



ADVANCING REFINING PETROCHEMICALS INTEGRATION IN THE ARABIAN GULF





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Introduction

Petrochemicals facilities transform gas and liquid hydrocarbons to a wider range of petrochemical products. The feedstocks used to produce these chemicals, such as LPG, naphtha and gasoil, are often from refinery sources. Integrating refinery and petrochemical production can provide operational and economic gains. Globally, approximately 74% of ethylene production is based on liquid feedstocks, the large majority of which is derived from refinery streams. As shown in Figure 1.1, the most commonly encountered liquid streams for petrochemical production are naphtha and gasoil.



Figure 1.1 Global ethylene production by feedstock type, 2016 Capacity



The refinery - petrochemical interface

The optimum way of operating an oil refinery is to maximize the production of fuels from crude oil. Fuel production is different from petrochemical production. Fuels are produced as a blend of refinery streams, each stream having its own process route. A number of process technologies can be required to be coupled together in order to produce blend components for each fuels pool. Most refineries have more than one fuel pool but typically include a gasoline and diesel pool.

To illustrate further, a gasoline pool and its component blend streams can be considered. Propylene from an FCC is processed with isobutane to produce alkylate. Naphtha is processed in a reformer to produce reformate, a component that is rich in aromatics and has a high value into gasoline blending. Reformate and alkylate amongst other blendstocks are blended to produce finished gasoline. These streams also have uses in petrochemical facilities and can be used to generate higher profitability. This is detailed in Table 1.1. A petrochemical facility, typically in the production of olefins, predominantly removes hydrogen to produce functionalized, more reactive, unsaturated molecules which are used to produce intermediates. Byproducts are also formed which are of lower value to the petrochemical facility. In most cases, these byproducts can be used by the refinery in some way. For example, a steam cracker generates light olefins (ethylene and propylene) and produces hydrogen and methane as major byproducts. Methane can be used as fuel, whereas hydrogen has been increasingly consumed as a raw material in refineries because of cleaner fuels programs. Increases in the price of natural gas have resulted in the hydrogen requirement becoming a troublesome, additional operating expense for refiners, especially in regions with high natural gas prices. Integrating a steam cracker with a refinery provides a useful outlet for the hydrogen byproduct. Other cracker byproducts are also useful for refineries.

Stream	Origin	Refinery Use	Alternative
Refinery Dry Gas	CDU, Process Units	Refinery Fuel System	Petrochemical Feedstock
Ethylene	FCC, Coking, Visbreaking	Refinery Fuel System	Petrochemical Building Block
Propylene	FCC, Visbreaking	Alkylation Value	Petrochemical Building Block
Propane	CDU, Conversion Units	Refinery Fuel System	Petrochemical Feedstock
Butane	CDU, Conversion Units	Gasoline Blend Component	Petrochemical Feedstock
Naphtha	CDU, Process Units	Reformer Feedstock	Petrochemical Feedstock
Reformate	Reformer	Gasoline Blend Component	Aromatics Production

Table 1.1 Select refinery streams and alternative uses

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Transfer prices for interface streams

An effective way of addressing the commercial aspects relating to the hydrocarbons which are transferred between a refinery and a petrochemicals facility is a transfer pricing mechanism. At an early stage, an upper and lower limit for each stream can be developed. The limits facilitate broad agreement across stakeholders. For key streams, there is a value to the refiner and a value to chemicals. The exact valuation is site specific and a function of:

- an alternative physical market for the stream, if it exists
- alternative value within the location linking to alternative streams or molecules
- cost to produce or dispose

During commercial negotiations, the upper and lower limits are negotiated to an agreeable formula. To achieve transparent and fair pricing, separate consideration for each stream is required. Project location and consideration of prevailing supply, demand and net trade positions are required to define pricing terms. One of the most critical streams is naphtha, which is the main feedstock for both steam cracking and aromatics production. There is a large transparent liquid market for naphtha from the Middle East and many transactions are conducted by reference to the prevailing Arabian Gulf price. The process does not work for a number of other streams such as hydrogen, dry gas, pygas and mixed C4s, for which local prices need to be agreed.

At the interface between refinery production and petrochemical feedstock supply, the real complexity of integrating production can be observed. In an optimized situation, both facilities operate to maximize profitability making use of byproduct streams from the adjacent facility to their individual and eventually overall economic benefit. Stream transfers are established in both directions for mutual commercial and operational benefit. Often complex pricing relationships control value transfer. A summary of the potential interfaces between the refinery and petrochemicals can be seen in Figure 1.2.

Refinery Stream	PC Transfer Direction	Pricing Boundaries	
		Lower	Upper
Hydrogen	←	Fuel Value parity	On purpose production cost
Ethane	\rightarrow	Market price	Fuel Value
Naphtha	\rightarrow	Export Parity	Import Parity
Dry Gas	\rightarrow	Fuel value	Contained value for each component
Pyrolysis Gasoline	←	Gasoline Blend Value	Full aromatics extraction
Pyrolysis Fuel Oil	←	Fuel Oil Value	Fuel Oil Value
Mixed C4's	←	Gasoline Blend Value	Value to Butadiene
Raffinate 1	<i>←</i>	Gasoline Blend Value	

Table 1.2 Potential exchange stream pricing guidelines







Figure 1.2 Summary of refinery petrochemical interface options

Integration options

The most common ways in which refineries are integrated with petrochemicals production include:

- Refinery integrated with steam cracker
- Refinery integrated with aromatics complex
- Refinery integrated with steam cracker and aromatics complex

Integrating a refinery with a steam cracker provides feedstock for light olefin production with a significant production of valuable co-products. Some of the co-products have refinery uses such as hydrogen and pygas which can be used for fuels production. Some indicative processing options for feedstock and the resulting possible return streams from the cracker to the refinery are shown in Figure 1.3. In the case of integrating aromatics with refinery production, an analogous situation can be envisaged. Heavy naphtha from the refinery is used to produce reformate, rich in aromatics, and other byproducts which have refinery uses. The simplified diagram in Figure 1.4 shows this relationship.

Although the integration of a steam cracker and a refinery is probably the most common example of refinery petrochemical integration, the most complex embodiment includes the addition of an aromatics complex to the scheme. The integration of a refinery, a steam cracker and an aromatics complex result in a large number of potential exchanged streams, creating a higher level of interdependency and complexity. The scheme is illustrated in Figure 1.5.

There are several key processing advantages with this type of integrated scheme which is capable of making the best use of all of the streams in the complex.





Figure 1.3 Refinery integrated steam cracker



Figure 1.4 Refinery – Aromatics interface









Figure 1.5 Refinery – Aromatics-Steam Cracker Interface







Regional analysis

Figure 1.6 Industry integration global)



Para-xylene is generally more integrated to refineries than olefins (ethylene and propylene) in most regions of the world. Ethylene has the lowest share of integration since most ethane based ethylene are not integrated to refineries, typically in the US and the Middle East.

The extent to which any of the technically feasible integration options can be implemented and produce economic benefit is a complex discussion. Regional trends for feedstock availability, process economics and product demand as well as ownership issues all potentially play a role. As a result, the extent of refinery petrochemical integration is not uniform across regions. The degree of refinery integration for ethylene production is illustrated in figure 1.7.



Figure 1.7 Ethylene integration by region







Figure 1.8 Propylene integration by region



A number of factors give rise to the varying level of integration. However, some inferences can be drawn. Petrochemical feedstock is an important driver in the large majority of cases. Availability of NGL feeds, such as ethane, reduces the dependence on refinery based liquid feedstocks as seen in the US and the Middle East. The result is a lower degree of refinery petrochemical integration. The converse situation is also true in which reduced availability of NGL's forces increased levels of integration. The analysis shown is for ethylene. Although propylene and aromatics production have different levels of integration than ethylene, similar trends can be drawn.

The level of integration in the Middle East is relatively low as propane is used to generate propylene in standalone facilities.

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Incremental economic analysis

Petrochemical integration does improve overall process economics for both the component refinery and petrochemical facility. Assessing the overall economic benefit is important in the planning stages of any such project. Nexant's economic analysis addresses the overall profitability gains for a refinery-integrated petrochemical complex by comparing it to a standalone refinery. The refinery model is based upon a fluidized catalytical cracker and visbreaker refinery which converts heavy residues into diesel) and is capable of processing light sweet to medium sour crude oil, ranging from Brent crude oil for Western Europe and up to Arab Light for Asia and the U.S. Gulf Coast.

For the case of a refinery-integrated petrochemical complex, a steam cracker is added to the configuration. The model has been developed to select the economically optimum cracker feedstock between light and medium naphtha, allowing both or either to be processed.

Integration of steam cracker byproducts with the refinery production is modeled so as to reflect commercial practice. Methane from the steam cracker is used by the refinery fuel system. Byproduct hydrogen of high purity is used within the refinery for hydroprocessing and other hydrogen consuming processes, reducing the requirement from reforming of natural gas. Ethylene and propylene are sold as final products on a polymer grade basis. Butadiene is extracted from the C4 fraction and sold, with the remaining C4 sold as Raffinate 1. Most integrated naphtha crackers extract valuable benzene from the pygas. This is advantageous as it recovers a valuable product as well as enables more of the pygas to be blended back into the gasoline pool without reaching the maximum benzene limit. The remaining fractional product, pyrolysis fuel oil or the C10+ stream, is allowed to be blended into the fuel oil pool as a cutter stock, reducing viscosity and sulfur content.

Impact on the refinery

Integrating a petrochemical facility with a refinery does invariably affect the refinery production. The overall impact of petrochemical integration on the refinery yields is illustrated in Figure 1.7, for the Western European case. Distillate range kerosene and diesel fuels production remains largely unchanged. The operation of the FCC and diesel and kerosene hydrotreaters is also not affected by the addition of the cracker. A small net increase in the fuel oil production is due to the production of pyrolysis fuel oil as a blending component. The predominant impact is on the gasoline pool, where balances are changed significantly. The overall production of gasoline is reduced by approximately 5,000 tons per day or approximately 42,000 barrels per day. This reduction is counterbalanced with an increase in higher value cracker products.

The increase in petrochemical production is significant in the integrated model, with total ethylene production of approximately 1,900 tons per day or 630,000 tons per year. About 470,000 tons per year of propylene are produced, with around 100,000 tons per year being recovered from the refinery FCC and the balance coming from steam cracking. Other products have a smaller, but significant contribution. Butadiene is approximately 1% of the total complex production, and benzene accounts for approximately 2%.

The light olefins production is the most significant petrochemical contribution to the refinery yield, accounting for approximately 15 weight percent of the refinery production from crude. The associated higher value brought by these products improves the economics and profitability of the refinery.

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Figure 1.9 Refinery-petrochemical integration - changes in product tonnage (Western European case)

Incremental revenues and margins

In order to examine the economic benefits of integration, a comparison of the economics of the standalone refinery and the integrated complex was developed from historical pricing data between 2005 and 2014, based upon the same crude oil and the same processing capacity of approximately 200,000 barrels per stream day (BPSD). Figure 1.10 shows the revenue streams for both the standalone refinery and the integrated refinery/ olefins complex.

The integrated complex clearly has higher overall revenue than the standalone refinery, which is a result of the net increase in petrochemical volume from the integrated complex. The actual profitability of either complex is determined by computing the margins achieved. The gross margin, in dollars per barrel, has been defined as follows:

(Total product revenue - Cost of feedstock purchases) / Barrels of crude processed.









As shown in Figure 1.11, the actual gross margin of the standalone refinery varied between approximately USD 3.3 to USD 6.4 per barrel between 2005 and 2014. Strong refining margins in the period of 2005 to 2008 were due to high levels of demand for refined products from strong global GDP growth, particularly diesel. Economic growth took a downturn in 2008, with global recession causing refining margins to decrease. Margins remained low until 2011 and improved thereafter. Throughout this period it can be seen that the comparable margin for the integrated complex is considerably higher. Petrochemical product revenue almost doubles the observed gross margin from the complex. Another important benefit is the difference in the nature of the two profiles when considered from the perspective of cash flow. In 2008 and 2009, when refining margins declined sharply, overall gross margins for the integrated complex also reduced but fared better with overall cash flow being higher as a result of associated petrochemical production. Post 2009, the recovery was also much more marked for the integrated complex than for the standalone refinery.

The impact of the benefits of integration can be summarized in the following way, with averages over the period 2015-2014 included:

- Average refinery gross margins of USD 4 per barrel
- Average leader cracker variable cost margins, including butadiene and benzene extraction: USD 600 per ton of ethylene, equivalent to USD 5.2 per bbl of oil
- Average integrated refinery/petrochemical gross margins of USD 12 per barrel.

This means that integration has enhanced the overall margin by approximately USD 2.8 per barrel of oil, and most of this will arise from the processing of alternative feedstocks than naphtha into ethylene.

Figure 1.11 Comparative gross margins (Standalone refinery and integrated complex, Western Europe)





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Ownership structures

When integrated, refinery and petrochemical production can result in increased profitability. The two entities are actually separate businesses largely having different growth rates and business cycles. This can sometimes lead to each entity being organized under separate ownerships structures and part of wider organizations having independent profit and loss accounting. Sometimes the two entities are owned by the same company without a higher central reporting structure. Between these two boundaries, specific variations exist.

The process of integrating a refinery and petrochemicals facility for common production can be challenging, both technically and economically. Consideration needs to be given to the most important technical aspects of the integration which are driven by the largest commercial gains for both parties.



Opportunities and challenges for the GCC

Refinery and petrochemicals integration challenges are not radically different from those seen in other regions. Western Europe has had to review and seek maximum benefits where possible from such integration due to the cost pressures on its operations. Asia has seen the greatest amount of new petrochemical plants built alongside refineries, driven by the need for new refineries and also petrochemical capacity. It has been seen in recent years that many new refinery projects would not have been financed without the support of the additional margins arising from the adjacent petrochemical assets.

The GCC challenges arise from the lack of new low cost ethane availability. In addition new olefins projects in the region will be processing mainly liquid feedstocks such as LPG and naphtha. The national governments are also offering licenses to produce to those companies that can demonstrate that their project will be able to diversify the range of chemicals being produced, which in itself necessitates the use of LPG/naphtha feedstocks as the building blocks.

All these factors lead to the conclusion that the region will see increased levels of integration between refineries and petrochemicals. The Liwa Plastics project, due to come onstream in 2020, is one example of an integrated refinery/ polyolefins complex. However the level of integration is linked to an existing refinery and a portion of a new expended refinery.

Key challenges for the region

- Most refineries are owned by the national governments. Investment strategies are linked to long term policies on fuels management.
- Investments in chemicals are often undertaken in partnership with foreign investors. Foreign investors may have different project objectives to state owned refineries. This can also impact governance issues.
- A world scale fully integrated refinery and petrochemical complex can be a very large investment. Project financing of these mage projects create their own challenges.

Integrating a mixed feed ethylene plant with a refinery can lead to a wide range of new building blocks for petrochemicals. This increases the potential for greater diversified industries, depending upon the level of integration, there are significant margin enhancement opportunities. The Middle East is poised to take advantages from both of these opportunities.

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About Nexant

Nexant Energy & Chemical Advisory Services offers clients a suite of products and advisory services with an exclusive focus on the energy, chemicals, and related industries. Using a combination of business and technical expertise, with deep and broad understanding of markets, technologies and economics, we provide solutions that these industries have relied upon for over 45 years. Services include Strategic Investment Studies, Market and Technical Due Diligence, Strategic Growth Plans, Independent Engineering, Project Feasibility Studies, Industry Analytics, Forecasting and Market Research, Litigation Support and Expert Testimony. NexantThinking report subscription programs and online product portal, formerly known as ChemSystems®, provides customers with insightful analytics, forecasts, and planning tools for the fertilizers, chemicals, polymers, oil & gas, energy and clean tech sectors. Global in scope, Nexant serves its clients from over 30 offices located throughout the Americas, Europe, the Middle East, Africa and Asia.

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The Gulf Petrochemicals and Chemicals Association (GPCA) represents the downstream hydrocarbon industry in the Arabian Gulf. Established in 2006, the association voices the common interests of more than 250 member companies from the chemical and allied industries, accounting for over 95% of chemical output in the Gulf region. The industry makes up the second largest manufacturing sector in the region, producing over US\$ 108 billion worth of products a year.

The association supports the region's petrochemical and chemical industry through advocacy, networking and thought leadership initiatives that help member companies to connect, to share and advance knowledge, to contribute to international dialogue, and to become prime influencers in shaping the future of the global petrochemicals industry.

Committed to providing a regional platform for stakeholders from across the industry, the GPCA manages six working committees - Plastics, Supply Chain, Fertilizers, International Trade, Research and Innovation, and Responsible Care - and organizes five world-class events each year. The association also publishes an annual report, regular newsletters and reports.

For more information, please visit **www.gpca.org.ae**

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