export hub closely integrated with the U.S. automotive supply chain. These trade relationships can be influenced by trade policies, economic conditions, global market trends, and logistics/distance timing and costs. Luis Torres, a senior business economist with the Federal Reserve said [structural trend] shifts [noticeably} started to occur after 2017, during the Trump Administration's trade war with China.

In July, U.S. imports of goods from China came to $36 billion, according to the Census Bureau, while imports of Mexican goods came to nearly $39 billion. Bloomberg's analysis found that in the 12 months through July, China's share of U.S. imports was an average of 14.6% — its lowest level since 2006. Mexico's average share during the same period was 15%.

VIVA MEXICO!!!!! Until *EPM's* November 2023 edition, and the next installment of *The View from Rock Bottom*, I bid you health, happiness, and prosperity.

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