Oil-to-Chemicals: Advanced Process Configurations to Address the Fuels/Chemicals Imbalance

By John J. Murphy and Clyde F. Payn

Refiners and petrochemical producers who gathered at the Annual Meeting of the American Fuel and Petrochemical Manufacturers (AFPM) (Mar. 11-13 in New Orleans) got the following messages: (1) Refiners who only think about transportation fuels production must think differently; and (2) Standalone producers of chemicals (i.e., olefins, aromatics) really do have the opportunity to break free from buying naphtha as the only feedstock at lower cost. Beyond that, integrated refinery/chemicals producers (and the trend of more will continue) need to question the conventional wisdom that a complex 400,000 BPSD refinery, coupled with a 2-3 MIL Mt/yr steam cracker with its high CAPEX, is the best solution. FEED studies need to be more innovative in their thinking! If you already have plant site investments in place, there are better margin and lower cost retrofits that need to be taken into consideration, while simultaneously improving your chemicals production and site margins.

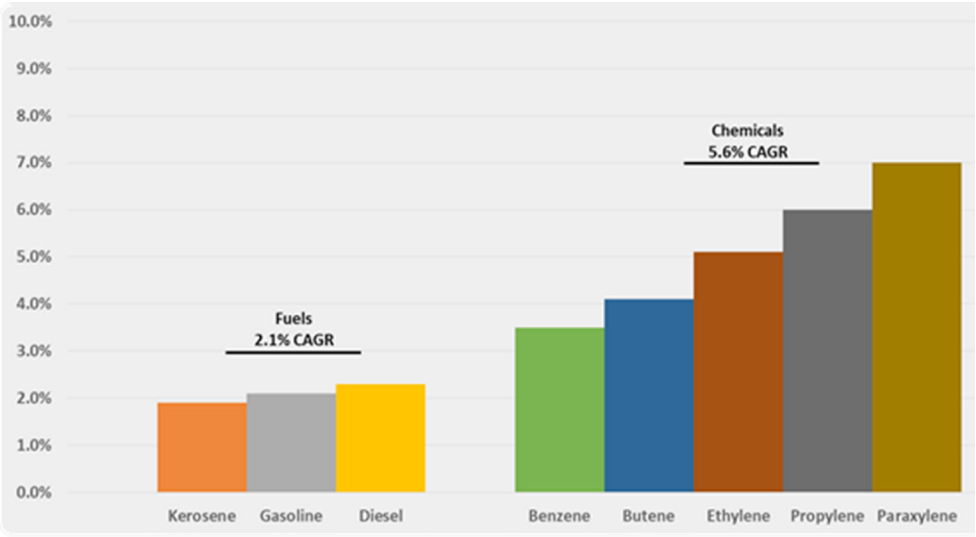
Introduction

There has been a long history in the incremental developments (decades in fact) leading to what can be described as "Oil-to-Chemicals (OtC)" today. For a long period of time, building larger and larger world scale and more complex refineries and steam cracking (SC) plants was the economic solution best suited to the fundamentals of medium to heavy crude oil conversion, and in some countries this will still be the case. However today, we have entered into a different era, where the socioeconomic, as well as supply/demand trends are shifting, and the traditional business models of segregated refining vs chemicals production no longer hold true. In the future we will see fewer naphtha SC's, more petrochemical FCC's and more swing olefin/BTX units being adopted. The molecular science and process technology needed to do this is here today.

With the "shale revolution" which started in the US, and is spreading worldwide, lighter feedstocks will continue to be readily available, so that on purpose molecular production, e.g., methane to ethylene (not yet commercial), ethane to ethylene, propane to propylene, butane to butylenes, etc., represent a chemical course that is already firmly entrenched. To remain or be competitive over the next 5-10 years, both integrated and sole chemical producers will need to adopt these same models, if they intend international participation (i.e., import/exports of products).

The movement towards the production of chemicals and petrochemicals such as olefins and aromatics directly from crude oil, as opposed to via thermal cracking of naphtha/ethane (for olefins) and via traditional refining reforming (for aromatics), is being driven by numerous factors—the most important of which is the imbalance between demand for oil-derived liquid fuels (diesel, gasoline) and the more rapid growth in markets for petrochemicals like olefins (ethylene, propylene), aromatics (BTX) and specialty intermediate streams like C_4s and higher olefins. The imbalance (**Figure 1**) has made the idea of using crude as a direct feedstock more appealing for integrated producers of fuels and chemicals as well as direct chemical companies.

Figure 1. Growth for Oil-derived Fuels (Diesel, Gasoline) vs. Petrochemicals/Chemicals (Olefins, BTX, etc.)



The technologies for these novel, and important, chemical/petrochemical production processes are being pursued by industry leaders like ExxonMobil and Saudi Aramco/SABIC, but are also affecting the competitiveness of peer participants—i.e., all chemical producers, as well as EPCs, process licensors and technology developers like CB&I, Axens, and UOP/Honeywell. Added to this are traditional routes potentially being made uncompetitive, such as naphtha cracking, and there is strong, widespread and urgent interest in approaches to, and justification for, these opportunities/threats.

Depending on the crude oil feedstock, the avoidance of refinery fuels production and using specialty hydrocracking (HC) processes to naphtha or via fluid catalytic cracking (FCC) to olefins or BTX could provide lower costs than participating in the current/historical refinery value chain. As an example, CP Chem's Aromax™ can provide BTX from olefins and the resid FCC unit could be more inexpensively tailored towards $C_2^=$ and $C_3^=$ olefins production, rather than the more costly and less selective steam cracking of naphtha. Of particular interest to chemical producers is how from the end-product (e.g., BTX) can you back integrate into the best configuration for costs based on the crude oil type and are there attractive margins to consider these new configurations/combinations?

Oil-to-Chemicals: Advanced Approaches

There are noteworthy recent catalyst and process advances relevant to olefins and BTX chemical products that avoid the upfront investment in catalytic distillation units (CDUs) and vacuum distillation units (VDUs) and other parts of the refinery while maximizing BTX and olefin yields (primarily C_{3+} and C_{4+}) beyond typical refinery economics and normal/known process configurations that have historically been optimized for fuels production.

There are many different process approaches/alternatives that can be pursued together or individually to improve an "oil-to-chemicals" strategy. As demonstrated, ExxonMobil's steam cracker (SC) modification(s) is one of them; the approach by Saudi Aramco/SABIC may be, as well. Others, like petrochemical FCC e.g., UOP-PetroFCC or Axens-HSFCC with metathesis are also all good examples. Also worth highlighting are swing unit strategies, e.g. KBR/SK-ACO, Gasolfin, Omega, Chiyoda. A directional step-out idea involves the utilization of radial flow reactors.

The major conclusions and take-aways include:

- There have been advances in petrochemical FCC cracking, as well as fixed bed/swing reactor olefin processes, plus BTX reactor technologies. If the objective is to maximize olefin + BTX production, then taking a LTO approach based on these high paraffin compositions is scientifically and margin justified.
- With certain feedstocks, e.g. 35+ API, 50 ppm sulfur and 30 ppm metals, you do not need to add hydrogen (or should not add hydrogen) if the product goals are either olefin or BTX. Secondly, pyrolysis approaches should be ruled out because they are inefficient, as well as energy intensive. They produce too much coke and refractory products to be useful.
- In new process configuration designs, engineers should be targeting combination schemes that yield 80wt% olefins + BTX with only 20wt% byproducts (such as fuels, LPG's) and be aiming for an ISBL+ OSBL CAPEX in the $400-600 MIL, without post treatment steps.
- FCC olefins production has already gone through a steady progression of higher olefin production steps. This has led to the commercialization of petrochemical/chemical FCC units such as PetroFCC-UOP, HSFCC-Aramco, R2P-Total, Axens, TechnipFMC, DCC-Sinopec, etc. Most of these will produce 35-50wt% olefins, and perhaps using LTO's as high as 62wt% olefins and BTX, with the by-products gasoline of about 38wt% maximum. Newer catalysts might advance this position in the future.

A series of cameos of newer technologies in various stages of commercialization reveals:

- The RFR proposed process considers utilizing radial flow reactors, currently commercial in styrene (ethylbenzene) processes. It provides a thermodynamic and kinetic, as well as an economic, rationale for this new approach. New catalysis would be required to optimize this approach; advances in catalytic distillation provide intensification of a proposed configuration.
- Other new olefin processes worthy of note include ACO (which could be viewed as an FCC modified process), Gasolfin, Omega and Chiyoda. These fixed bed swing olefin + BTX technologies provide a new approach and dimension to reconfigurations; on-purpose aromatics routes, such as UOP's Cyclar, has made advances.
- New separation processes are needed, as for LTOs, adopting some upfront feedstock separations that avoid the VDUs, as well as the incorporation of olefins/paraffins, is commercially close at hand.

A snapshot of an oil-to-chemicals SWOT analysis appears in **Table 1**.

Table 1. Oil-to-Chemicals (O-t-C): SWOT Analysis

Strengths	Opportunities
• Light tight oils, condensates and NGLs will be in plentiful supply and feedstock competitive • At $50/barrel LTO is equivalent to $367/mt vs. naphtha at $550/mt • Long-term chemical growth +5-6% pa; fuels growth flat to 1% pa growth • Higher margins by pursuit of this strategy	• Integrated refiners/chemical producers need to think differently, not as primary fuel producers • Lower CAPEX, modular OtC units of 10,000 BPSD (1 MIL mt/yr) are technically feasible • Regional and site specific opportunities exist based on local demands • Complexity and larger scale is not always the best strategy
Weaknesses	**Threats**
• Current commercialized options, still are high in fuels production 30-45wt % • Most interesting, new technologies not commercial today, but piloted	• Already majors (including ExxonMobil, Aramco/SABIC) are developing technology positions • Naphtha based SC's are losing their competitive edge

Conclusion

Refiners who only think about transportation fuels production must think differently. Standalone chemicals producers really do have the opportunity to break free from buying naphtha as the only feedstock at lower cost. For the integrated refinery/chemicals producers (and the trend of more will continue) you do not need to consider the conventional wisdom that a complex 400,000 BPSD refinery, coupled with a 2-3 MIL Mt/yr SC with its high CAPEX being promoted by EPC's is the best solution. FEED studies need to be more innovative in their thinking. This is not to dismiss that either complex refineries nor SC's do not have their place, what it does mean is that if you already have plant site investments in place, there are better margin and lower cost retrofits that need to be taken into consideration, while simultaneously improving your chemicals production and site margins.

The above is excerpted from TCR's recently completed multi-client study, **"Oil-to-Chemicals: Technological Approaches and Advanced Process Configurations,"** *which was completed in December 2017. The study takes an end-market based approach, using numerous, subscriber-defined process considerations, with the objective of documenting the available technologies, plus those in development (including the needed combinations) to maximize the return on conversion based on product slate (chemicals/petrochemicals and specialty/intermediates). Such optimization is required if such practices are expected to be competitive with low-cost thermal cracker routes as well as increasingly large, aromatics complexes based on scale. It also contains some serious conclusions useful to producers, EPC's, licensors and catalyst producers on what is required by these industries moving forward. In this regard, the major take-aways from this unique study are that times are changing, chemicals is where the future action will be and you must develop your own unique approach to remain a competitive player.*

Additional details , including a full study presentation with the report's Table of Contents, can be obtained at http://www.catalystgrp.com/multiclient_studies/oil-chemicals-technological-approaches-advanced-process-configurations/ *or from Mark Wiley at mwiley@catalystgrp.com or +1.215.628.4447.*