UNLOCKING PERMIAN VALUE

Goutam Biswas and Theo Maesen, Chevron Lummus Global, alongside Kandasamy M. Sundaram, Lummus Technology, look at how to unlock the value of Permian crude through its direct conversion into chemicals.

Polyolefin resins are integral to human prosperity and are found in everyday applications ranging from food packaging and detergents, to automobiles, durable goods, and plastics. The olefins to make these polyolefin resins are produced primarily through the thermal cracking of hydrocarbons such as ethane, LPG, naphtha and complex feedstocks that boil in the gas oil boiling range. Each of these hydrocarbons stem from crude oil or natural gas. A location's preferred feedstock depends on local economics and feedstock availability.

Ethane is slated to remain abundantly available as a low-cost petrochemical feedstock for olefin production in North America. Similarly, it is available at low cost in the Middle East. This provides the US and the Middle East with a comparative advantage when it comes to the manufacturing of low-cost polyethylene.

These two regions are expected to build more world-scale ethane crackers to meet increasing demand for polyethylene across both internal and overseas markets. Most of the demand growth for polyolefins will be in the Asia Pacific region. Here, limited ethane availability made naphtha the predominant feed for steam crackers.

In China, producers have built large and complex refineries integrated with petrochemical units to produce olefins and aromatics from crude oil instead of naphtha, assuming historic trends would continue so that crude oil would remain less expensive than naphtha on a mass basis. These crude-oil-based facilities enjoy an economy of scale, and manufacture ethylene at a cost that is competitive with stand-alone naphtha crackers. With the cost advantage of crude oil over naphtha projected to increase, the economic incentive for converting crude oil into chemicals is also expected to increase.

Today, steam cracking technology has advanced enough to enable thermal cracking of light crude oils and condensates without prior refining. Such 'direct crude oil cracking' implies a major capital advantage.

This article will address the routes to crack crude oil directly into ethylene and the economics of this process. Along with ethylene, pyrolysis yields other valuable chemical products, such as propylene, butylene, butadiene and aromatics.

Table 1. Permian WTL properties

Name	Permian light crude
Density (API)	48.6
Total sulfur (wt%)	0.01
Total nitrogen (ppm)	26
Total metals	0.5
Hydrogen (wt%)	14.5
520°C+ (wt%)	4.8
Micro carbon residue (MCR) (wt%)	0.07
Paraffins (vol%)	48.5
Naphthenes (vol%)	39.5
Aromatics (vol%)	11.62

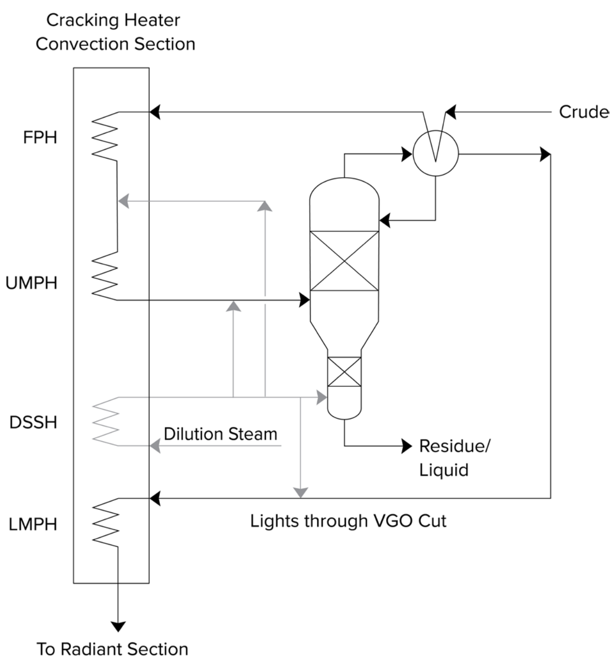

Figure 1. Simplified diagram of the convection section with HOPS: FPH = feed preheat, UMPH = upper mixed preheat, DSSH = dilution steam superheat, LMPH = lower mixed preheat.

Why Permian crude?

The world has witnessed a remarkable increase in US crude oil production. In 2018, the US became the world's largest producer, producing over 12 million bpd. The Permian oilfield in Texas is the world's most prolific oilfield, and produces a light (tight) crude oil.

Based on their density (38 – 56 API), Permian crudes are subdivided into three grades of crude, namely West Texas Intermediate or WTI (38 – 43 API), West Texas Light or WTL (44 – 50 API) and West Texas Condensate or WTC (50+ API).

Contemporary steam cracking technology enables the direct conversion of light crude oil into olefins at refinery scale, without having to first refine the oil to make it ready for steam cracking. Such direct crude conversion requires the external placement of a heavy oil fraction, as this more hydrogen-deficient fraction produces excessive (pyrolysis) fuel oil and dramatically shortens the onstream time of cracking furnaces. Provided the feed portfolio is limited to lighter crude oils, refining of crude oil prior to steam cracking or placement of heavy oil fractions outside the facility can remain at a minimum.

A feed portfolio anchored on Permian WTL would be highly suitable for direct steam cracking into chemicals, as Permian WTL exhibits low impurity levels and high hydrogen and paraffin content. It consists mostly of naphtha (approximately 50%), some vacuum gas oil (VGO) (typically 10 – 18 %) and a minimum of vacuum residue (1 – 5%), so that only a small (residue) fraction requires rejection. See Table 1 for a full breakdown of Permian WTL properties.

Lummus Technologies' Heavy Oil Processing Scheme (HOPS) technology enables the cost-effective steam cracking of oils with a relatively small residue fraction (such as condensates, WTC and WTL)[1] without prior fractionation, as the technology integrates fractionation and pyrolysis, enabling rejection of the residue fraction from within the steam cracker.

HOPS to steam crack Permian crude

In addition to an attractive boiling range, Permian WTL is a preferable feedstock for direct steam cracking because of its high paraffin and low polynuclear aromatic compound content. Paraffins produce the most olefins and exhibit the lowest coking tendency. Minimum polynuclear compounds minimise the coke make. Figure 1 shows a simplified sketch of the residue rejection section, which is a key HOPS design feature that contributes to the economic attractiveness of HOPS in direct steam cracking of condensates and ultra-light crudes such as WTL.

The convection section in a steam cracker enables the heating of feed components to temperatures high enough to vaporise (fractionate) them. It controls vaporisation through mixing with dilution steam and further superheating. A HOPS vessel adds more superheated dilution steam to vaporise the feed to the desired level. It has tailored furnaces and proprietary internals that ensure vaporisation at minimum fouling. The vaporised feed leaves the convection section for the radiant section, and the radiant section then pyrolyses the vapour. Feed that remained in the liquid phase then leaves the HOPS as residue. In its economic sweet spot, a HOPS bleeds up to 5% of the feed.

Table 2 shows the overall material balances for the direct cracking of Permian WTL crude and naphtha. Case 1 corresponds to high severity, whilst Case 2 corresponds to low severity conditions. Valuable chemicals are olefins (ethylene, propylene, butadiene, butylenes) and aromatics (benzene, toluene, and xylene [BTX]).

The material balances in Table 1 are anchored on 1.5 million tpy ethylene production and 8000 hours of operation. Light saturates (ethane, propane, butane) are recycled to extinction. Products from a two-stage dry pyrolysis gasoline hydrogenation (DPG) unit and from a pentene saturation unit are recycled to extinction. Aromatics (BTX) are extracted from the C6-C8 DPG heart cut. The remaining resin (a non-aromatic C6-C8 fraction) is recycled back to the steam cracker heaters to extinction.

Economics of Permian crude

Economic analyses based on the yield of directly steam cracking WTL and naphtha were based on the 2019 IHS price forecast of feeds and products delivered in South Asia.[2] In-house capital index correlations yielded Total Installed Costs (TIC) values. Naphtha is considered the reference case. The WTL required investment is estimated at US$250 million over the naphtha case. The energy cost, maintenance cost, catalyst, chemicals, and other operating costs are included in the economic analysis.

Gross margins and internal rate of return (IRR) of steam cracking either WTL or naphtha into chemicals are based on stock balances generated through linear programming. Stock balances assume that the residue fraction is sold as very-low-sulfur fuel oil (VLSFO). The analyses show that WTL exhibits approximately US$250 million incremental margin over conventional naphtha-based steam crackers (see Figure 2). This translates to > 1.5% better IRR over a generic naphtha cracker.

Paths to feed flexibility

Saudi Aramco, Lummus Technology and Chevron Lummus Global (CLG) have co-developed the Thermal Crude to Chemicals (TC2C^{TM}) process that expands the crude oil feedstocks suitable for nearly complete conversion into petrochemicals beyond light crudes and condensates. TC2C is a departure from the conventional crude refinery and includes a pre-conditioning section to increase the hydrogen content of the middle and heavy components of crude oil.

This higher hydrogen content makes more oil suitable for steam cracking. TC2C designed for Arab Light (or heavier feed) can process more Permian WTL (or other paraffinic low-sulfur crudes and condensates), and introduce heavy orphan streams (e.g. FCC slurry oil) or lower cost feeds (e.g. high-sulfur fuel oil) to utilise the robust residue upgrading capability while processing Permian. If it is designed exclusively for Permian WTL, it will lower CAPEX, OPEX and crude oil throughput for the same quantity of ethylene.

Alternately, CLG's ISOTREATING and ISOCRACKING technologies can be deployed to increase a crude oil's hydrogen content and to eliminate coke precursors and contaminants. An increase in hydrogen content facilitates steam cracking, as it increases the olefin yield and reduces pyrolysis oil yield.

Upgrading residue all the way into steam cracker feedstock requires a dedicated residue hydrocracker or catalytic cracker. Hydrocracking Permian residue is not

Table 2. Permian crude cracking yields

	Case		
	Case 1	Case 2	Case 3
Feed	WTL	WTL	Naphtha
Severity	High	Low	High
Crude specific gravity	0.786	0.786	0.725
Crude feed (BPSD)	114 079	125 287	116 250
Ethylene to crude ratio	0.316	0.287	0.336
Chemicals to crude ratio	0.684	0.682	0.748
Total feed ('000 tpy)	4756	5224	4471
Rel.sp.energy (Kcal/kg ethylene)	1.04	1.16	1.00
	Products ('000 tpy)		
Hydrogen and methane off gas	669	632	775
Ethylene	1500	1500	1500
Propylene	672	864	656
Butylenes, butadiene	414	620	407
Pygas (BTX)	770	750	882
PGO and PFO	502	605	249
Residue	227	249	0
Acid gases	3	3	2
Total ('000 tpy)	4756	5224	4471

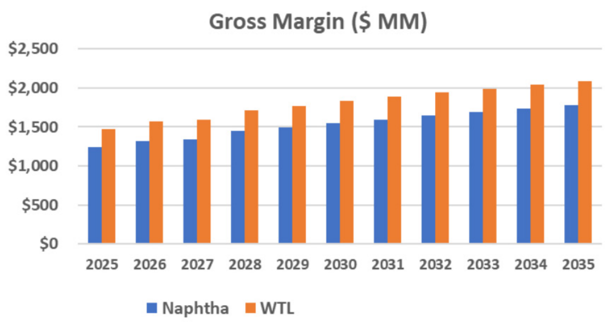

Figure 2. WTL vs naphtha gross margin comparison.

economical, as Permian crude contains too little residue to fully utilise residue-upgrading technologies. Permian residue is better placed in the oil market or sold as VLSFO.

Resid Fluid Catalytic Cracking (R-FCC) can upgrade the heavy part of crude oil if manufacturing transportation fuel is economical. Lummus has marketed both Indmax™ (with Indian Oil Corp. Ltd [IOCL]) and SRDC™ technology to maximise propylene production. Typically, Y-zeolites and amorphous components crack large molecules while simultaneously converting olefins into aromatics. The addition of ZSM-5 zeolite to an FCC enables the cracking of particularly paraffinic moieties into small olefins (mostly propylene), and ZSM-5 preserves these olefins. This enables the cracking of VGO (350°C+) and residue into propylene and light gases (both olefins and paraffins). Novel technologies such as Indmax and SRDC FCC preserve more of the light olefins partly by enhancing the contribution of the ZSM-5 catalyst. The higher the integration value is available, the more the refinery and steam cracker can exchange feeds and products.

Whether ethylene or propylene is more valuable depends on how quickly an economy is growing. Nearly irrespective of economic growth, normal butylene is less valuable than ethylene or propylene. This implies that it is attractive to upgrade butylene into propylene using Lummus' Olefin Conversion Technology (OCT).[3] OCT is a low-CAPEX technology enabling the energy-neutral conversion of ethylene and butylene into propylene – or vice versa – to optimise product slates.

Conclusion

The chemical and refining industries face a trade off between available capital and return on capital. Maximising crude oil valorisation requires a complex integrated refinery-petrochemical facility that can require more capital than is accessible, even for capital-effective options such as TC2C. Starting with steam cracking, Permian WTL offers a staged investment pathway toward more complex and versatile processing options.

Permian WTL crudes provide the opportunity to produce chemicals at an advantaged cost without significant prior investment in operations to first condition the crude oil. The capital required for directly steam cracking a crude oil such as Permian WTL (or another light crude) into chemicals is comparable to that of a naphtha cracker, but the returns are significantly higher. To crude oil consumers, Permian feedstocks are slated to continue to be an attractive choice, providing a window of opportunity to harvest the benefits of the mature technology to directly steam crack crude oil into chemicals. To crude oil producers, direct steam cracking is an opportunity to unlock maximum Permian value.

References

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