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Closing the Sustainability Cycle: The Role of Plastics Recycling Technologies in the Future of Downstream Industry

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INTRODUCTION AND CONTEXT

According to recent forecasts, the petrochemical market tends to rise in the next years and, in middle term, will be responsible by a major part of the crude oil consumption over passing the transportation fuels this fact have been made the refiners to looking for closer integration with petrochemical assets through the maximization of petrochemical intermediates in their refining hardware as a strategy to ensure better refining margins and higher value addition to the crude oil. Figure 1 present an overview of the trend of growing to the petrochemical market in middle term.

Some markets already are facing with the gasoline surplus, in these cases, directing naphtha to petrochemicals against gasoline can be an attractive way to ensure competitiveness to refiners. Figure 2 present the evolution of gasoline surplus in the Russian domestic market, as an example.

Again, being a high demand and most profitable market, the alternative to convert naphtha to petrochemicals should be a trend to refiners inserted in markets with gasoline surplus in the next years. According to data from Wood Mackenzie Company (2021), the highly integrated refiners can add from US$ 0,68 to US$ 2,02/ bbl. Still according to Wood Mackenzie, the Asian Market presents the major concentration of integrated refining plants.

As presented in Figure 3, the petrochemicals demand tends to drive the crude oil demand for the next years.

This fact tends to restrict the consumer market which tends to offer lower refining margins, another great advantage to refiners capable to convert naphtha to petrochemicals against gasoline.

Additionally, it’s important to quote that the gasoline demand will be sustained by the in developing economies, as presented in Figure 4.

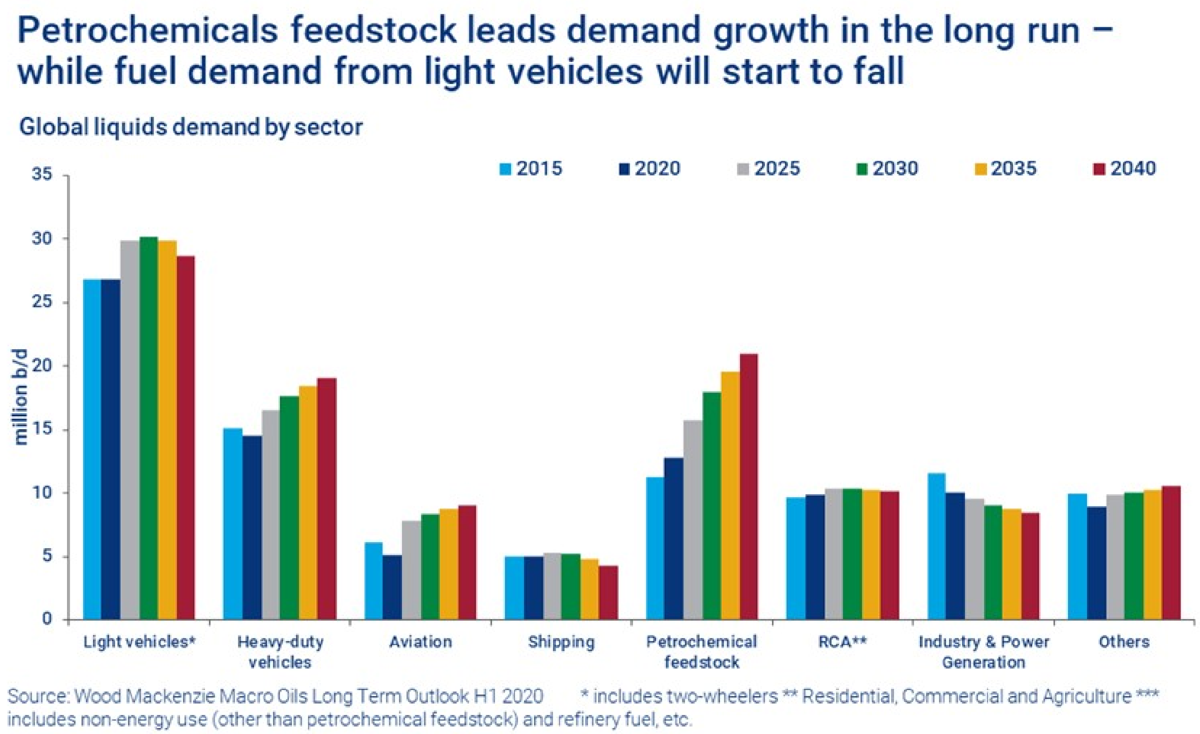


Figure 1 – Growing Trend in the Demand by Petrochemical Intermediates (Wood Mackenzie, 2020)

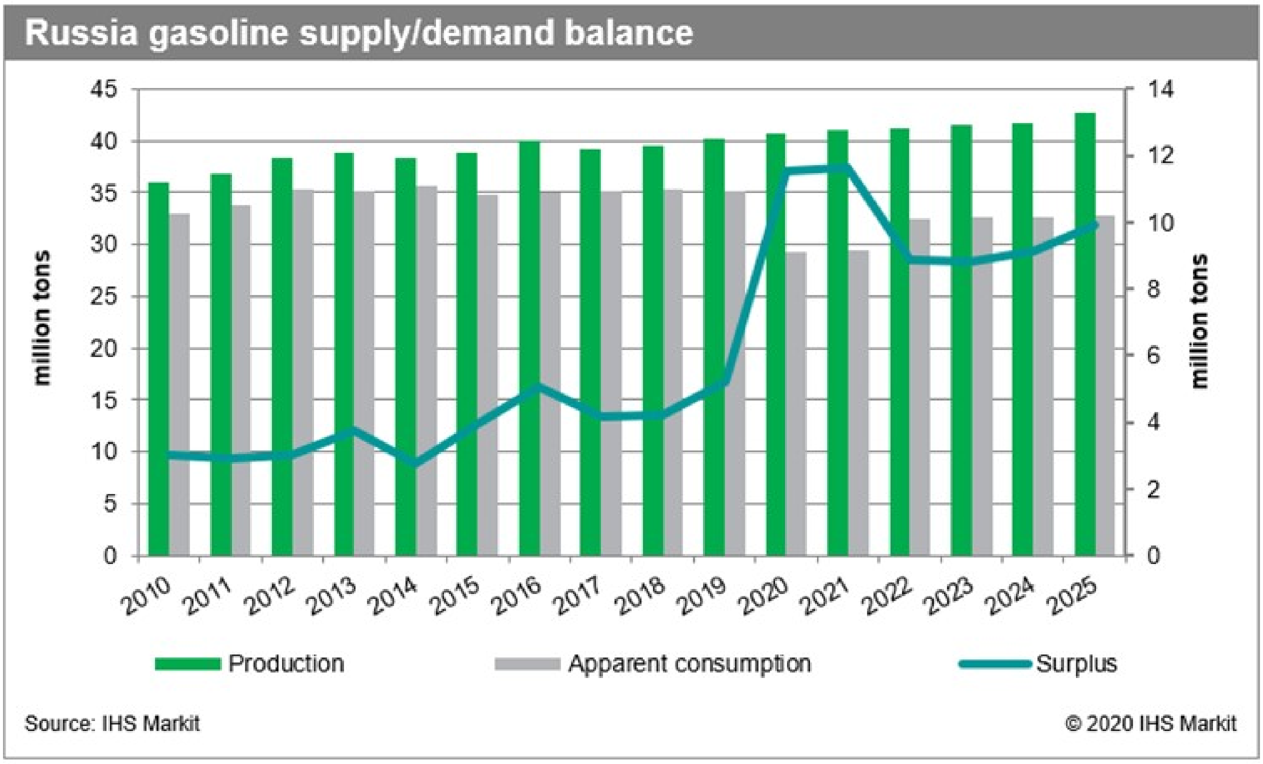


Figure 2 – Evolution of Gasoline Surplus to the Russian Domestic Market (IHS Markit, 2020)

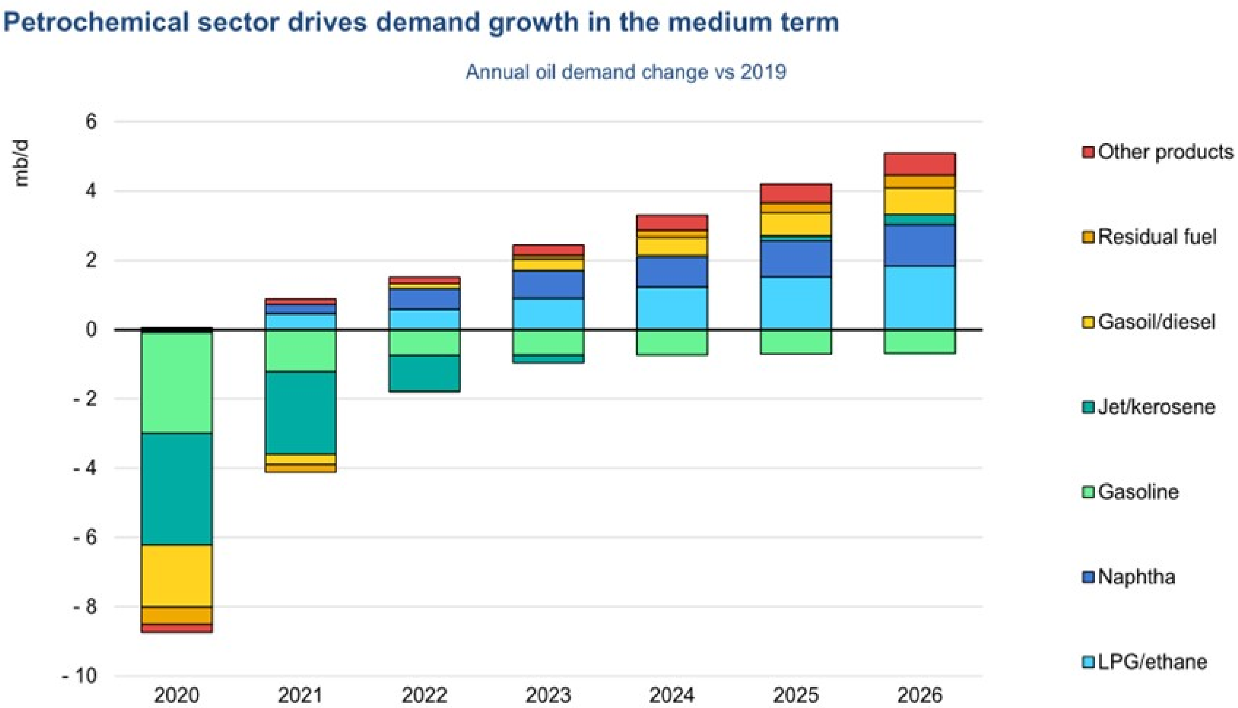


Figure 3 – Growth of Petrochemicals as Driver for Crude Oil Consumption (IEA, 2021)

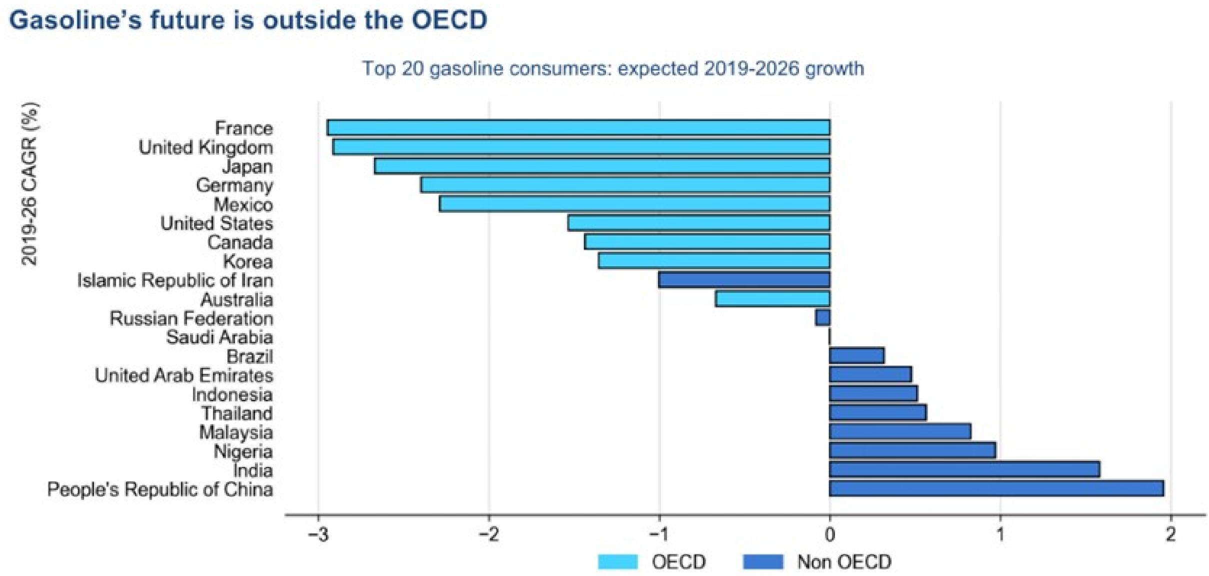


Figure 4 – Growth of Gasoline Demand for the Next Years (IEA, 2021)

Based on 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.

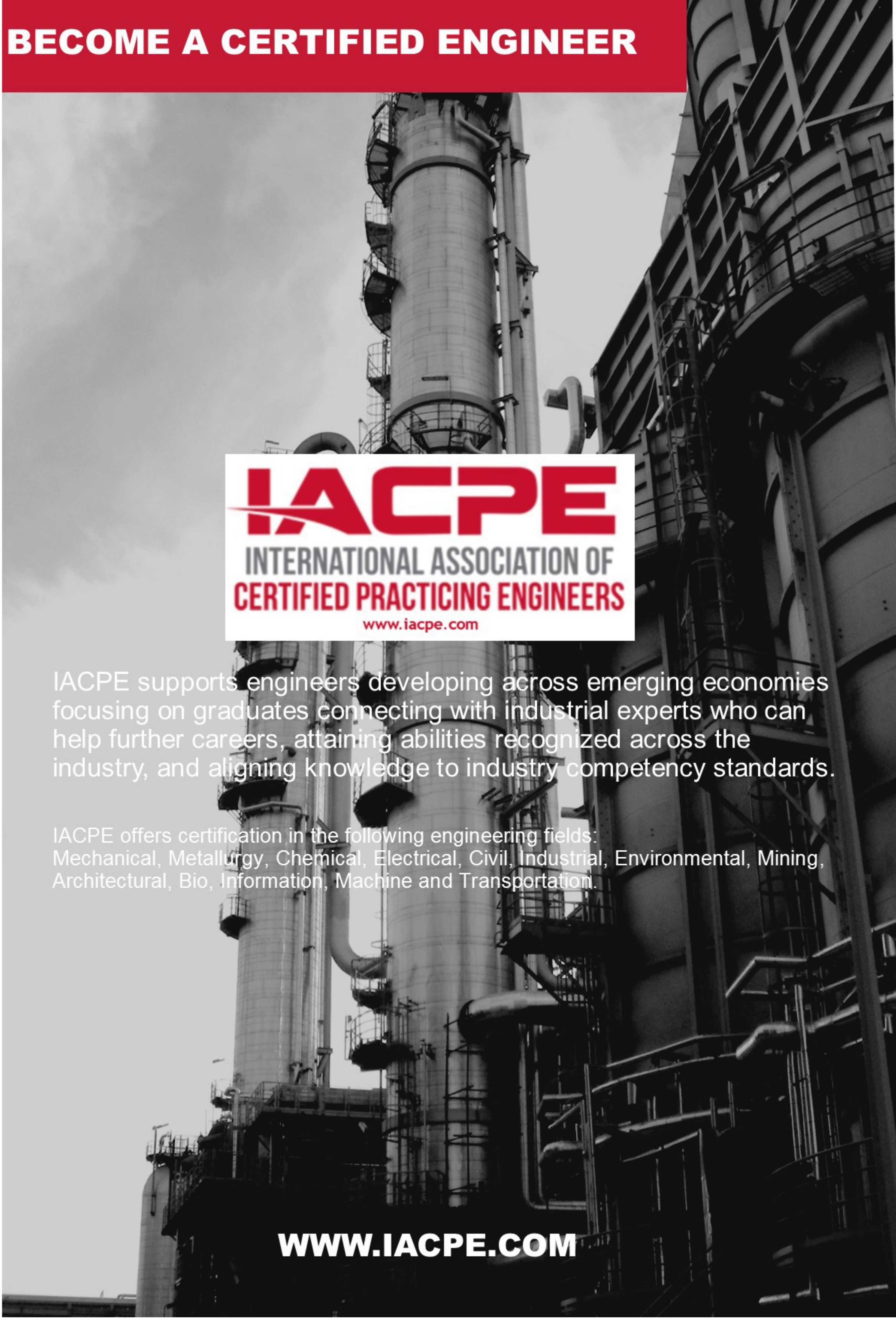
Due his characteristics, the transportation fuels market can be imagined like the red ocean, where the margins tend to be low and under high competition between the players with low differentiation capacity. On the other side the petrochemicals sector can be faced like the blue ocean where few players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

MAXIMIZING ADDED VALUE TO THE PROCESSED CRUDE – PETROCHEMICAL INTEGRATION

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.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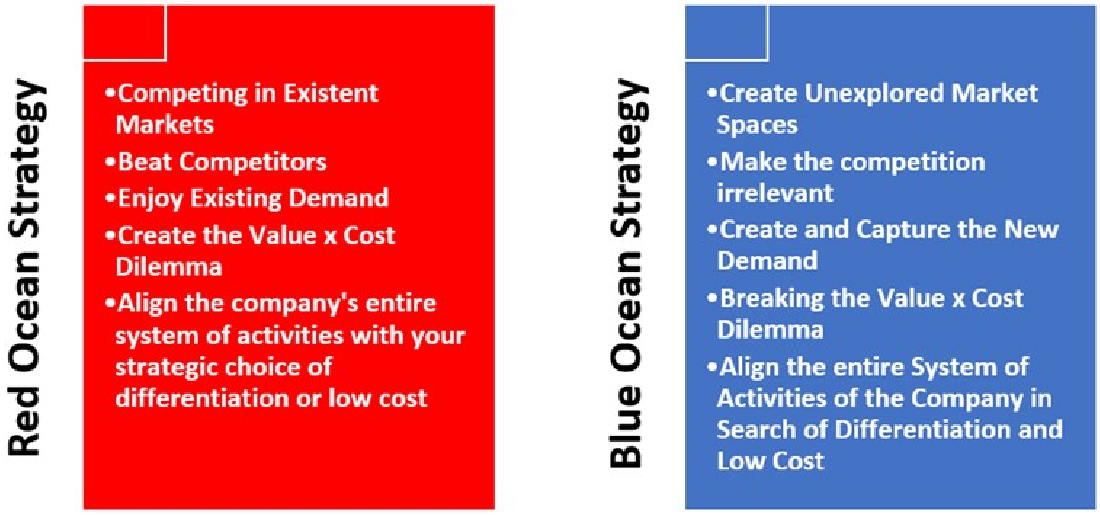

Figure 5 – Differences between Blue and Red Ocean Strategies (KIM & MAUBORGNE, 2004)

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

Figure 6 presents a block diagram that shows some integration possibilities between refining processes and the petrochemical industry.

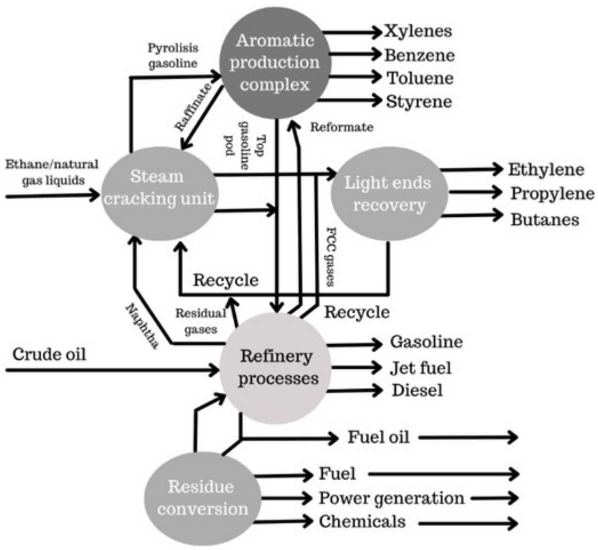

Figure 6 – Synergies between Refining and Petro chemical Processes

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

Table 1 – Refining and Petrochemical Industry Characteristics

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

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

The IHS Markit Company proposed a classification of the petrochemical integration grades, as presented in Figure 7.

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.

CLOSING THE SUSTAINABILITY CYCLE – PLASTICS RECYCLING TECHNOLOGIES

As described above, we are facing a continuous growing of petrochemicals demand and a great part of these crude oil derivatives have been applied to produce common use plastics. Despite the higher added value and significant economic advantages in comparison with transportation fuels, the main side effect of the growth of plastics consumption is the growth of plastic waste.

Despite the efforts related to the mechanic recycling of plastics, the increasing volumes of plastics waste demand most effective recycling routes to ensure the sustainability of the petrochemical industry through the regeneration of the raw material, in this sense, some technology developers have been dedicated investments and efforts to develop competitive and efficient chemical recycling technologies of plastics.

One of the most applied technologies for plastics recycling in the catalytic pyrolysis

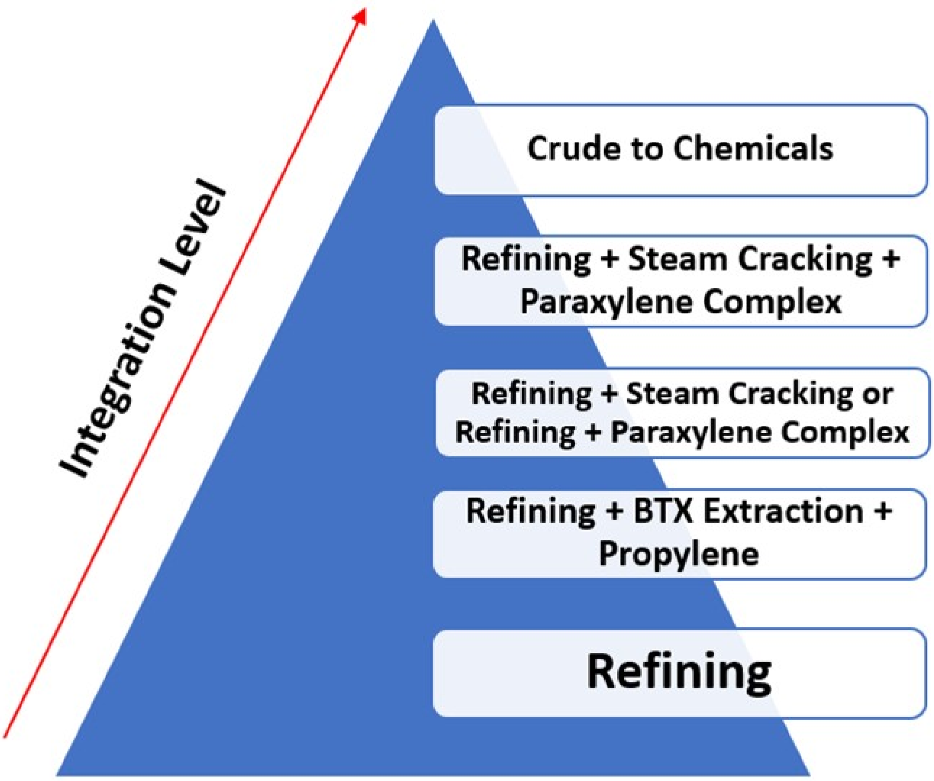

Figure 7 – Petrochemical Integration Levels (IHS Markit, 2018)

where the long chain polymeric are converted into smaller hydrocarbon molecules which can be fed to steam cracking units to reach a real circular petrochemical industry. Another route is the thermal pyrolysis of plastics, is this case, it's possible to quote the Rewind™ Mix technology developed by Axens Company.

Another promising chemical recycling route for plastics in the hydrocracking of plastics waste, in this case the chemical principle involves the cracking of carbon-carbon bonds of the polymer under high hydrogen pressure which lead to the production of stable low boiling point hydrocarbons. The hydrocracking route present some advantages in comparison with thermal or catalytic pyrolysis, once the amount of aromatics or unsaturated molecules is lower than the achieved in the pyrolysis processes, leading to a most stable feedstock to steam cracking or another downstream processes as well as is more selective, producing gasoline range hydrocarbons which can be easily applied in the highly integrated refining hardware. Figure 8 presents a summary of the available and promising routes to plastics recycling.

The chemical recycling of plastics is a great opportunity to technology developers and scientists, especially related to the development of effective catalysts to promote depolymerization reactions which can ensure the recovery of high added value molecules like BTX. More than that, the chemical recycling of plastics is an urgent necessity to close the sustainability cycle of an essential industry to our society, as presented in Figure 9, nowadays around 96 % of the plastic are not totally recycled and the UOP Company estimates that advanced recycling plastics technologies have potential to reduce this number to close of 17 %.

SOME COMMERCIAL PLASTICS RECYCLING TECHNOLOGIES

Due to the relevance of the topic, the main refining technologies developers are engaged to develop competitive technologies capable to recycle plastics in an efficient manner. Figure 10 presents an overview of the Rewind™ process developed by Axens Company.

Among another plastics recycling technologies we can quote the UpCycle™ process developed by UOP Company and the ChemCycling™ process in development by BASF Company which applies the pyrolysis route to produce pyrolysis oil which will be applied as feedstock to the production of petrochemical intermediates. The Hoop™ process, in development by Versalis Company, presented in Figure 11, is another plastics recycling process based on pyrolysis route.

Another commercial technology based on pyrolysis route is the New Hope™ process, developed by Lummus Company which can reach a yield of 70 % of liquid hydrocarbons for further processing according to the licensor.

It's fundamental to understand that the plastics recycling is necessary to the achievement of a real circular economy as required by the society, especially considering the growing demand for petrochemical intermediates in the next years. Data from 2019 pointed that there is around of 300 US billion dollars in capital investment to build crude to chemicals refining assets which are focused to produce petrochemicals from crude oil, with minimum transportation fuels which face a hostile environment. Close to 64 % of this capital investment are localized in the Asian Market, leading to a potential imbalance in the global downstream market.

These data reinforce the relevance of the plastics waste recycling technologies to the sustainability of the downstream industry at the same level of the energy management efforts of the players of this industry.

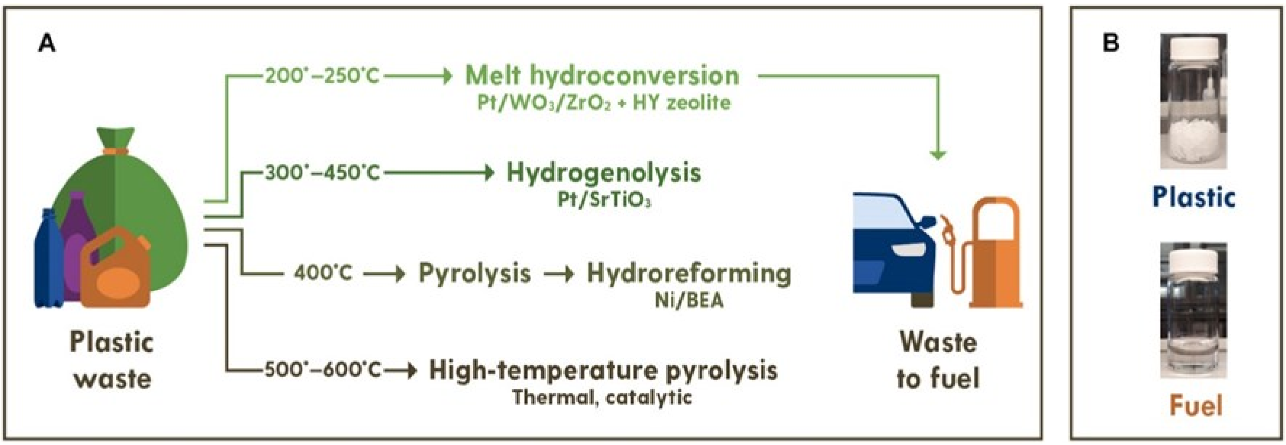

Figure 8 – Current and in Development Route of Plastics Waste Recycling Routes (LIU et. al., 2021)

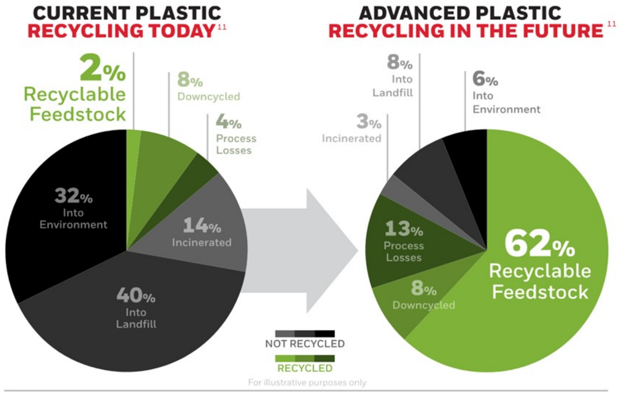

Figure 9 – Current and Future Plastics Recycling Scenario (UOP Company, 2021)

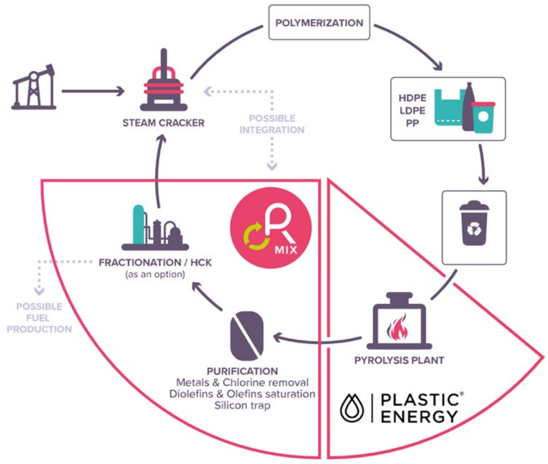

Figure 10 – Rewind™ Plastics Recycling Technology by Axens Company

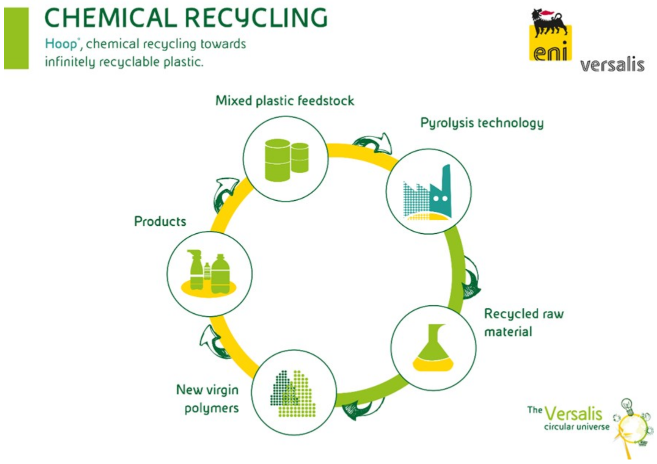

Figure 11 – Hoop™ Plastics Recycling Technology by Versalis Company

CONCLUSION

Nowadays, is still difficult to imagine the global energetic matrix free of fossil transportation fuels, especially for in developing economies. Despite this fact, recent forecasts, and growing demand by petrochemicals as well as 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 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.

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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.

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.

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. As discussed above, even the players with less capital power can take actions to maximize the petrochemicals yield in their refining hardware. Despite this scenario, disruption is still a hard word in the case of downstream industry, but the crude to chemicals refining assets can produce a competitive imbalance in the market, especially due to the concentration of capital investments in the Asian market. Less integrated refiners tend to compete in a kind of red ocean market where the refining margins tends to be lower due to the lower added value to the crude oil like transportation fuels, high sulfur fuel oil, and asphalt. Despite this, and according to the characteristics of the local markets it's possible to reach economic sustainability, in this case, the capital discipline and operational efficiency are even more important for these players.

Despite the benefits of petrochemical integration, it's fundamental taking 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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