Petrochemicals: Changing Trends in Refineries

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Petrochemicals: Changing Trends in Refineries

National oil companies and international firms alike are focusing increasingly on integrating their refineries with petrochemicals. This offers product synergies, cost savings and value creation through greater flexibility. The grander strategic theme is to protect against a future of falling demand for fuel products. These multi-billion-dollar facilities present greater design and operational challenges, but threaten the economic position of non-integrated refineries.

Construction at Shuaiba refinery, Kuwait (Source: 2014, Fluor; Wikimedia Commons)

Executive Summary

- Integration of refineries and petrochemical plants is becoming increasingly popular because of technology improvements, added value and robustness to future market trends.
- For two reasons, advantaged feedstock has become less available: Middle East countries have allocated their associated gas and cheap non-associated gas, and reformed subsidised pricing; and the rise of US shale has lowered North American natural gas and ethane prices dramatically.
- The world is close to peak required refining capacity, meaning new plants need sources of competitive advantage beyond simply meeting growing demand.
- Petrochemicals are seen as the main source of future oil demand growth.
- Key petrochemical feedstocks – LPG, naphtha and gasoil – are refinery outputs, offering gains from integration. Petrochemical output can be boosted from 8-10% to 20% by integration, and further to 45% by direct crude-to-chemicals plants.
- Further value is created by the flexibility to vary inputs and outputs, enhanced by artificial intelligence methods. Integrated plants can also have lower environmental footprints.
- Cost savings can be achieved from integration by reducing duplication and increasing economies of scale.
- However, integrated plants are more complicated to design and operate, putting a premium on expertise. Proprietary technologies can be combined with those of vendors.

Implications for leading oil and gas exporters

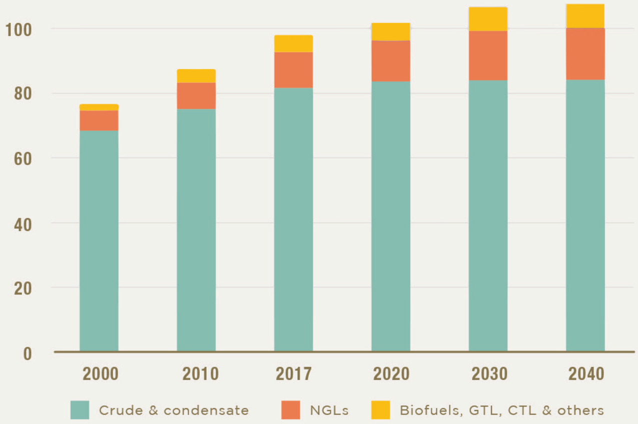
- Leading oil exporters are seeking to ensure future demand by increasing refining and petrochemical capacity. Integration is important to assure the competitiveness of these plants, and orientation towards the growing segments of the demand barrel.
- Greenfield integrated plants will primarily be built in areas with access to technology, contiguous land and large, growing petrochemical demand, notably the Gulf, China, India and south-east Asia.
- Refinery-petrochemical integration does not have to be via direct ownership – neighbouring plants can be integrated by commercial agreements and transfer pricing.
- Technology partnerships and proprietary technologies, including in artificial intelligence, are important for designing and implementing competitive integrated plants.
- Further developing the integration concept, and adding environmentally-friendly components such as hydrogen, biomaterials and carbon capture, will make deeper integration a key feature of the 2030s.

Refinery-petrochemicals integration is increasingly being pursued

In the global picture, refineries face a major challenge. Demand for crude and condensate – and hence refining capacity – is expected to be flat from about 2020 onwards (FIGURE 1). Growth in demand for petroleum liquids is contributed mainly by natural gas liquids (NGLs) and synthetic fuels (biofuels, gas- and coal-to-liquids) which require little or no refining. Increased NGL output is driven by rising world gas production and, particularly, by North America's shale boom. A large part of these NGLs will be targeted for petrochemical production.

Conversely, demand for the traditional refining outputs of fuel oil, diesel and gasoline is set to fall to 2040, or at best grow slightly. This is driven by the replacement of fuel oil with gas and renewable energy; pressure on fuel oil because of the IMO 2020 regulations reducing marine fuel sulphur content; replacement of diesel generators by renewable energy with batteries; and the reduction of on-road gasoline and diesel consumption because of improving vehicle efficiency, and the expansion of the hybrid and electric vehicle fleet.

FIGURE 01: **PETROLEUM LIQUIDS SUPPLY FORECAST[1] (MBPD)**



Flat refining capacity will be met by growth in some regions and shrinkage in others (FIGURE 2). China, India and the Middle East will grow to 2040, and other regions, particularly Europe, Japan and to an extent North America, will shrink. In this highly-competitive environment, only refineries with unique strengths, and those tailored to the growing fractions of the demand barrel, will remain economic.

Petrochemical feedstock is set to be the fastest-growing area of demand to 2040 (FIGURE 3). Bans on single-use plastics could reduce this growth by 6 million barrels per day (Mbpd) by 2040, though it would still be in positive territory.

Petrochemical integration is therefore seen as a way to 'future-proof' refineries. Beyond that, for leading national oil companies with long reserves lives, it ensures future demand for their crude oil and NGL production. Meanwhile, most petrochemical demand growth is expected to be in Asia, with rising incomes and countries at plastics-intensive stages of development, owing to construction and consumer goods.

FIGURE 02: **CHANGE IN WORLD REFINING CAPACITY TO 2040**[2]

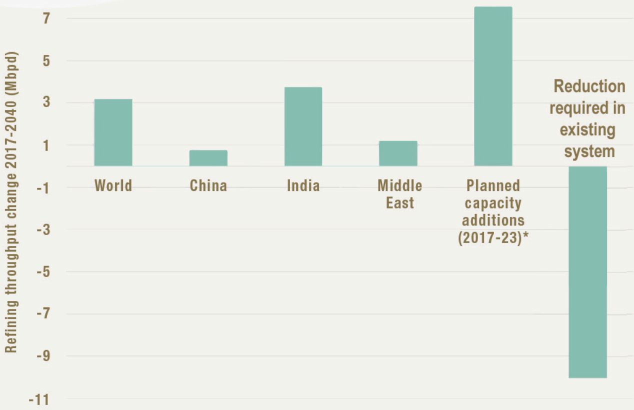
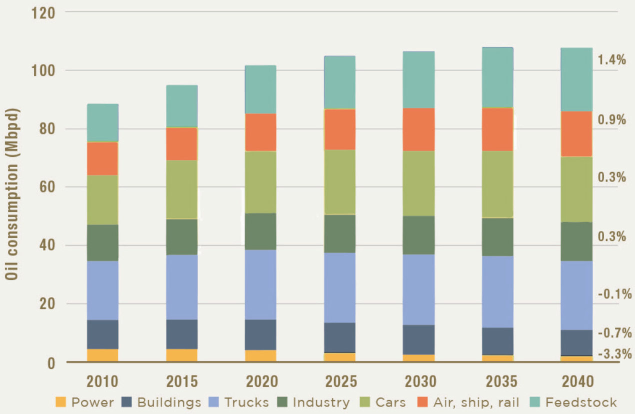


FIGURE 03: **OIL CONSUMPTION 2010-2040 AND ANNUAL GROWTH RATE 2020-40**[3]



Recent announcements on new refineries are focussed particularly on integration, especially in the case of joint-venture refineries built by Middle East national oil companies (NOCs) in their home territories and in Asia.

Domestically, the PetroRabigh and Sadara ventures in Saudi Arabia; the Liwa Plastics project in Oman; the Al Zour refining complex in Kuwait; and ADNOC's plans to turn Ruwais into the world's largest integrated refining and petrochemical hub, are notable.

The Refinery and Petrochemical Integrated Development (RAPID) project in Malaysia is a $27 billion joint venture between Petronas and Saudi Aramco, while Saudi Aramco and ADNOC, in partnership with several Indian state oil companies, are planning a 1.2 Mbpd integrated refinery at Ratnagiri in western India. Saudi Aramco announced on 26th June 2019 a $6 billion steam cracker and olefin project with South Korea's S-Oil, using refinery naphtha and off-gas, with its thermal crude-to-chemicals technology.

Middle Eastern NOCs are not the only ones setting up such facilities. Several are led by Chinese groups, such as Shenghong's Lianyungang complex in Jiangsu, and PetroChina's Guangdong Petrochemical refinery. Pertamina of Indonesia and Russia's Rosneft plan an integrated 300 kilo barrel per day (kbpd) plant in east Java.

The average global refinery yields about 8-10% chemicals. By contrast, Saudi Aramco's integrated refineries produce up to 20% chemicals, and the global demand for feedstocks is currently about 15-16% of total petroleum liquids. By 2040, feedstock will amount to 20.4% of petroleum liquids, so deepening the opportunity for integration.

The extension of a highly integrated refinery is the conversion of crude directly to chemicals, pioneered by an ExxonMobil cracker in Singapore (Singapore Integrated Manufacturing Complex) that can run anything from crude oil or naphtha to ethane[4]. The most notable new such project is the Saudi Aramco/SABIC Crude Oil To Chemicals (COTC) plant at Yanbu', costing $20 billion, with 45% chemicals yield. Further technology development could take this to 70-80%[5].

Three plants in China and one in Brunei are tailored to maximise output of paraxylene, which is used to make polyesters for fibres, films and plastic bottles. One of these, Hengli Petrochemical in China, is in the process of starting up a facility that processes 400 kbpd of medium and heavy crudes to yield 42% chemicals, including 4.3 million tonnes per year (Mt/y) of paraxylene along with benzene, polypropylene, MTBE and other chemical products.

TABLE 01: **CAPACITY OF SELECTED INTEGRATED REFINING-PETROCHEMICAL PROJECTS**[6]

(LLDPE = LINEAR LOW-DENSITY POLYETHYLENE; LDPE = LOW-DENSITY POLYETHYLENE; PP = POLYPROPYLENE; HDPE = HIGH-DENSITY POLYETHYLENE; MEG = MONOETHYLENE GLYCOL; INA = ISONONANOL; MTBE = METHYL TERT-BUTYL ETHER)

PROJECT	REFINERY, KBPD	BASIC PETROCHEMICALS KT/Y	FINAL PRODUCTS, KT/Y
RAPID	300	1300 ethylene, 609 propylene, 250 raffinate-1, 185 butadiene	350 LLDPE, 900 PP, 400 HDPE, 800 MEG, 250 INA
PetroRabigh (Saudi Arabia)	400	1600 ethylene, 900 propylene	Cumene, phenol, MTBE, LDPE, paraxylene, benzene
Ratnagiri	1200	18000	
Lianyungang	320	1100 ethylene, 2800 paraxylene	
Guangdong	400	1200 naphtha cracker, 2600 aromatics	
Yanbu' COTC	400	9000 chemicals and base oils	

Integration builds on refining-petrochemical synergies

The concept of refining-petrochemical integration stems particularly from the synergies in intermediate and by-products. Surplus and intermediate products from the refinery, such as aromatics, which do not have a ready end-market, can be used in the petrochemical plant; conversely, the refinery consumes methane and hydrogen, which are produced in excess by a steam cracker.

TABLE 02: PRODUCT SYNERGIES BETWEEN REFINERY AND PETROCHEMICAL PLANT[7]

REFINERY	PETROCHEMICAL PLANT
Surplus of benzene and other aromatics due to tightening product specs	Uses aromatics
No use for ethane	Consumes ethane for ethylene
Surplus of unsaturated gases	Uses ethylene, propylene for further conversion
Shortage of methane for fuel	Excess methane
Shortage of hydrogen for desulphurisation	Excess hydrogen
	No use for C4, pygas, pyoil, C9 aromatics

Different levels of integration are possible

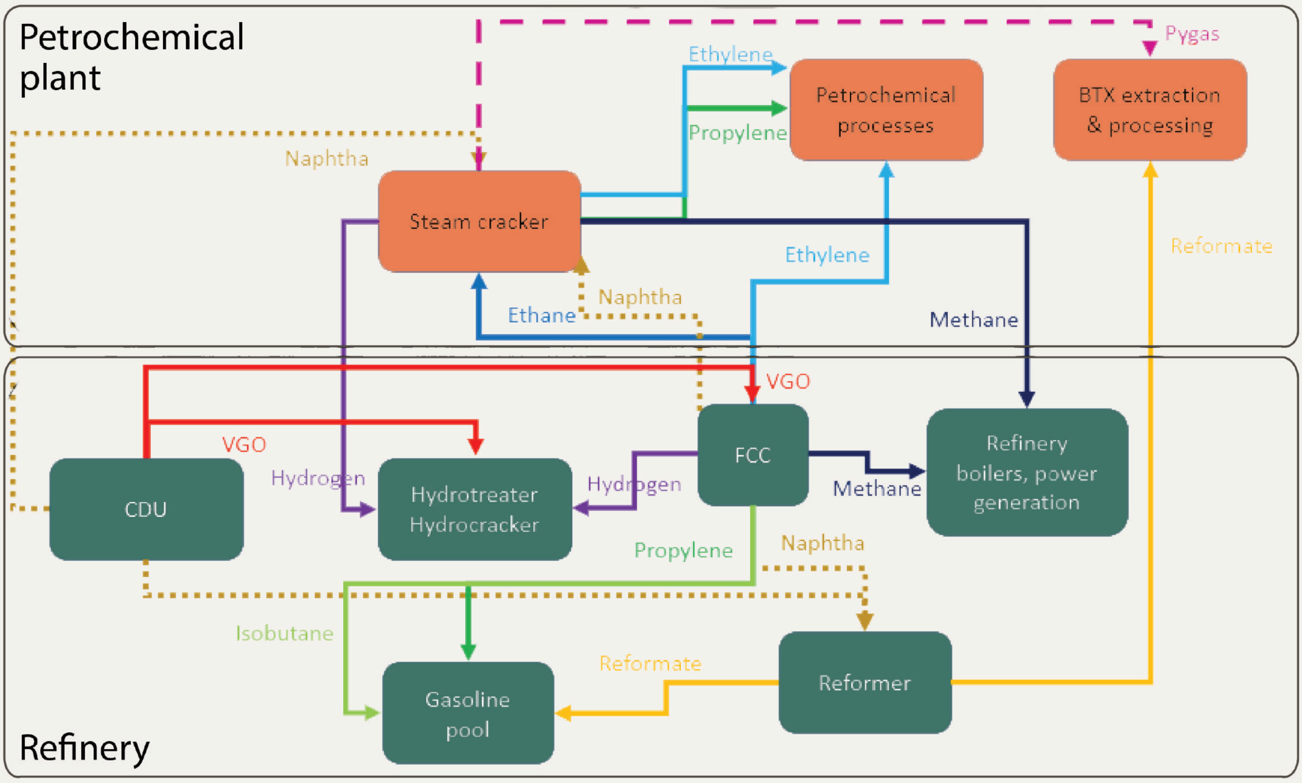
The degree of achievable integration is limited by existing facilities, and can be greater for custom-designed greenfield complexes. An existing refinery for instance, could add a catalytic olefins unit producing ethylene, propylene and aromatics; a propane dehydrogenation unit to make propylene, polypropylene, phenol and acrylic fibre; and a fluidised catalytic cracking (FCC) unit generating additional ethylene.

FIGURE 4 shows how the various feedstocks, intermediate and final products can flow in an integrated refining-petrochemical complex.

Globally, about 85% of paraxylene, 56% of propylene and 38% of ethylene production is integrated with refineries[8]. Ethylene production is less-integrated because most in the Middle East and US derives from ethane. To a lesser extent, this is also true for propylene made from propane.

However, clearly not all plants in future can be crude-to-chemicals plants, or they will saturate the market. Allowing for an average of 16.2% chemicals output from refineries producing fuels, the estimated average figure for 2020, about 7 Mbpd of feedstock (from total feedstock of 22 Mbpd) could be used in COTC plants by 2040.

FIGURE 04: EXAMPLE OF PRODUCT FLOWS IN AN INTEGRATED PLANT[9]



LEVEL OF INTEGRATION	SHARE OF CHEMICALS IN OUTPUT	INCREASING INTEGRATION
No integration	8-10%	↓
Additional refinery units, e.g. catalytic olefins unit, propane dehydrogenation		
Integrated with steam cracker		
Integrated with aromatics complex		
Integrated with steam cracker and aromatics complex	20%	
Crude oil to chemicals conversion (current)	45%	
Crude oil to chemicals conversion (future)	70-80%	

Integration brings several benefits

Most studies of the benefits of integration focus on the product synergies. However, there are a number of other areas of cost saving and value addition. Overall benefits include:

- Production of **higher-value products** and alternative use of **lower-value streams.**
- **Flexibility** to vary inputs and outputs depending on market conditions.
- **Reduced volatility** of refining margins due to lower correlation between oil product and petrochemical prices.
- **Heat integration** (re-use of waste heat and hot feeding of products to other units).
- **Saving on common facilities** (feedstock and product storage, power generation, control room, water, waste disposal, marine terminal).
- **Savings on storage** (less requirement to store intermediate products/byproducts).
- **Cost reduction** via common management, administration, HR, security, etc.
- **Reduced emissions** by greater use of by-product methane (and in future, potential incorporation of carbon capture).

Considering just the exchange of stranded products (for example, naphtha and LPG from the refinery to the petrochemical plant, and hydrogen the other way), a Fluor study suggested that operating margins would increase by 45-70%. Allowing for increased investment costs, simple payback time was improved by 10-25%[10].

A Nexant study considered a 200 kbpd refinery, where integration reduced gasoline output by 42 kbpd in return for producing 1900 tonnes/day of ethylene, 1300 tonnes/day of propylene, and additional amounts of benzene and butadiene. In this case, gross margins of $4/bbl in the refinery and $5.2/bbl in the petrochemical plant were increased to $12/bbl in the integrated complex, a gain of 30%. However, this does not allow for changes in investment cost.

'Big data' and machine learning can be used to optimise the output from integrated complexes, based on changes in feedstock and product prices. Control room decisions can be linked to their economic implications. Repsol's Tarragona refining complex is working with Google to optimise its operations, with potential margin gains of $0.3/bbl[11].

Integration also brings a number of challenges

The required investment in an integrated plant is much larger and the project management risks higher. Designing and operating the plant optimally is more complicated. COTC plants have not been built yet, except for ExxonMobil's relatively small facility in Singapore, so the concept is still exposed to cost and design challenges.

The huge volumes of specific chemicals produced by these large integrated complexes hit the market in a 'lumpy' fashion. This puts more emphasis on a skilled sales and marketing function, to ensure sales prices are not depressed.

Where the petrochemical and refining components have different ownerships, commercial agreements can be complicated and the objectives of each owner can be misaligned. Finally, the combined plant may ultimately be less flexible if there is a substantial long-term unanticipated change in demand patterns or feedstock availability.

Most of these studies consider green-field projects. For existing refineries, integration may be constrained by the existing equipment and space requirements. If the petrochemical plant is too distant, the required capital (for connecting pipelines) and the heat losses would undo some of the benefits of integration.

As noted, integration involves added complexity. Therefore, refinery developers pursuing it have to work closely with technology providers, equipment suppliers and EPC firms. This presents an opportunity to develop proprietary technologies. Companies with relevant technologies include Chevron Lummus Global, McDermott, Axens and Fluor.

Integration can go further

Refinery-petrochemical integration can go beyond the current status. Five possible areas stand out:

1. Further development of the **crude to chemicals** concept can take chemicals output to 70-80% from the current 45%. At this point, the plant would almost cease to be a refinery.

2. **Artificial intelligence** can be used to a much greater extent to optimise operations, inputs and outputs. Plants can be designed specifically for extra flexibility, to make full use of such flexibility.

3. The complex can make more use of **alternative feedstocks**: imported hydrogen, which could be generated with renewable energy; biomaterials; recycled plastics; and gasified inputs such as petcoke and, in some countries, coal. The use of hydrogen, recycled materials and biomaterials would improve the plant's environmental sustainability.

4. Growing environmental pressure will favour plants and products with **lower carbon footprints**. Highly-integrated plants with greater efficiency, including waste heat re-use, can be more competitive, especially as companies come under greater pressure to report and reduce greenhouse gas emissions. The logical next step would be inclusion of carbon capture and storage (CCS), which can be applied to units such as the FCC and hydrogen plant.

5. Finally, the large petrochemical output of world-scale integrated plants requires markets. These can be created by co-located industrial zones, taking the plant's output to produce speciality chemicals and final products such as plastic automobile and construction components, cables, films, synthetic rubber and adhesives. This further serves the NOCs' goal of moving up the value chain and developing more sophisticated outputs and high-skilled employment.

But is integration always necessary?

The simple fact of the projections of petrochemical demand for oil – reaching 20.4% by 2040 – shows that not all refineries can be highly integrated. Refineries with a high chemicals output may still find themselves competing in a crowded market, with margins falling for at least the more basic products.

On the petrochemical side, facilities with access to cost-advantaged methane, ethane and NGL feedstock can still enjoy a competitive advantage.

On the refining side, relatively simple condensate splitters have a role in countries producing large condensate volumes, notably the US, Iran and Qatar. US super-majors, such as Chevron and ExxonMobil, are retooling their Gulf of Mexico coast refineries to process light feedstock, the output from their shale developments in the Permian Basin and Eagle Ford.

And in smaller and geographically-remote markets, such as many African countries, landlocked countries and some islands, the local demand may be insufficient to support a world-scale integrated complex. In these cases, a simpler, smaller and well-run refinery, tailored to local needs, may be more suitable.

Conclusions

Refinery-petrochemical integration has become almost standard for large greenfield projects in the Middle East and Asia. It is important for NOCs with large crude oil exports, and for the competitiveness of Asian refiners such as Petronas, PetroChina and Oil India. Non-integrated legacy refineries, particularly in areas of declining demand such as Europe and Japan, will struggle to compete with integrated plants.

As well as developing or acquiring proprietary technologies, NOCs can access expertise in integrated plants via partnerships with technology providers, Chinese refining-petrochemical giants, and select international oil companies, such as ExxonMobil.

However, integration may be less important for countries with continuing access to low-cost methane and ethane, notably the US, Qatar, Iraq and Iran.

Keiyo Industrial Belt – Idemitsu Chiba oil refinery, Mitsui Chemicals Chiba plant, Sumitomo Chemical Chiba plant. (Source: Nanashinodensyaku, Wikimedia Commons)

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