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From crude oil to chemicals: How refineries can adapt to shifting demand

The energy transition will reduce demand for oil products but increase opportunities to capture the growing demand for petrochemicals.

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Many analysts forecast that the world's energy transition will soon result in a peak in the use of oil-based fuels followed by a decline. The transportation sector is at the forefront of this trend, with total global demand expected to peak in the next one to two years and then begin a gradual decline. Gasoline will experience the greatest impact because it is primarily used for light-duty passenger vehicles, and the market for these vehicles is shifting toward electric. In addition, these vehicles are subject to efficiency improvements and changing consumer mobility habits.

In contrast, demand for petrochemical feedstocks will continue to grow. The major oil-derived petrochemical feedstocks are ethane, liquid petroleum gas (LPG), and naphtha. These are primarily used in the production of polymers for plastics, synthetic fibers, and other petrochemical intermediates. Demand for these products will continue to grow with rising global wealth.

These two developments pose a dual challenge for the world's more than 600 refiners. Lower overall demand means less need for refining capacity. At the same time, the remaining refining capacity must evolve to match a shift in product mix to meet petrochemical demand. Refiners will need to find ways to make much less gasoline, marginally less diesel, and more jet fuel and petrochemical feedstocks.

Forward-looking refiners are already looking for opportunities to adjust or modify their production modes to capture growing demand for petrochemicals by, for example, increasing their output of naphtha, propylene, and reformate, the building blocks of other petrochemicals. (Refineries already produce some petrochemical feedstocks but typically at rates no higher than 10 percent of total output.)

The world's refiners must fundamentally rethink how refineries are designed and operated. Given how long it takes to make capital investments and build new plants, they should begin this review now. In this article, we consider the emerging options available to refineries in terms of technology and overall operations strategy.

Rethinking refinery operations

Globally, refiners have the capacity to process nearly 100 million barrels of crude oil per day. As global demand declines, refinery utilization is expected to drop in the key markets of Western Europe and Asia. By the middle of this decade, utilization in those markets could drop from the current rate of 85 percent to percentages in the low 70s.[1] Refinery utilization in North America will be slightly stronger due to location advantages for export markets and crude supply. But all markets will see a significant contraction in profit margins as a result of the general decline in utilization.

Overall, the drop in utilization and profitability could result in capacity closures that will affect the least efficient plants and those less able to adapt to new demands. This scenario leaves most of the current plants operating but with growing pressure to adapt to new conditions, despite narrow margins and decreased cash flows to fund changes.

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[1] The utilization estimates are based on the "further acceleration" scenario described in the McKinsey report *Global Energy Perspective 2022: Executive summary*, April 2022.

Many refiners are considering shifting away from refining crude into mostly fuels and are instead looking to refine crude into chemicals—though few have begun the transition in earnest. Part of the challenge is that there is a wide array of approaches, and they all require significant capital investment. We see three ways for players to increase the petrochemical yield of refinery operations: change individual process units, change the mix of process units, or build more direct crude-to-chemicals plants.

New process technologies

The individual process unit that receives the most attention is the fluid catalytic cracker (FCC), the longtime workhorse of refining. The FCC is a cracking unit that converts vacuum gasoil—a high-density, low-value component of crude oil—into more valuable products, such as gasoline. FCC production typically accounts for about 40 percent of the total gasoline pool. Gasoline from units that use FCC products as feedstock for processes such as alkylation bring the total to more than 50 percent of the pool. FCC gasoline contains naphtha and aromatic materials that could be separated out as petrochemical feedstock, but few FCCs are designed for this process. The FCC also produces light olefins that some refiners can separate as a petrochemical feedstock, but the typical output is relatively small. Refiners have shifted toward catalysts that produce higher olefin yields, but output generally tops out at 10 to 15 percent of the total.

New technologies under development could allow FCCs to produce much higher petrochemical yields, which in turn could lead to increased production of olefins, aromatics, and steam cracker feeds such as LPG and naphtha.

High-severity FCC. This approach optimizes propylene yield by adjusting catalysts, operations, and unit design, but it remains a conventional technology. It allows refineries to produce petrochemicals from heavy oils by converting a low-value refinery stream into high-value products suitable for integrated processes. It was developed by the JX Nippon Oil and Energy Corporation, King Fahd University of Petroleum and Minerals, Axens, and Saudi Aramco. In 2019, S-Oil of South Korea became one of the first companies to commercialize this technology.[2]

FCC to steam cracking. India's Reliance Industries aims to use steam cracking in the innovative multifeed cracker it is planning.[3] The company's goal is to maximize monomer output by upgrading a refinery's unsaturated light and heavy streams through catalytic cracking. When operational, the feedstock used by the unit is expected to yield about 70 percent petrochemicals (24 percent ethylene; 33 percent propylene; and 14 percent benzene, toluene, and xylene).

New refinery configurations

Beyond individual unit changes, refiners can further shift their product yield toward petrochemical feedstock by changing the mix and arrangement of refinery process units. A typical modern refinery employs dozens of process technologies, each focused on a different product yield. Coking, residual hydrocracking, and visbreaking eliminate residuum; FCC, isomerization, reforming, and alkylation maximize gasoline output; and hydrocracking maximizes diesel and jet fuel production. Specific changes in refinery design and operation would increase petrochemical yields.

Increased hydrocracking. Hydrocrackers typically compete with FCCs for the same feedstock, with hydrocrackers yielding more (and higher-quality) diesel, jet fuel, and steam cracker feed such as LPG and naphtha. FCCs yield more (and better-quality) gasoline. Refiners can boost potential petrochemical output while still preserving diesel and jet fuel production by increasing hydrocracker capacity and shifting toward a higher yield of light-ends feedstock, such as LPG. This process can also generate additional naphtha.

[2] "S-OIL ushers in a new era from 'oil to chemical,'" S-OIL Corporation, June 26, 2019.
[3] Asit K. Das, *Waste to value: RIL's breakthrough technologies*, Gasification India – Waste to Energy 2020 Web Conference, December 15, 2020.

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Maximizing aromatics reforming. Reforming is a common refining technology used primarily to upgrade low-value naphtha into higher-value gasoline by raising its octane. Reforming can also be used to produce aromatics instead of gasoline. Refiners can maximize value from aromatics by increasing reformer severity, leaving benzene precursors in the feedstock, and adding aromatics separation and conversion units at the back end. This approach could also complement an increase in the production of hydrocracker naphtha and a modification of the FCC for aromatics extraction.

Some newer refineries are already demonstrating the potential of this strategy. China's recently commissioned Hengli Petrochemical refinery can generate more than 40 percent petrochemical feedstock yield compared with about 10 percent yield for most refineries.[4] The scale of these units is very large. Hengli, for example, has capacity for 4.3 million tons of paraxylene per year. Refineries near big markets will therefore have the strongest value proposition.

Direct crude to chemicals conversion

Some players are considering new technologies to move directly from crude oil to petrochemicals without using traditional refining technologies. Saudi Aramco is researching this strategy, aiming for a target of 70 to 80 percent chemicals for each barrel of crude.[5] These technologies are not widely used, so actual performance and the economics are not well understood. However, it appears that they are most attractive when focused on processing very light crude oil.

Different oil-to-chemicals technologies have varying costs and degrees of conversion. The simplest modification, employing new technology in a single FCC unit, would result in up to 40 percent of refinery output as petrochemicals. Alternatively, using a mix of conventional technologies reconfigured for maximum chemical yield could bring chemicals' share closer to 50 to 60 percent of total output. Combining these—reconfiguring the mix of conventional-process units and employing new technologies—could push petrochemical yields to 80 percent of total output. Direct crude-to-chemicals production could yield output of nearly 100 percent chemicals. The price of these approaches rises with the level of yield shift. Individual unit modifications cost $50 million to $100 million. Full-refinery reconfigurations can cost multiple billions of dollars.

Choosing the right path

Given the range of approaches, a single strategy is unlikely to work for all refiners. Some refineries may not be candidates for a major shift to petrochemicals and will have to consider other strategies for survival or even plan to shutter their plants. For those that are ready for a crude-to-chemicals shift, a number of factors will underpin their decision about the best way forward.

Fuels business outlook

Demand for some traditional refined fuels will be more resilient than for others, allowing some refineries to shift toward petrochemicals more gradually or selectively and still be profitable. Many

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[4] Paresh Avinash Kulkarni, *Crude oil to chemicals (COTC): A technology update*, Gulf Petrochemicals and Chemicals Association, May 2021.
[5] "Crude oil to chemicals," Aramco.

geographic markets will see a delayed impact of the energy transition due to a combination of slow government action and strong underlying economic growth. Also, petrochemicals are not the only nonfuel products. Specialty products such as lubricants, asphalt, solvents, and waxes could see stronger demand and serve as alternative options for refiners to increase operating rates.

Existing configuration and operation

Not all plants are equally well placed to shift toward higher petrochemical yields. Larger refineries typically are in a better position to add new process units because their scale reduces unit capital costs and provides greater flexibility in design, location, and integration. There is also a clear advantage for plants that already have some of the more desirable chemical-oriented processes (such as hydrocracking and reforming) and supporting processes (such as hydrogen generation, aromatics separation and handling, and light-ends storage). Plants that are less complex or that are heavily invested in FCCs and other gasoline technologies may require a level of reconfiguration on par with building a new plant.

Petrochemical integration

Many refineries already benefit from physical integration with a petrochemical plant and are even co-located and operated as a single site. This integration leads to reduced costs of handling and moving exchanged streams; better overall optimization of refining and chemical plant throughput; and scale-driven efficiencies in the cost of maintenance and operations support. While these advantages may not be enough to justify building a new chemical plant at an existing refining site, the refinery might require further reconfiguration to be more focused on petrochemicals.

Enabling a circular economy

The energy transition and shift to a more circular value chain (recycling) will provide refiners with new integration opportunities—for example, supplying renewable and bio-based feedstock to petrochemical units, as demonstrated by Finnish firm Neste in partnership with petrochemical producers.[6] In addition, we see opportunities for refiners to play an important role in enabling advanced recycling of plastic waste or integrating with waste gasification units.[7]

As demand declines for traditional refined crude-oil products, refiners and chemical companies should consider how they can take advantage of the growing oil-to-chemicals opportunity. To develop the right strategy, refiners and chemical incumbents will have to reflect on their current strengths, capabilities, and positioning. The right answer will differ by company and regional fundamentals. In all cases, however, it is essential for players to begin considering their positions now.

[6] "Neste and LG Chem building a strategic partnership to drive the polymers and chemicals industry transformation towards a circular bioeconomy," Neste Corporation, November 5, 2020.
[7] "Plastic2Plastic: ReOil completes the circle in plastics recycling," OMV Group, May 14, 2021.

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