Petrochemicals: Changing Trends in Refineries

July – 2019

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

INTRODUCTION

PETROCHEMICALS: CHANGING TRENDS IN REFINERIES

We live in a time of economic uncertainty. Energy is buffeted by potential responses to climate change and the need to reduce CO2 emissions on the one hand, whilst responding to a growing world population and progression towards achieving the United Nations Sustainable Development Goals (SDGs) on the other. (see Appendix 2).

Within this context the Al-Attiyah Foundation hosted four international expert speakers to explore how the refining industry is evolving in response to these challenges.

CEO Roundtable Series

H.E. Abdullah Bin Hamad Al-Attiyah founded the CEO Roundtable Series as a platform for knowledge exchange and support for the global community in the quest towards a sustainable energy future. The quarterly events which have been hosted in Qatar for three-years are a crucial networking and learning opportunity in the calendar of industry CEOs.

** The series of events take place under the Chatham House Rule and will not be attributed to any individual.*

CEO ROUNDTABLE, 27 JUNE 2019, DOHA. SPEAKERS:

Dr. Andrew Spiers

Senior Vice President, Nexant Energy & Chemicals Advisory International.

Alan Gelder

VP Refining, Chemicals and Oil Markets Wood Mackenzie.

Professor Paul Stevens

Distinguished Fellow in the Energy, Environment and Resources Department, Chatham House.

Eric Duchesne

Senior Vice President Manufacturing and Projects, Total.

MODERATOR

Nawied Jabarkhyl

TV Presenter, Thomson Reuters.

HISTORICAL CONTEXT

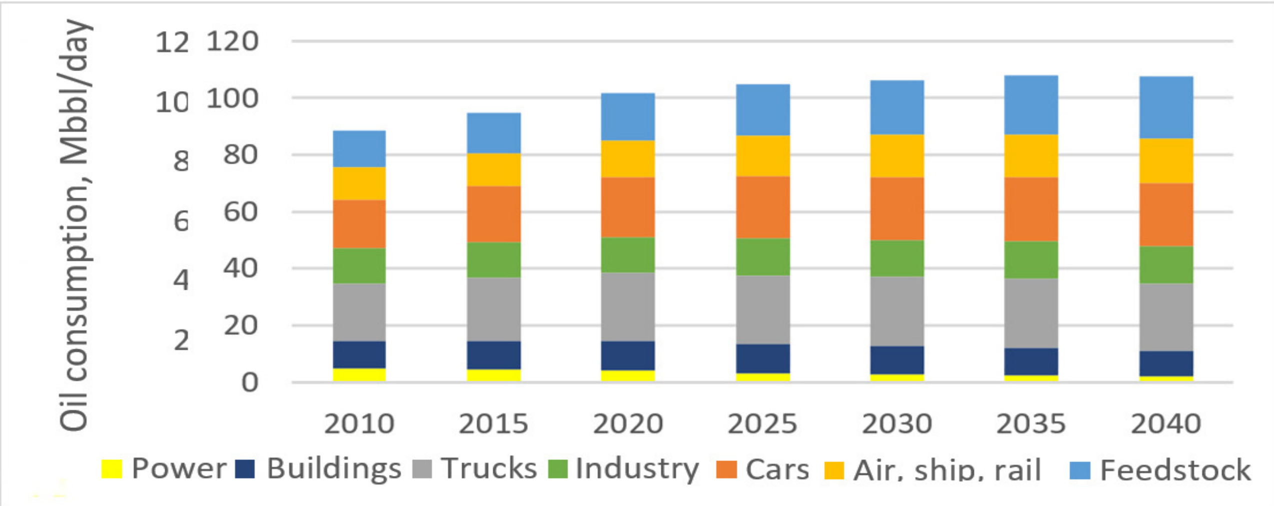
Historically, the basic economics of refining has been to refine at the place where demand exists – as crude oil and products are shipped by volume rather than weight – so it is always cheaper to ship crude rather than products! The advent of large crude carriers has emphasised this trend.

Small refineries were often established in crude supplying countries to provide a small domestic market and to ensure security of product supply. Gradually, crude suppliers have sought to capture some of these refining margins (that is the price to be gained from selling refined products above the price of the crude oil). In the meantime, domestic markets in crude oil supplier's home markets have grown dramatically. Consequently, concerns over the security of supply of all refined products has required those domestic refineries to grow.

FORECASTS OF OIL REFINING DEMAND

The general pattern of future demand is agreed by most oil company forecasters. Overall demand for oil products is seen to plateau out by 2040. Usage is not curtailed up to that date but switching has occurred from most uses into petrochemicals. Fuel efficiency in the vehicle fleet is considered to be a major factor in reducing demand for naphtha.

FIGURE 1 OIL CONSUMPTION 2010-2040 AND ANNUAL GROWTH RATE 2020-40[2]



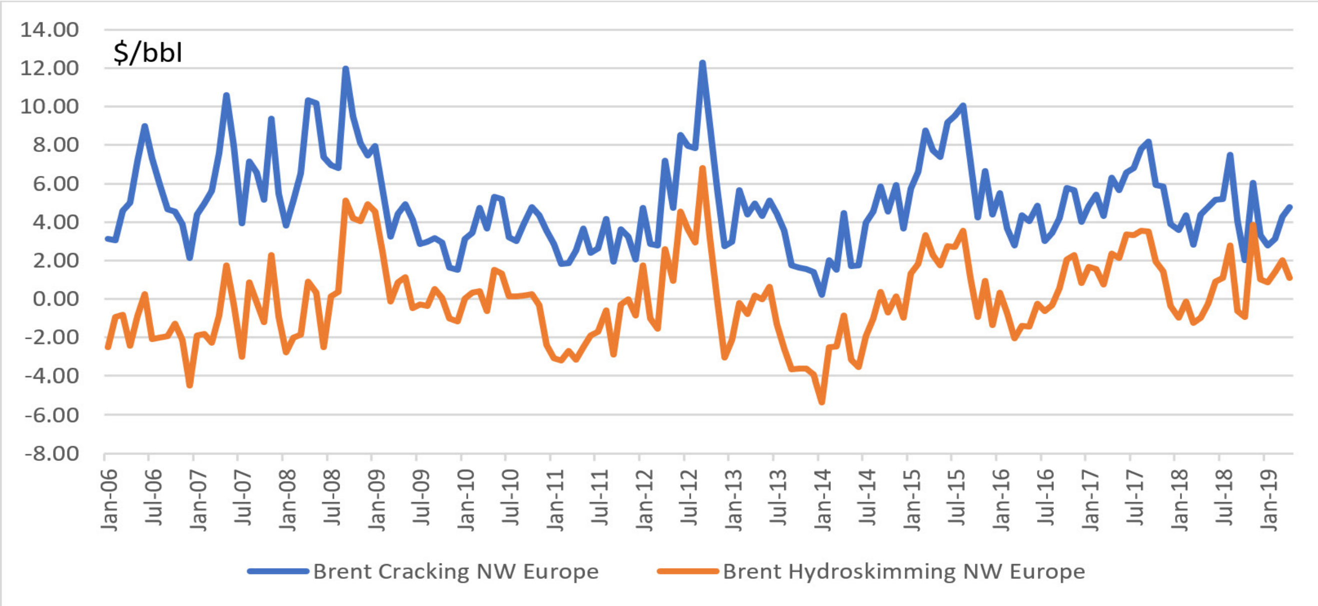
> Professor Paul Stevens gave a word of caution about these forecasts and said there was a probability that they were over optimistic about underestimating the speed of change. He talked about changes which should come about due to energy efficiency across the whole range of energy uses.

THE FIGHT FOR MARGINS

All industries need to make a profit, so there is a continuous fight to achieve a margin, the difference between revenue and costs. The fossil fuel and petrochemical industries are no different.

Refining margins in the energy industry have typically been tight; sometimes negative, often following investment cycles. As demand has increased then so too have the margins. Eventually, the margins are large enough to justify investments and so this occurs. As the new investment comes on stream, margins again narrow. We see that margins for a typical hydroskimming refinery in Europe rarely exceed \$4 / bbl. Cracking margins are always greater and can exceed \$10 / bbl. (See Appendix 1) .

FIGURE 2 REFINING MARGINS BRENT CRUDE EUROPE[3]



Ethane is essentially a by product of natural gas where fields can be considered wet i.e. rich in by products higher than C4's (methane). As long as ethane can achieve a margin higher than its thermal value, then it pays to extract ethane from natural gas. For wet, gas rich, countries this makes much sense as this margin is easily reached. Furthermore, ethane cracks (converts to ethylene by hydrogen removal) easily to ethylene, which is the most useful building block available to the petrochemical industry.

Ethane also comes from cracking naphtha, condensate and LPG's. This route is used by many producers in Asia and Europe who do not have a ready availability to competitively priced ethane. However, naphtha cracking is more expensive than ethane cracking as by product streams such as propylene and butadienes have also to be monetised and logistically handled. Cracking may also occur for light distillate, in the longer term, but demand for such distillate for aviation and household kerosene and diesel appears to be undiminished at present.

This has given a distinct advantage to petrochemical producing countries who have ethane rich natural gas available. It is noted that ethane crackers also produce hydrogen which refineries are always short of to sweeten product streams and some methane which is used for fuel.

HISTORICAL CONTEXT

PRICE FLUCTUATIONS

Basic petrochemicals such as polyethylenes have their own boom bust cycles but these tend to be more stable than for oil and gas Also, petrochemicals because petrochemicals are more closely linked to GDP than oil and gas. World GDP is growing steadily and is driven by population growth and the desire of populations to attain the United Nation's Sustainable Development Goals. (UN SDGs) The economic treatment of cycles of boom-bust and price cobwebs are explained more fully in Appendix 1.

Dr. Andrew Spiers

> Dr. Andrew Spiers of Nexant emphasised that with limited availability of gas for new petrochemical investments in the region, it is turning its attention to petrochemical production from refineries. This is a trend that has successfully been used in Europe to significantly add value to refined products. It will be down to the economies in the region to further diversify their industrial base.

VILIFICATION OF PLASTICS

The role of plastics in society was discussed during the roundtable. Undoubtably, there is a groundswell of opinion against single use plastics bags and against plastics causing ocean pollution. The moves towards a Circular Economy and greater recycling of products will alleviate some of these concerns. However, the debate can be complex. Is it easier to recycle designed artificial products or natural ones? Which saves the most fossil fuel and water?

Whilst perhaps a minor point, it was noted that when petrochemical prices dip, then of course petrochemicals become more competitive against natural products. This drives technological innovation. It is a competition from which natural products find hard to survive.
Some examples of this competition are easy to identify:

- Wood to PVC or ABS (Acrylonitrile Butadiene Styrene);
- Wool and cotton to nylon and polyesters;
- Hemp to polypropylene and polyesters;
- Natural rubber to Poly-butadiene's and Poly-chloroprene's.
- It is noted that natural products are gradually being driven to become niche or premium products rather than mainstream ones.

THE CAR INDUSTRY

Conversations about climate change and the move towards electrification tend to be somewhat gloomy for the car industry. The gloomy picture may be true for gasoline and diesel consumption, but more cars generally means more petrochemicals which can be (high value and clever) engineered plastics.

> Alan Gelder of Wood Mackenzie emphasised that forecasting the future when technical change is fast is not easy. When transport becomes electrified then change may be dramatic.

Alan Gelder

OBSERVATIONS: THE OUTLOOK FOR THE INDUSTRY

The refining industry will have to cope with a plateauing demand and more emphasis on petrochemicals. The industry therefore, should seek to become more efficient and more integrated.

> Mr. Eric Duchesne, Total, said that whilst he recognised that projects were getting larger and more integrated, the industries had an over whelming problem. That was a shortage of talent within the industry. The engineers and other design staff were ageing and manufacturing industry in general does not have a positive image.

Eric Duchesne

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 1 PRODUCT SYNERGIES BETWEEN REFINERY AND PETROCHEMICAL PLANT4

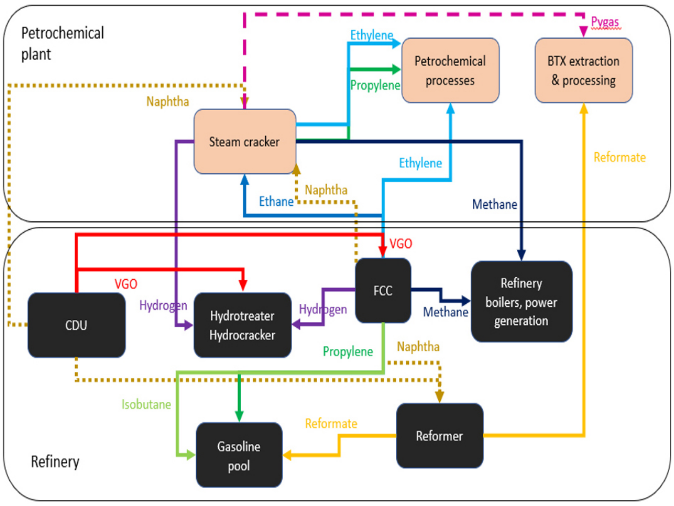
Refinery	Petrochemical plant
Surplus of benzene and other aromatics due to tightening product specs	Uses aromatics
No use for ethane	Consumes ethane for ethylene
Surplus of unsaturated gases	Uses ethylene, propylene for further conversion
Shortage of methane for fuel	Excess methane
Shortage of hydrogen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

The petrochemicals industry is also changing, as commented previously, petrochemical margins have historically been more stable than refining margins. Therefore, refineries seek to integrate further downstream to stabilise overall margins and mitigate the inherent price risk. This switch to petrochemicals will provide an outlet for light distillate and naphtha which would have otherwise gone to gasoline, jet kerosene and diesels.

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

FIGURE 3 EXAMPLE OF PRODUCT FLOWS IN AN INTEGRATED



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

TABLE 2 PRODUCT SYNERGIES BETWEEN REFINERY AND PETROCHEMICAL PLANT[4]

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%	

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 Mbbl/day of feedstock (from total feedstock of 22 Mbbl/day) could be used in COTC plants by 2040.

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%.

A Nexant study[4] considered a 200, 000 bbl/day refinery, where integration reduced gasoline output by 42 000 bbl/day in return for producing 1900 tonnes per 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, with a potential margin gain of $0.3 per barrel .

INTEGRATION ALSO BRINGS A NUMBER OF CHALLENGES

The required investment in an integrated plant is much larger and the project management risks are higher.

Designing and operating the plant optimally is more complicated. Crude oil to chemical (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.

Most of these studies considered green-field projects. However, 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.

We observe that much is already happening. Middle East National Oil Companies and Asian conglomerates (primarily Chinese) appear to be the key developers of new capacity. Recent announcements on new refineries focus particularly on integration, mainly in the case of joint-venture refineries built by Middle East national oil companies (NOCs) in their home territories and in Asia. Regionally, 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 all notable. The Refinery And Petrochemical Integrated Development (RAPID) in Malaysia is a $27 billion joint venture between Petronas and Saudi Aramco, while Aramco and ADNOC, in partnership with several Indian state oil companies, plan a 1.2 million bbl/day integrated refinery at Ratnagiri in western India.

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 kbbl/day plant in East Java. The average global refinery yields about 8-10% chemicals. By contrast, 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% 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 that can run anything from crude oil or naphtha to ethane . The most notable new such project is the Aramco/SABIC COTC plant at Yanbu', costing $20 billion, with 45% chemicals yield. Further technology development could take this to 70-80%.

TABLE 3 SHARE OF REFINERY OUTPUT BY PETROCHEMICALS PLANT[4]

Level of integration	Share of chemicals in output	Increasing integration
No integration	8-10%	
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The discussion noted that new large integrated plants may solve problems on the refining side by shifting demand from gasoline to chemical naphtha. But these plants are large and any given plant coming on stream may exceed an annual increase in demand for those petrochemicals. The boom–bust cycle may be reinforced.

However, new large integrated refinery–petrochemical plants will be flexible, efficient and achieve economies of scale. Standalone and small refineries are already in danger of becoming non-economic and a few have already closed for this reason.

Refinery size has also been driven by economies of scale being achieved. Refinery investment does not have a linear relationship with refinery size on a barrel per day capacity. Furthermore, operating costs have similar non-linear relationship – particularly on operator costs. Technology has also improved on control systems, and thereby moving the 'diseconomies of scale' further to even bigger refineries.

SUMMARY OF DISCUSSIONS

There are many uncertainties surrounding the demand for refined products and for petrochemicals. Refining, in its current form, has a challenging future, as the energy transition takes hold and the focus on climate change gathers momentum along with the need for greater circularity. The energy transition reduces the demand for transportation fuels. These factors threaten the sustainability of conventional refineries that are competitively weak.

A Circular Economy ultimately requires chemical recycling of plastics. Refining retains a role in the production of high-quality fuels, but it needs to migrate away from the sole focus of converting crude oil. Refiners need to extend their role along the value chain, so integration with petrochemicals and the local community (through district heating schemes) and ultimately chemical conversion of waste.

Capacity additions will continue to outpace demand growth, so reducing global utilisation and ultimately driving capacity rationalisation in OECD markets.

Chemical integration is key to achieving a strong competitive position and providing future optionality (fuels or chemical feedstocks). Standalone refineries and chemical plants without a strong feedstock advantage are vulnerable to closure.

RECOMMENDATIONS FOR QATAR

The competitive advantage for Qatar for ethane is obvious. Qatar is already going down this route with its recently announced LNG expansion and the availability of ethane for the building of a new large ethane cracker.

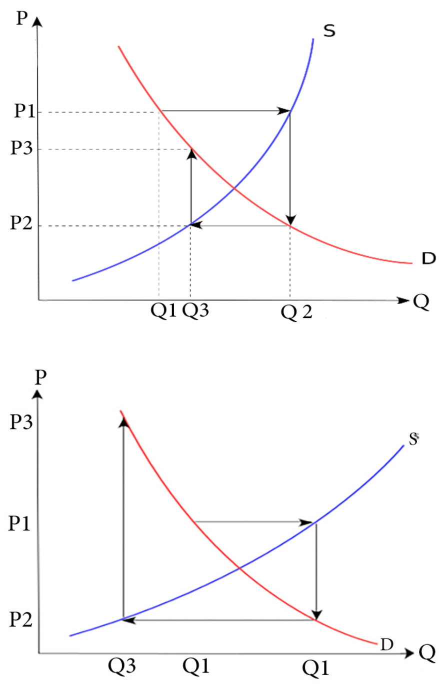
Outside the LNG and Petrochemical industries, many other possibilities exist to optimise the use of by products and side streams. Particular emphasis was made as to the availability of hydrogen from the proposed new ethane cracker in Qatar. Hydrogen is particularly useful in refineries for sweeting of all refinery streams. Hydrogen may also become short in refineries as reforming activities for gasoline production are curtailed.

APPENDIX 1

Price Fluctuations

Prices and margins have often fluctuated widely in the Fossil Fuel and Petrochemical industries. This is because they are acting as typical commodities and give rise to typical boom – bust or cobweb cycles.

FIGURE 4 PRICE “COBWEBS”[iv]



The cobweb model is generally based on a time lag between supply and demand decisions.

Agricultural markets are a context where the cobweb model might apply, since there is a lag between planting and harvesting (Kaldor, 1934, p. 133-134 gives two agricultural examples: rubber and corn). Suppose for example that as a result of unexpectedly bad weather, farmers go to market with an unusually small crop of strawberries.

This shortage, equivalent to a leftward shift in the market's supply curve, results in high prices. If farmers expect these high price conditions to continue, then in the following year, they will raise their production of strawberries relative to other crops. Therefore, when they go to market the supply will be high, resulting in low prices. If they then expect low prices to continue, they will decrease their production of strawberries for the next year, resulting in high prices again.

This process is illustrated by the adjacent diagrams. The equilibrium price is at the intersection of the supply and demand curves. A poor harvest in period 1 means supply falls to Q1, so that prices rise to P1. If producers plan their period 2 production under the expectation that this high price will continue, then the period 2 supply will be higher, at Q2. Prices therefore fall to P2 when they try to sell all their output. As this process repeats itself, oscillating between periods of low supply with high prices and then high supply with low prices, the price and quantity trace out a spiral. They may spiral inwards, as in the top figure, in which case the economy converges to the equilibrium where supply and demand cross; or they may spiral outwards, with the fluctuations increasing in magnitude.
The cobweb model can have two types of outcomes:

If the supply curve is steeper than the demand curve, then the fluctuations decrease in magnitude with each cycle, so a plot of the prices and quantities over time would look like an inward spiral, as shown in the first diagram. This is called the stable or convergent case.
If the slope of the supply curve is less than the absolute value of the slope of the demand curve, then the fluctuations increase in magnitude with each cycle, so that prices and quantities spiral outwards. This is called the unstable or divergent case.

APPENDIX 2

United Nations Sustainable Development Goals
The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice. The Goals interconnect and in order to leave no one behind, it ís important that to achieve each Goal and target by 2030.

1. No Poverty
2. Zero Hunger
3. Good Health and Well-being
4. Quality Education
5. Gender Equality
6. Clean Water and Sanitation
7. Affordable and Clean Energy
8. Decent Work and Economic Growth
9. Industry, Innovation, and Infrastructure
10. Reducing Inequality
11. Sustainable Cities and Communities
12. Responsible Consumption and Production
13. Climate Action
14. Life Below Water
15. Life On Land
16. Peace, Justice, and Strong Institutions
17. Partnerships for the Goals.

APPENDIX 3

References

1. https://en.wikipedia.org/wiki/Sustainable_Development_Goals

2 . BP World Energy Outlook 2019

3. Nexant 'Advancing Refining Petrochemicals Integration in the Arabian Gulf' https://gpca.org.ae/wp-content/uploads/2018/03/Refining-Petrochemical.pdf

4. June 2019 Al-Attiyah Foundation Research Series

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