REFINING AND PETROCHEMICALS: A NEW LOOK AT INTEGRATION OPPORTUNITIES

Produce Petrochemicals and Increase Refinery Margin

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Abstract

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Refiners worldwide are moving production away from fuels toward petrochemicals. This is due to expected future declines in fuels demand, combined with significant petrochemical demand growth expectations throughout the world. New grassroots complexes are being built around the world with petrochemicals integration to meet this demand growth, and to enable increased margins.

In the U.S., both gasoline and diesel demand is expected to decline. Additionally, U.S. refiners currently export off-specification gasoline to countries where specifications are currently less stringent. Refinery expansions and fuel specification changes in these regions will reduce demand for U.S. gasoline. U.S. refiners will therefore need to consider alternatives to fuels production in light of decreasing domestic and export demand. There is also a potential scenario where refiners must produce higher octane gasoline than is produced today. In a future where high compression ratio engines are needed to meet CAFE fuel efficiency standards, refiners must find a way to produce greater amounts of higher octane gasoline.

Through petrochemical integration, refiners will be able to maintain crude capacity and produce higher value petrochemicals, while co-producing on-specification gasoline at a reduced rate.

There is an abundant supply of low cost feedstock in addition to very cheap natural gas that will put refiners at a global advantage. Entering the petrochemical market through an integration strategy will enable refiners to capitalize on these advantages and reduce economic exposure to declining fuels demand.

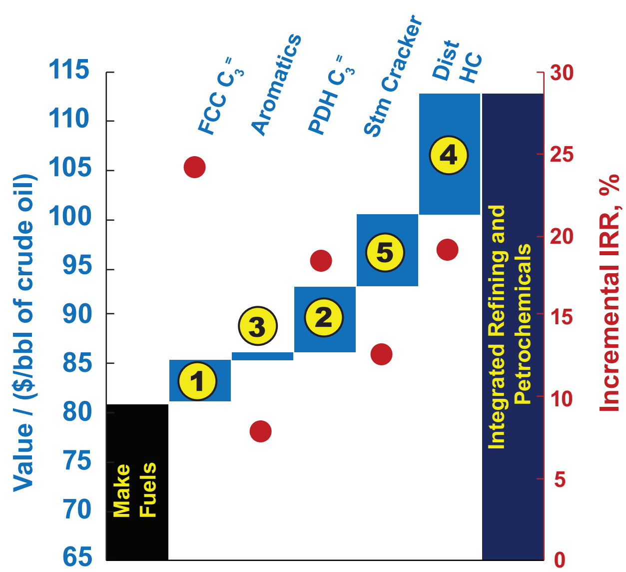
Petrochemical integration strategies that optimize internal rate of return (IRR) require expert domain knowledge. The strategy must go beyond the development of typical

production pathways. Simultaneous optimization of process configuration, technology selection and molecule management is key to maximizing project value.

Petrochemical integration avenues are available to increase the upgrade value of crude. Refiners have already captured at least one third (or $15 per barrel) of the available crude upgrade value by producing fuels. This business model has served refiners well for many decades, but now there is an opportunity to further increase this upgrade value to $45 per barrel.

This paper presents a potential stepwise petrochemical integration strategy developed for a typical fluid catalytic cracker (FCC) based U.S. refinery focused on making Tier 3-compliant fuels. The investment steps build upon each other, and may be implemented sequentially, depending upon market conditions and the availability of capital. It also presents examples highlighting the importance of scrutinizing Invitation to Bid (ITB) configurations to determine if higher value solutions are possible.

Figure 1 – Value of Petrochemical Integration



Market Drivers for Petrochemicals

Declining Fuel Demand Drives U.S. Interest in Petrochemicals

The U.S. fuels market is expected to start declining soon. In 2035, gasoline demand is expected to be 15 percent lower than in 2018. Similarly, diesel demand will be down 6 percent.(1) This decline is due to several factors including continued technology improvements in vehicle energy efficiency, renewables substitution, autonomous vehicles, shared and connected vehicles and changing demographic behaviors to name a few. As both gasoline and diesel decline, the refiner's ability to maintain profitability will require further diversification.

Global petrochemicals demand is expected to grow three to six times the global fuels demand between 2018 and 2026. The global compound annual growth rate from 2018 to 2026 for gasoline, propylene and paraxylene is <1 percent, 4 percent and 5 percent respectively.(1) This demand growth is being driven by the rise of the middle class in emerging nations. Refineries will continue to be built where demand for fuels exist, putting downward pressure on refiners who have enjoyed those export markets. Extension into petrochemicals will be included to improve the profitability of those investments.

Diversification into petrochemicals ensures crude capacity is maintained, reduces economic exposure to declining fuels demand, and results in higher margins.

To offset the expected decline in U.S. fuels demand, and declining export markets, a refiner can choose to reduce crude capacity or they can diversify into higher value petrochemicals. The former solution would result in stranded capacity and lost refining margin. Diversification into petrochemical production ensures crude capacity is maintained, and results in a much higher margin compared to just producing fuels.

Petrochemical Demand Supports Value Premium

The current 2018 U.S. price spread between paraxylene and naphtha is approximately $400 per metric ton, and the spread between propylene and propane is approximately $500 per metric ton. These uplifts are expected to be maintained into the future due to the high demand growth for petrochemicals.(1)

Additionally, with the cost of U.S. natural gas approximately one third that of LNG in China, the U.S. benefits from an energy cost advantage.

Refiners are uniquely positioned to produce petrochemicals at economics that compete in the world market.

U.S. Poised as Global Propylene Producer

Today, there is an oversupply of LPG (propane and butane) in the U.S. By 2023, this surplus is expected to be 40 million MTPA – approximately 140 percent of what it what is in 2018.(1) This surplus is primarily due to expanding natural gas field developments. This LPG has low value and is approximately $100 per metric ton lower cost than the Middle East. The majority of this LPG is currently being exported, not upgraded.

Demand for propylene is expected to rise both globally and in the U.S. By 2023, U.S. propylene production capacity is anticipated to be 20 percent larger than it is today – an increase of 3 million metric tons per annum.(1) However, neither steam cracking nor fluid catalytic cracking are expected to contribute significantly to this increase. The abundance of propane feedstock, combined with a cost of production advantage, will continue to favor propane dehydrogenation (PDH) technology as the leading technology for on-purpose propylene production.

Refiners have an opportunity to expand into propylene with PDH technology.

Independent producers in the U.S. are already exploiting this opportunity with two operating PDH facilities, and a number of projects in development. Refiners can invest to capture this value as well.

U.S. Cost Advantage Enables Global Paraxylene Export

A state-of the art, world-scale paraxylene complex, integrated into an existing U.S. refinery would have a $120 per metric ton cash cost of production advantage over the existing smaller, less efficient complexes in China. World-scale production, efficient technology and low energy cost enable a U.S. refiner to produce paraxylene, ship it to China, cover their debt service and still make a profit over 80 percent of the installed paraxylene base capacity.

The existing benzene shortfall in the U.S. is forecast to continue, even with the addition of a world-scale paraxylene complex. In fact, 2.1 million metric tons per annum of benzene is estimated to be imported in 2023[1] to meet demand. This presents an opportunity for refiners to produce on-purpose benzene from naphtha currently being used in the gasoline pool.

Benzene can be perceived negatively by those not already in that market. Refiners will have to change their negative mindset and their business models, in order to take advantage of the aromatics opportunity.

Opportunity to Increase Margin by $30 per Barrel through Petrochemical Integration

Petrochemical integration enables a significant increase in value compared to just producing fuels. Development of an integration strategy is complex, and requires evaluation before arriving at the optimum economic solution and a feasible investment plan. Examples of specific items to be evaluated include:

- Optimum use of each stream and molecule
- Selection of the most advanced technologies
- Gasoline and diesel production targets and specifications
- Efficient utilization of energy and capital

The following integration case study evaluates options, illustrates the opportunity for value creation, and identifies a viable investment plan. The base case was a typical FCC based refinery, focused on producing Tier 3-compliant fuels, common in the U.S. The analysis was based on average yearly USGC prices from 2013 to 2017 and this resulted in an average crude price of $65 per barrel.

The integration was carried out in five consecutive steps:

- **Step 1:** Revamp existing FCC, and add propylene recovery for polypropylene production.
- **Step 2:** Add an aromatics complex to produce paraxylene from naphtha
- **Step 3:** Increase polypropylene production via propane dehydrogenation (PDH)
- **Step 4:** Introduce polyethylene production via steam cracking
- **Step 5:** Increase paraxylene via distillate hydrocracking

The order of implementation of these steps depends upon return on investment, market conditions and the availability of capital. The results of the analysis case be seen in Figure 1. A block flow diagram of the integrated refinery is shown in Figure 2. Based on the results, the following implementation strategy is recommended for this case:

Step 1. The existing FCC is revamped to increase propylene yield. While this contributes to the propylene supply, it does not fill the global demand gap. The revamp will reduce gasoline yield, and increases both concentration and quantity of benzene in the naphtha produced.

Step 2. A world-scale PDH is added to further increase propylene production. Propane feedstock purchase is required to meet the supply needs of this unit. Recovery of the FCC propylene can be integrated into the PDH propylene recovery system to reduce capital and improve efficiency.

In a scenario where gasoline and diesel demand both decline, the concurrent implementation of both Step 3 and 4 below make a compelling case for aromatics.

Step 3. A world-scale aromatics complex is built, where heart-cut naphtha from the naphtha pool is diverted to aromatics production. The impact on the gasoline pool must be considered in this case.

Step 4. A distillate hydrocracker is added to produce more naphtha for additional aromatics production.

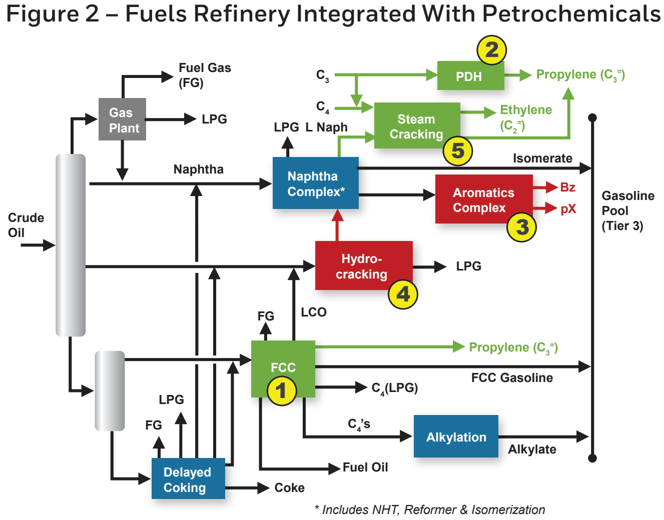
Step 5. A steam cracker, predominantly fed by refinery LPG, is added to enable polyethylene production. Typically, this is the last step because it is a multi-billion-dollar capital investment.

Petrochemical integration increases margin - opportunity to add up $30/BBL over making fuels.

Whereas refining margins brought a $15 per barrel margin over the price of crude, $30 per barrel of additional value can be realized through integration into petrochemicals (see Figure 1). Each discrete step builds on the previous, increasing petrochemicals while producing fuels that comply with the required Tier 3 specifications. The internal rate of return for each step is a decision point in an investment plan. Each case integrated into an existing refinery moves the refiner from 100 percent fuels production to 56 percent petrochemicals. Options are available to further increase petrochemicals production, but that would add further cost to the project. The ultimate balance of fuels and petrochemicals will be unique for each project.

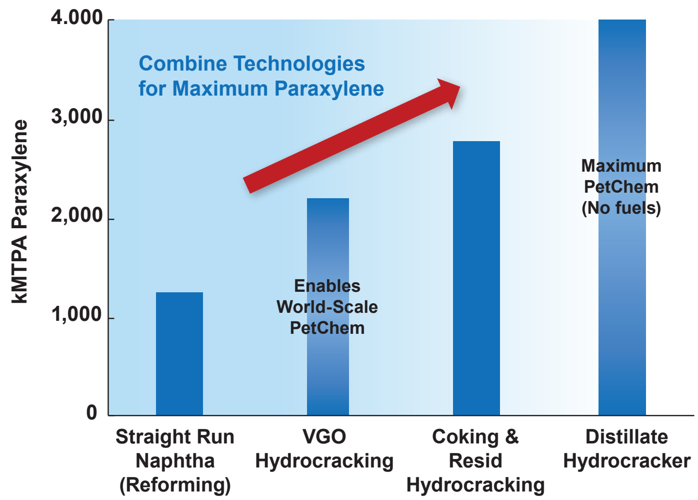
Note: Polypropylene and polyethylene units are included in the study, but are not shown.

Figure 2 – Fuels Refinery Integrated With Petrochemicals



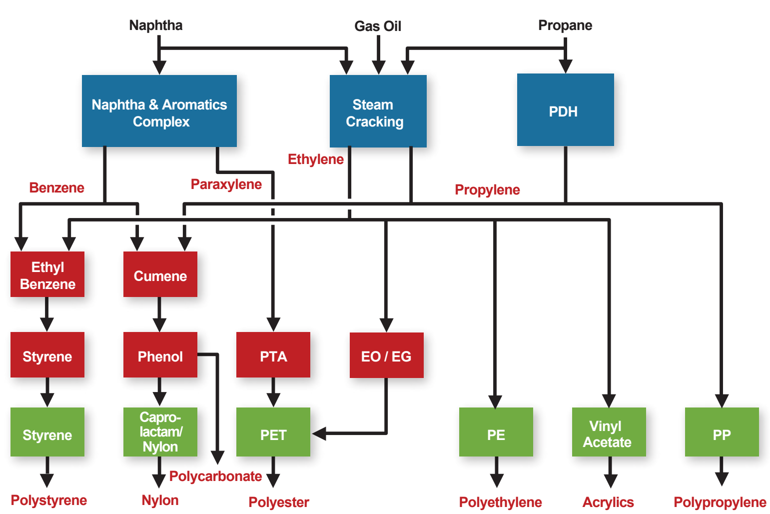
Diverting high octane reformate to aromatics production negatively impacts the gasoline pool. It is important to properly manage the naphtha molecules within the naphtha and C_4 complexes to ensure that gasoline specifications continue to be met. A typical U.S. refinery does not produce enough heavy naphtha for a world-scale aromatics complex. A strategy to increase heavy naphtha production will be necessary to produce the desired amount of heavy naphtha (see Figure 3).

Figure 3 – Paraxylene from 300 KBPSD (15 Million TPA) of Crude



The primary routes for expansion into base petrochemicals is shown in Figure 4. The petrochemicals interface begins with intermediate feedstock selection, typically propane and naphtha for refiners. Extending beyond this level is a move towards specialty chemicals.

Figure 4 – Primary Petrochemical Landscape



Real Commercial Examples: Optimization Enables Improved Economics

Examples of optimized integration plans, developed from an ITB, are shown below. The ITB configurations offered valid technical and economic solutions. However, having the flexibility to optimize ITB process configurations, technology selection and molecule management will ensure the best project return. These examples identified integration solutions that delivered improved economic outcomes over the traditional configurations that were presented in the ITB.

Optimizing Propylene Economics

This example is part of a world-scale grass roots refining and petrochemicals complex producing aromatics and polypropylene, while making fuels meeting Euro V specifications.

The ITB sought to optimize propylene production and economics, and it called for a new FCC, operating at high severity to produce a propylene yield of 14 Wt%, and a PDH unit to produce the balance of the required propylene.

Increasing FCC severity to produce more propylene has an impact on the other products. Naphtha yield will be decreased, affecting the gasoline pool. Butylene yield will increase, impacting alkylation capacity. Producing more propylene from the FCC also leads to an increase in capital and operating costs, increasing the cash cost of production of propylene.

FCC technology can produce the required amount of propylene that this project required, but it may not be the best way to run the FCC. As a licensor of both technologies, Honeywell UOP has the knowledge necessary to thoroughly evaluate the cost of propylene production from both the FCC and the on-purpose C_3 Oleflex™ PDH units.

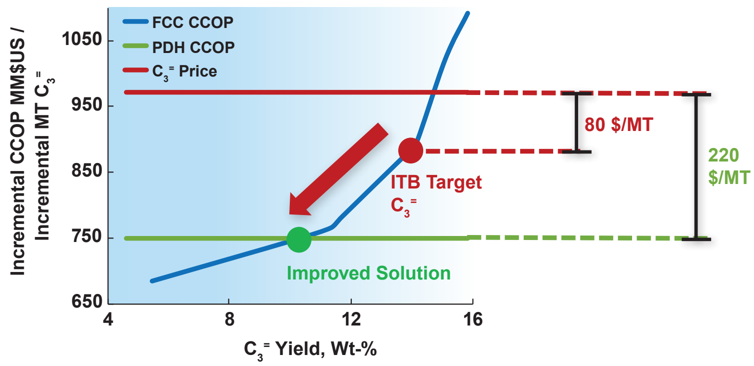
In the new configuration, propylene production was rebalanced between the FCC and the PDH. FCC propylene yield was lowered to 10wt%, which resulted in a propylene cash cost of production equivalent to the PDH. Adjusting the propylene balance saves $140/MT, because the PDH cash cost of production is lower than that of the FCC in the ITB case (Figure 5). The ITB case achieves a margin of $80/MT, compared to a new margin of $220/MT. World scale propylene production at a significantly lower cost was achieved. Rebalancing propylene yield led to a 1 percent increase in IRR.

PDH enables optimal FCC investment

Over the past 15 years, there has been a push for higher propylene FCC units during the bid phase. However, after a few months on stream, they generally tend to be operated in the range of 10 to 12 Wt% propylene, depending on feed quality. The economic reason is clear - market pricing is being set by the PDH units and not FCCs.

In the U.S., revamping an existing FCC and installing a new PDH would enable a refiner to become a world-scale producer of propylene. Propane would have to be purchased as the refinery propane will not be sufficient for a large PDH. However, low-cost propane is in abundant supply.

Figure 5 – Balancing FCC & PDH Propylene (C_3=)

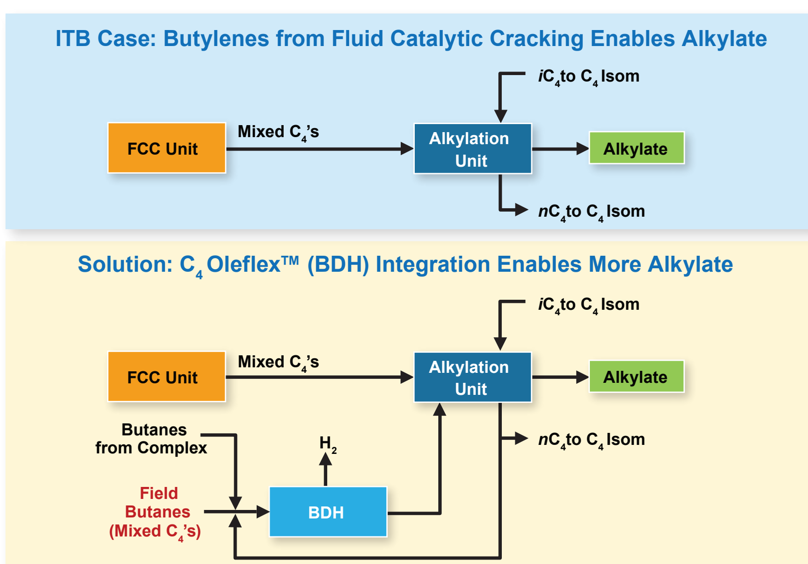


C_4 Optimization Increases Project Value

Considering the same complex, this example looked beyond propylene, leveraging assets to optimize the use of C_4 products. The complex was in a region where low-cost butanes were available from expanding natural gas processing – similar to the situation in the U.S.

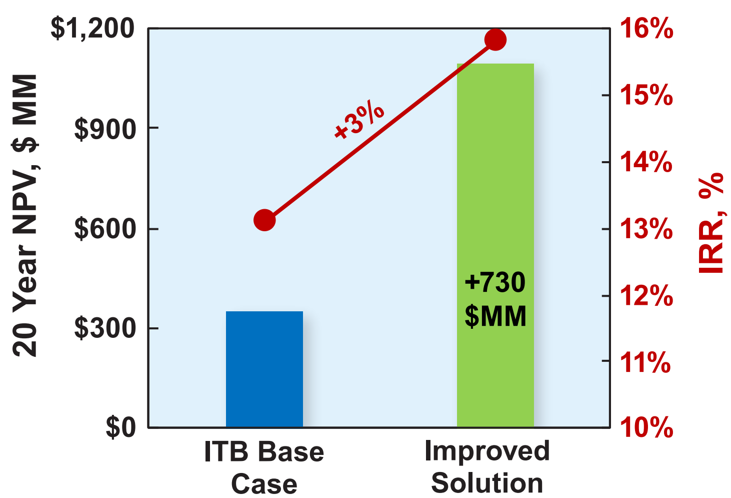
The ITB specified a paraxylene production target and a 100-percent 95 Research Octane Number (RON) gasoline pool requirement. Alkylate from FCC butylenes allowed the octane target to be met, though production was constrained by FCC capacity. After achieving the paraxylene production target a significant amount of light naphtha remained, and it could not be blended off in the gasoline pool. The excess light naphtha was slated for export. The ITB solution was valid, resulting in reasonable project economics (see Figure 7). However, if export naphtha could be upgraded, the refiner would capture additional value.

Figure 6 – Integration of Butane Dehydrogenation (BDH) Unit with FCC & Alkylation



The new solution provided better feedstock utilization, eliminated naphtha export, and maximized gasoline production while maintaining the target paraxylene production. Additional alkylate allowed all the export naphtha to be blended into the gasoline pool. The additional butylene feed for the alkylation unit was provided by UOP's C_4 Oleflex™ butane dehydrogenation (BDH) technology. The C_4 feed to the BDH unit came from cost-advantaged butanes. Low value butanes and naphtha could now be sold as higher value gasoline increasing the value of the project. The configurations are compared in Figure 6.

Figure 7 – Project Economics



Project economics are significantly improved. The IRR increased by 20 percent and net present value (NPV) was tripled (See Figure 7).

Global gasoline trends require more alkylate: BDH technology enables alkylation capacity expansion

Some U.S. refiners export off-specification gasoline to countries where specifications are currently less stringent. What happens when these regions move to higher fuel standards as is generally the trend around the world today? In a future where high compression ratio engines are needed to meet CAFE fuel efficiency standards, refiners are going to have to find a way to produce greater amounts of higher octane gasoline.

Leveraging low cost C_4s in the U.S., adding a BDH unit, and increasing alkylation capacity will enhance gasoline production and is a potential solution to both problems.

To meet 95 RON gasoline specifications, an expansion of alkylation capacity is likely to be needed. Alkylate will allow blending of lower quality light naphtha and can compensate for the loss of high octane reformate if it is re-tasked for aromatics production.

Summary

As fuels demand declines, diversifying into petrochemicals will enable refiners to remain competitive, and leveraging low-cost energy and LPG feedstock will maximize value. Crude capacity is maintained while moving into higher value petrochemicals, and on-specification gasoline will be co-produced, but at a reduced rate. For grass-roots projects and existing refinery upgrades, a high-value integration strategy will create additional value.

Petrochemical integration is a complex and capital-intensive problem, requiring a strategy that is definitively quantified to maximize value at each step. Optimization, not maximization is the key. Optimization means better molecule management and improved configurations. UOP is helping refiners develop an overall project and investment plan for integration by selecting the proper catalysts, adsorbents and advanced process technologies, and integrating them for maximum efficiency and flexibility.

References

1. IHS Markit

For more information

For more information, please contact your UOP representative or visit us online at www.uop.com.

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UOP8234 June 2018