New Models for Value Creation in Petrochemicals

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The Abdullah Bin Hamad Al-Attiyah International Foundation for
Energy & Sustainable Development

INTRODUCTION

NEW MODELS FOR VALUE CREATION IN PETROCHEMICALS

This report explores the short-term market uncertainties, the impact on petrochemicals of oil pricing volatility, and the acute need for certain petrochemical products whilst the need for others lessens.

In this latest report, we ask: What are the new models for value creation in petrochemical companies? What are the challenges to their business model? How has the Covid-19 crisis affected short and long-term value case for petrochemicals, and what new technologies and environmental pressures are firms responding to?

THE ABDULLAH BIN HAMAD AL ATTIYAH FOUNDATION

Energy Industry Report

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a prevalent energy topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed in hard copy to members, partners and universities, as well as made available online to all Foundation members.

EXECUTIVE SUMMARY

- Global petrochemical demand will fall seriously in 2020. A post-pandemic recovery in GDP should support strong but overall slowing growth in emerging markets.
- Short-term market uncertainties – the coronavirus outbreak, oil pricing volatilities – have resulted in an acute need for specific petrochemical products, shifting focus from traditional models.
- Chemicals shall become the new frontier for oil demand post-2020. A combination of smart chemistry and innovation is key to add value.
- Oil-based petrochemicals integrated with refining will make a comeback, versus gas-based, due to the overhang of cheaply priced crude and condensate, and the greater diversity of outputs.
- Post-crisis, the rate of growth for transportation fuels will continue to decline, causing refining companies to put more emphasis on their petrochemical strategies.

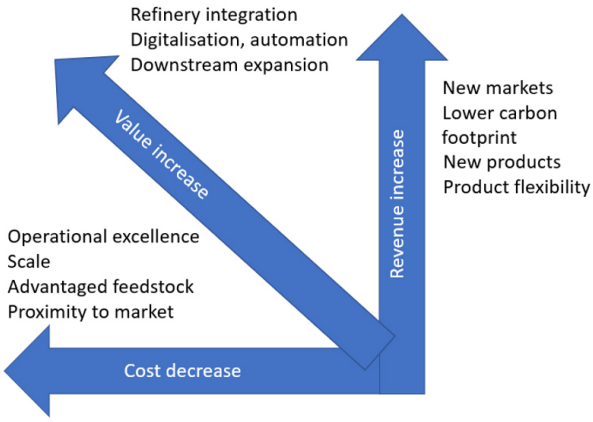
IMPLICATIONS FOR LEADING OIL AND GAS PRODUCERS

- Producers with access to low-cost oil assets will want to better monetise assets by seeking a higher conversion per barrel of oil into chemical products.
- Increasing focus on capital and construction efficiency, best process configuration and full use of digitalisation and automation technologies will protect profitability.
- In future, emerging market producers will back-integrate petrochemical projects for their captive use, which could limit availability to export markets.
- Technology competitiveness – carbon capture and utilisation, artificial intelligence (AI), big data analytics – will favour technology licensors that can convert oil-based feedstocks to produce the maximum chemicals with the fewest utilities and the least waste gas production.
- Environmental pressures post-2020 on petrochemical use in advanced economies will force exporters to adapt, reducing carbon footprint, improving energy efficiency, and moving towards the circular economy.

VALUE CREATION IN PETROCHEMICALS COMES FROM INCREASING REVENUE, DECREASING COSTS OR BOTH

As with all businesses, petrochemicals can create value by reducing costs, increasing revenues or a combination (FIGURE 1).

FIGURE 1 VALUE CREATION IN PETROCHEMICALS



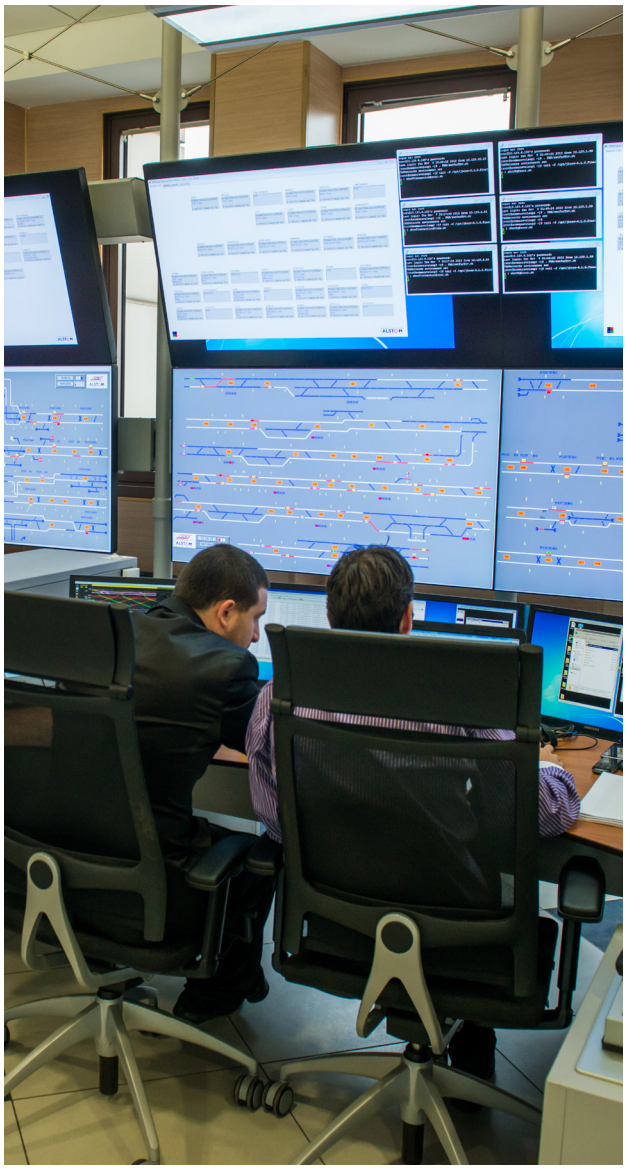
The period 2000-2014 saw a trend in pursuing advantaged (low-cost) oil and gas feedstock, whether in the Arabian Gulf, Russia or the US, or coal-to-chemicals in China. Pursuing economies of scale through building worldsize facilities, often integrated with refineries is another such trend.Chinese and Middle Eastern firms have made acquisitions, typically European companies, to gain technologies, access new markets, and improve operational practices. Large companies with low-cost feedstock, mostly in the C1 and C2 product lines, had about 20% of the industry's volume but captured 80% of the value additions in this period.

Meanwhile, oil-based producers in the C4 and C6+ chains, without low-cost feedstock, lost value over the same time. These include companies in Europe, Latin America, Japan, South Korea and Taiwan, many of which were forced to close or were acquired.

Product range and flexibility gains in mixed-feed crackers (typically running a combination of naphtha and ethane), give a broader range of outputs, though at higher cost.

Refinery integration can bring both savings in costs and gains in value, but with greater design, construction and operational complexity which must be managed.

Digitalisation and automation improve operations and gain value by greater market responsiveness. Downstream expansion – moving into more speciality chemicals, then into final products such as automobile components adds value, at both a firm and national level, but demands more sophisticated technologies.



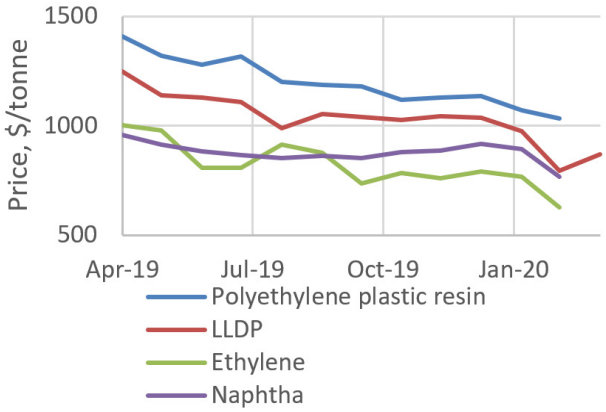
PETROCHEMICALS WILL BE THE NEW FRONTIER FOR OIL DEMAND POST-2020

The Covid-19 crisis has led to sharp declines in oil and gas demand and prices, interruptions to trade and normal activity in many countries, and disruptions to factory activities. The shape of the post-pandemic recovery is still uncertain, but the shock has emphasised the need for competitiveness, flexibility and robustness.

Even though 2019 represented an extended upcycle in petrochemical markets, global growth was already set for a decline in 2020 alongside forecasted declines in demand for transportation fuels, an erosion in margins from the entry of emerging market producers, and the imminent expiry of strategies based purely on the availability of the cheapest feedstock. Refinery-petrochemical integration was widely hailed as a buffer to future market trends with technology improvements, added robustness, and rising capital efficiency.

The falling prices of petrochemical products and feedstocks is shown in FIGURE 2. Even before the coronavirus struck China in late 2019, polyethylene plastic resin, linear low-density polyethylene and ethylene prices were already falling, but they dropped particularly sharply in March 2020, with the collapse in oil prices. The price of naphtha, derived from oil, was steadier before falling in March. Nevertheless, the margin between naphtha and ethylene almost disappeared in March, which would have made cracker operations unprofitable.

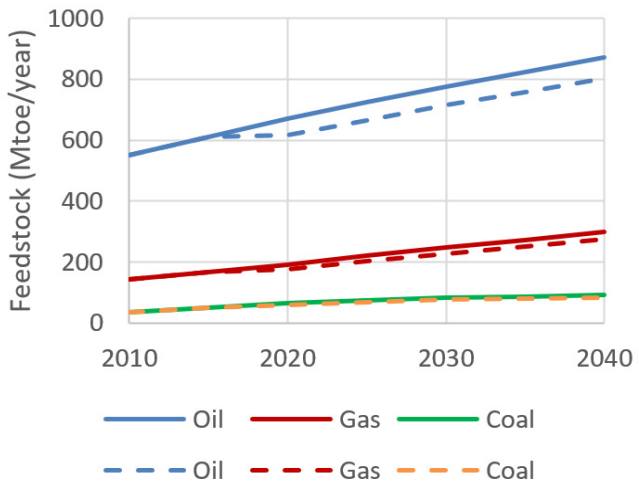
FIGURE 2 PETROCHEMICAL AND FEEDSTOCK PRICES IN CHINA[ii]



The Covid-19 crisis has exacerbated the trend of weakening demand – with a sharp downturn in 2020, and doubts over how quickly and fully the losses may be recovered. A relatively quicker rebound from the virus-related shutdowns in China and the rest of east Asia, is still overshadowed by the likelihood of losses in the key export markets of the US and western Europe.

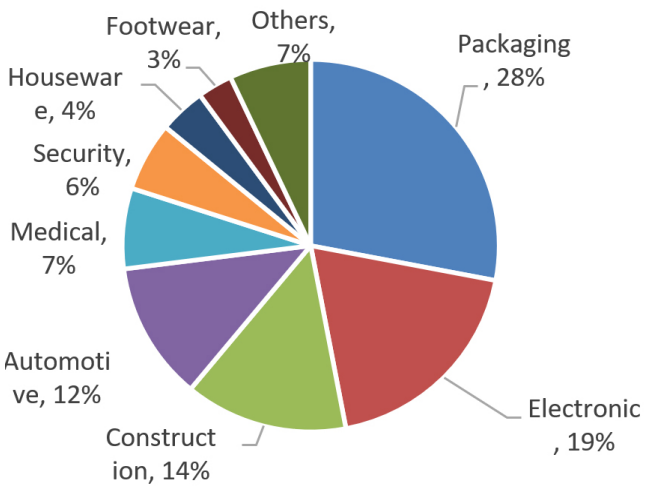
Assuming an 8% decline in global GDP in 2020,and a corresponding reduction in feedstock demand, not recovered post-crisis (an "L-shaped" recovery), the impact would be as shown in FIGURE 3. World demand by 2040 would be lower by 1.4 million barrels per day of oil, and 2.8 Bcf/day of gas. The impact is thus likely to be more consequential for the oil than the gas market, because use as feedstock is a larger share of oil demand, and is the sector of oil consumption expected to show most growth (this ignores permanent effects of the Covid-19 crisis on oil demand in transport and other sectors).

FIGURE 3 FEEDSTOCK DEMAND FOR INDUSTRY, PRE- AND POST-COVID (DOTTED LINES)[iii]



Petrochemicals cover a wide range of uses (FIGURE 4). In a post-Covid world, it can be imagined that packaging demand would grow due to more deliveries and need for disposable packaging ; medical use would also rise. Electronics may increase with more home working and entertainment, but construction and automotives are likely to fall, at least for a while, due to disruptions of production and construction, economic slowdown and the limited opportunities to make large purchases or move to a new house.

FIGURE 4 PETROCHEMICAL DEMAND BY END-USE



The staggering fall in the demand for transportation fuels and key refinery outputs – LPG, naphtha, gasoil/reformate – used as feedstock for petrochemical plants, has resulted in run cuts in major Asian and non-OECD markets. However, this has redirected attention to crude oil to chemicals (COTC) facilities as demand spikes for specific petrochemicals and polymers.

Cleaning chemicals, alcohol-based hand sanitiser plants, impact and heat-resistant polymers for thermal scanning, steam-sterilised polymers for medical use and chemical and bacterial resistance, and higher plastic packaging, will represent the largest segment of growth in the demand barrel in the near-term.

As European economies partially reopen, demand for specific polymer products shall soar to curb transmission and infection risks.

A REBOUND IN GLOBAL GROWTH AFTER 2021 WILL LEAD TO STRONG PETROCHEMICALS GROWTH

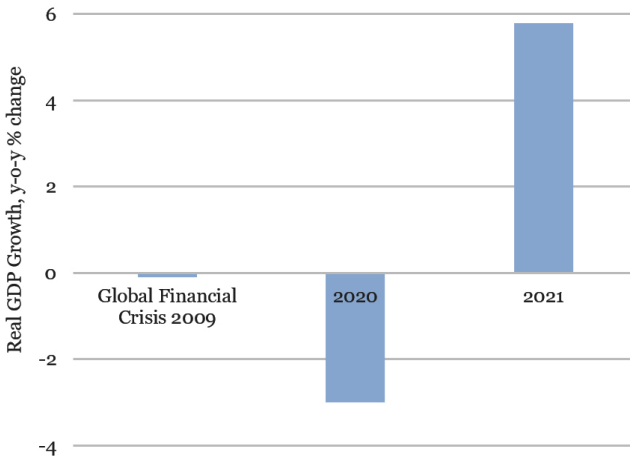
In future, flat refining capacity in OECD Europe and to an extent, in North America, will be counterbalanced by sharp growth in China, India, and other regions including the Middle East (see the Al Attiyah Foundation's Energy Research Paper Issue 40, December 2019). Countries still at plastics-intensive stages of development, mostly in Asia, will continue to lead demand. In the near-term, mature economies in Europe, North America, Japan, and Australia will witness a sharp spike in some plastics' utilisation due to virus-related measures.

A REBOUND IN GLOBAL GROWTH AFTER 2021 WILL LEAD TO STRONG PETROCHEMICALS GROWTH

In the long-term, per capita demand for plastics shall be concentrated in Asian economies, owing to a rise in construction and consumer goods, but mature economies shall lead in demand for specialty chemicals and polymers in medicine, R&D, and technological innovation in renewables and clean energy. Demand growth will shift from China, as its economy matures, to India and other large emerging economies such as Pakistan, Bangladesh, Indonesia and Vietnam, and also potentially some countries in Africa.

Traditionally petrochemical demand growth has tracked GDP growth in emerging markets, driven by the different end-user segments. However, since 1990, petrochemical demand elasticity has fallen, from 2x GDP to around 1.5x in 2018, forecast to 1x by 2025.

FIGURE 5 REAL GDP GROWTH, YEAR-ON-YEAR % CHANGE[v]

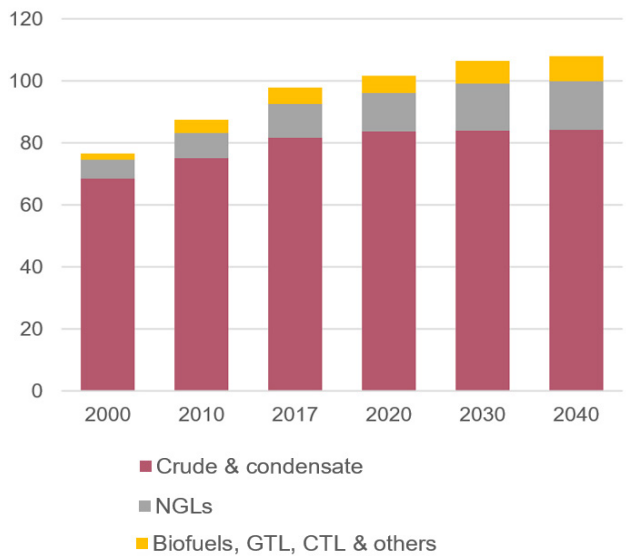


The current global recession has further slowed growth in China, and post-virus recovery in surrounding economies will also be slow. Global GDP is now forecast to diminish by 3% in 2020, the most since the Great Depression, (FIGURE 5), even if the pandemic peaks in the second quarter for most countries in the world, and recedes in the second half of this year. If not, the GDP reduction could be more severe, causing petrochemical demand growth to stagnate in the near-term.

The International Monetary Fund (IMF) predicts global growth to rebound to 5.8% in 2021, led by emerging markets. Anchoring future demand in emerging markets, will be key for oil exporters as other sources of demand growth, such as transportation fuels, slow or reverse. In the US, where the West Texas Intermediate (WTI) crude benchmark briefly entered negative territory for the first time in history, oil-based feedstocks can displace ethane in flexible crackers.

Growth in demand for petroleum liquids is forecast to be met mainly by natural gas liquids (NGLs) in the 2020s, and the current crude oil and condensate overhang means oil-based feedstock prices will remain low till global storage begins clearing. Crude and condensate will lead in meeting liquids demand, but post-2020, the rate of consumption growth shall stagnate. (FIGURE 6)

FIGURE 6 PETROLEUM LIQUIDS' SUPPLY FORECAST [vi]



In the short-term, gas-based feedstocks will lose out to oil-based petrochemicals, integrated with refining, as the cash cost advantages of shale gas and ethane in regions like the US and the Middle East decline. Most of the Middle East has allocated its associated and non-associated gas and reformed subsidies, while US shale production, which dramatically reduced natural gas and ethane costs, now faces massive production cuts. Oil-based petrochemicals can support value creation and have more room for sophistication and technology optimisation to convert maximum barrels into chemicals. Gas-based petrochemicals could still advance in some areas with low-cost feedstock, such as Iraq, Nigeria and East Africa, but these face difficulties of insecurity, lack of infrastructure and poor investment climates.

THE COVID-19 CRISIS EMPHASISES THE IMPORTANCE OF AUTOMATION AND DIGITALISATION

The spread of Covid-19 in early 2020 presented petrochemical plant operators with severe challenges. Normal staff rotations, and the use of specialist contractors and experts, were severely hampered by movement restrictions internationally and within countries. There was a risk of a severe outbreak spreading through a plant's staff and making it impossible to continue normal operations. Several oil and gas operations, including in the North Sea and Mozambique, did indeed suffer epidemics, as did other confined locations such as meat-packing plants in the US, cruise liners and naval vessels.

THE COVID-19 CRISIS EMPHASISES EVEN FURTHER THE IMPORTANCE OF AUTOMATION AND DIGITALISATION

Petrochemical plants also faced interruptions to supply chains, particularly because of the importance of China as a consumer and supplier of key equipment. Vessels suffered lengthy demurrage whilst waiting to unload while port operations were hampered.

Increased automation and the potential for remote inspection, monitoring and operations, would ease some of these concerns. Remote diagnostics of problems would limit the need to fly-in specialists. Drone inspections can be cheaper, safer and more comprehensive, covering areas not practically accessible to people. 3D printing / additive manufacturing of spare parts reduces the need to hold large stocks, especially for remote locations, and makes the supply chain more robust.

Such innovations would save costs and reduce health and safety exposure even in normal times. They are likely to become increasingly adopted as a standard way of working.

The turn to automation and digitalisation has longer-term benefits too, in reducing costs, increasing uptime, optimising maintenance through predictive methods, and increasing value creation by tailoring plant outputs to market signals. A "digital twin" of facilities allows operators to understand how to optimise and vary output. Similar models of competitors' facilities allow an understanding of how they will respond to price changes or market disruptions, allowing spotting arbitrage opportunities and inefficiencies.

Optimising operations will result in saving on feedstock and product storage, power generation, water, and waste disposal. In highly integrated petrochemical plants, artificial intelligence and big data analytics can be used to a much greater extent to design inputs and outputs specifically for extra flexibility, to make full use of such flexibility. Embedding existing refining units with AI can allow plants to predict future events such as equipment maintenance or possible disruptions by calibrating the plant's operations based on historical trends. Hybridisation and/or combination of several AI techniques can be applied to solve critical optimisation problems. Such techniques include evolutionary algorithms, swarm intelligence, fuzzy logic, artificial neural networks, and quantum computing. In the US, the Dow Chemical Company is partnering with 1Qbit and TeselaGen, to design experimental software using quantum computing to yield higher petrochemical output in response to market conditions. In Spain, Repsol's Tarragona refining complex is working with Google to optimise, with potential margin gains of $0.3 per barrel.

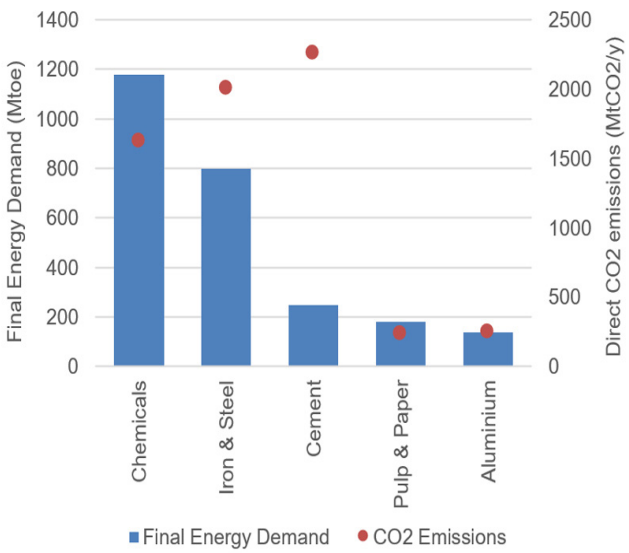
Such approaches are not a panacea, though, and must be adopted with careful planning. Many tasks can still only be done in person. Cybersecurity and data confidentiality are concerns for remote operations. 3D printing must address concerns over quality control and vendor certification.

Many of these challenges are common to oil and gas installations, refineries and other industries, and could usefully be addressed by consortia or industry fora.

VALUE CREATION ALSO ARISES FROM ADDRESSING RISING ENVIRONMENTAL PRESSURES

The global chemicals sector consumes close to 1200 million tonnes of oil equivalent (Mtoe) in energy annually, which is roughly the consumption of the iron and cement sectors combined. (FIGURE 7). However, CO^2 emissions are about 25% lower, partly because the sector consumes more oil and gas than other heavy industries, which tend to be more coal reliant. Carbon contained in petrochemical feedstocks is often locked into the final product, which also reduces emissions.

FIGURE 7 GLOBAL FINAL ENERGY DEMAND AND DIRECT CO^2 EMISSIONS BY SECTOR [vii]



Carbon taxation on imports of refined products and petrochemicals by European markets, in the medium-term, is a threat to less efficient producers or those in jurisdictions without carbon pricing or emissions caps. Governments in such areas may choose to introduce carbon taxation to retain revenues. In either case, petrochemicals producers would come under greater pressure to reduce greenhouse gas emissions. This can be done by methods such as:

- reducing fugitive emissions of methane;
- improving energy efficiency;
- increasing waste heat integration;
- improving preventive maintenance and operations to avoid unplanned shutdowns and process upsets;
- integrating with refineries to co-share by-products such as methane and hydrogen;
- co-locating with other industries to re-use heat and share utilities;
- switching from oil to gas for heating and power generation;
- making more use of renewable electricity and heat;
- employing carbon capture, use and storage (CCUS);
- introducing bio-feedstocks.

VALUE CREATION ALSO ARISES FROM ADDRESSING RISING ENVIRONMENTAL PRESSURES

In future, tougher environmental pressures will force petrochemical plants to adapt. Moves towards the "circular economy" and continuing demand for energy and resource efficiency and emissions reductions put a premium on environmental performance. Greenhouse gas emissions are probably the most important issue, but efficient use of water and materials (including their associated carbon footprints), and ensuring plastic reuse or recycling are increasingly important topics.

Tougher legislation on banning single-use plastics by 2021 in major world economies, shall threaten demand growth, but such measures may face delay in implementation due to the current crisis and acute need for polyethylene.

Environmental pressures can also come in the form of alternative non-fossil based feedstocks, such as bioplastics (from sugarcane, palm, and cassava), and possibly in future engineered life-forms such as algae, and synthetic materials made directly from CO^2 with renewable energy.

On the other hand, non-metallic materials offer growing promise for replacing traditional steel or aluminium in applications such as pipelines and well tubulars, and aeroplane and automobile bodies. A small amount of graphene can dramatically improve the tensile strength of concrete. Polymers and composites offer corrosion resistance and are light weight . Their carbon footprint is lower because of the lower energy consumption of manufacture and transport, and because they physically incorporate hydrocarbons permanently. On the other hand, they lack temperature and chemical resistance and have weaknesses in material properties. Continuing research can allow them wider applications.

CRUDE OIL TO CHEMICALS (COTC) IS THE LOGICAL NEXT STEP IN REFINING INTEGRATION – BUT FACES IMPLEMENTATION CHALLENGES

The COTC approach is described in detail in the Al-Attiyah Foundation's Research Paper Issue 34 (June 2019). Traditional refineries yield about 8-10% chemicals; integration with a steam cracker takes this to 20%; the current planned COTC plants achieve 45% and future technologies could reach 70-80%. Capital costs can be 10-20% lower and operating costs 5-15% lower than simple co-located plants .

The removal of a discrete refining step from the petrochemical value chain will increase the yield of high-value products such as ethylene (which yields polyethylene and PVC used in packaging and construction, and polystyrene in medicine and surgical applications), propylene (which yields polypropylene used in packaging, vehicles and consumer goods), and polycarbonates. Countries with large volumes of stranded petrochemical feedstock – such as China – will have the advantage of offering low-cost production, quickly and effectively, in the next few months as economic activity returns. However, other regions could capitalise on falling construction costs, to develop integrated refinery-petrochemical complexes and COTC facilities, once the outbreak recedes.

Countries like Saudi Arabia and China, that are developing major COTC projects currently, may lead global supply growth in the mid-2020s when these facilities are completed. However, Middle Eastern petrochemical projects are likely to face financing challenges as low oil prices diminish the resources of governments and state firms.

Because current refinery processing capacity is significantly higher than current world-scale petrochemical producers, COTCs can redefine the global scale at refinery level, increasing competitiveness against traditional refineries.

However, concerns over the rate of return on investment under the current climate will require high capital and construction efficiency in determining profitability, and the best process configuration and technologies to ensure operability and productivity. Engineering, operations and the overall investment size and project complexity for such expansions are greater, putting more emphasis on capital efficiency, technological know-how and execution, and a premium on expertise.

CARBON CAPTURE, USE AND STORAGE (CCUS) IS AN IMPORTANT TECHNOLOGY FOR THE INDUSTRY

CCUS will be an essential technique for maintaining the future environmental acceptability of petrochemicals. It applies to two sources of carbon dioxide (CO^2): that produced by the combustion of oil and gas for the plant's heat and electricity; and that released directly from cracking hydrocarbon molecules, including for hydrogen production.

In petrochemical processes where CO^2 is produced as a high-purity by-product (such

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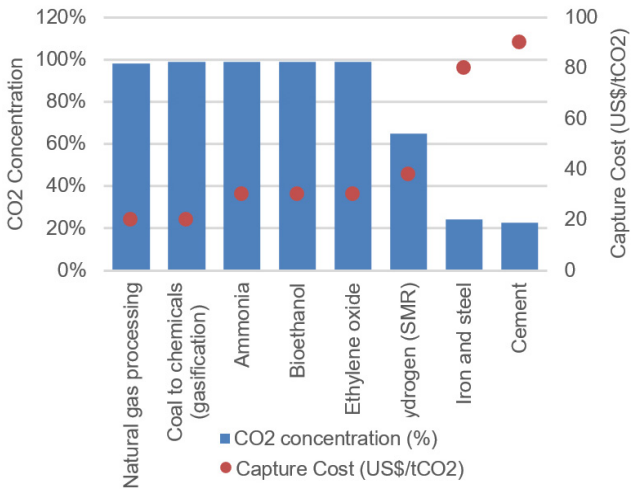
as ethylene oxide, methanol, hydrogen and ammonia production), it can be captured directly at relatively low cost. Waste products such as hydrogen and methane can be utilised as fuel and recycled, while CO^2 from ethylene oxide and ammonia production can be captured for use.

CO^2 can be used in several industrial applications. These include recycling for enhancing output of urea or methanol; greenhouses and agribusiness and horticulture, welding, construction, pharmaceuticals, medicine, packaging, bottling, and food and beverage processing. Future uses may include the direct production of synthetic ceramics, plastics and fuels. Enhanced oil recovery is a large-scale use very applicable in regions including the US Gulf coast, Arabian Gulf, north-east China and parts of Russia. If no beneficial use is readily available, CO^2 can be safely stored in deep saline formations underground.

Capturing CO^2 from many petrochemical processes is relatively cheap, at $28/t$CO^2$, compared to capture from other heavy industry and the power sector. (FIGURE 8). In the Middle East, petrochemical CCUS projects exist on a small-scale. These include Saudi Arabia's SADARA chemical facility in Jubail, which supplies captured CO^2 for regional industrial use, as well as for local production of methanol, urea, oxy-alcohols, and polycarbonates, and the Gulf Petrochemical Industries plant in Bahrain, which recycles captured CO^2 for increased urea and methanol production. In Qatar, the Qatar Fuel Additives Company has invested in a 0.18 $MtCO^2$/y capture facility at its refining operations to boost local methanol production.

FIGURE 8 CARBON CAPTURE COSTS BY SOURCE



Lower carbon footprints shall favour CCUS-integrated refinery-petrochemical operations. Highly-integrated refinery-petrochemical plants and direct COTC facilities with greater efficiency, including waste heat re-use (methane and hydrogen), can be more competitive. In China, single-use plastics were intended to be banned by 2020. Current CCS petrochemical projects directly captured CO^2 for enhanced oil recovery (EOR) operations, but in future could be integrated with existing COTC facilities such as Hengli and Zhejiang petrochemical plants to increase conversion to chemicals.

CO2 source/ industry	CO2 concentration (%)	Capture cost (US$/tCO2)
Natural gas processing	96-100	15-25
Coal to chemicals (gasification)	98-100	15-25
Ammonia	98-100	25-35
Bioethanol	98-100	25-35
Ethylene oxide	98-100	25-35
Hydrogen (SMR)	30-100	15-60
Iron and steel	21-27	60-100
Cement	15-30	60-120

CONCLUSIONS

Petrochemicals are currently challenged by the Covid-19 crisis, like most parts of the hydrocarbon business. However, they will still be key to future oil demand growth. This prospect is now solidly established, meaning that most national oil companies (NOCs) and several large international oil companies (IOCs) are already focussed on this area. With the fall in oil and gas prices and the full allocation of advantaged feedstock greatly reducing the competitive advantage of certain geographies, new petrochemical investments will have to be predicated much more on capital and operational improvements and market responsiveness.

Petrochemical companies will have to invest much more actively in technology, knowledge and skills, rather than just physical assets, to create value:

- Research and Devleopment of new products – non-metallic, bio-based and recyclable/re-usable;
- Redesigning capital assets and business models to make maximum use of digitalisation and its associated flexibility;
- Vertical integration (at a national and/or a firm level) into more sophisticated and speciality chemicals;
- Increasing refinery integration and considering the COTC approach for major new facilities;
- Re-invention of their business models around the circular economy, including using bio, CO^2 and recycled feedstocks;
- Environmental transformation, particularly in CCUS, and also in efficiency and use of renewables;
- Market insight and development, to grow beyond traditional markets in the OECD and China.

Such investment will require the major Middle Eastern and Chinese petrochemical firms to create or acquire more proprietary technology. This could involve purchases of existing, particularly European, firms, but this may be challenged by greater economic protectionism.

APPENDIX

i. https://www.mckinsey.com/industries/chemicals/our-insights/petrochemicals-2030-reinventing-the-way-to-win-in-a-changing-industry
ii. Data from ceicdata.com
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xi. Qamar Energy Research

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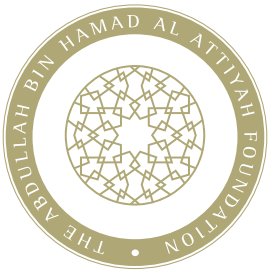

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