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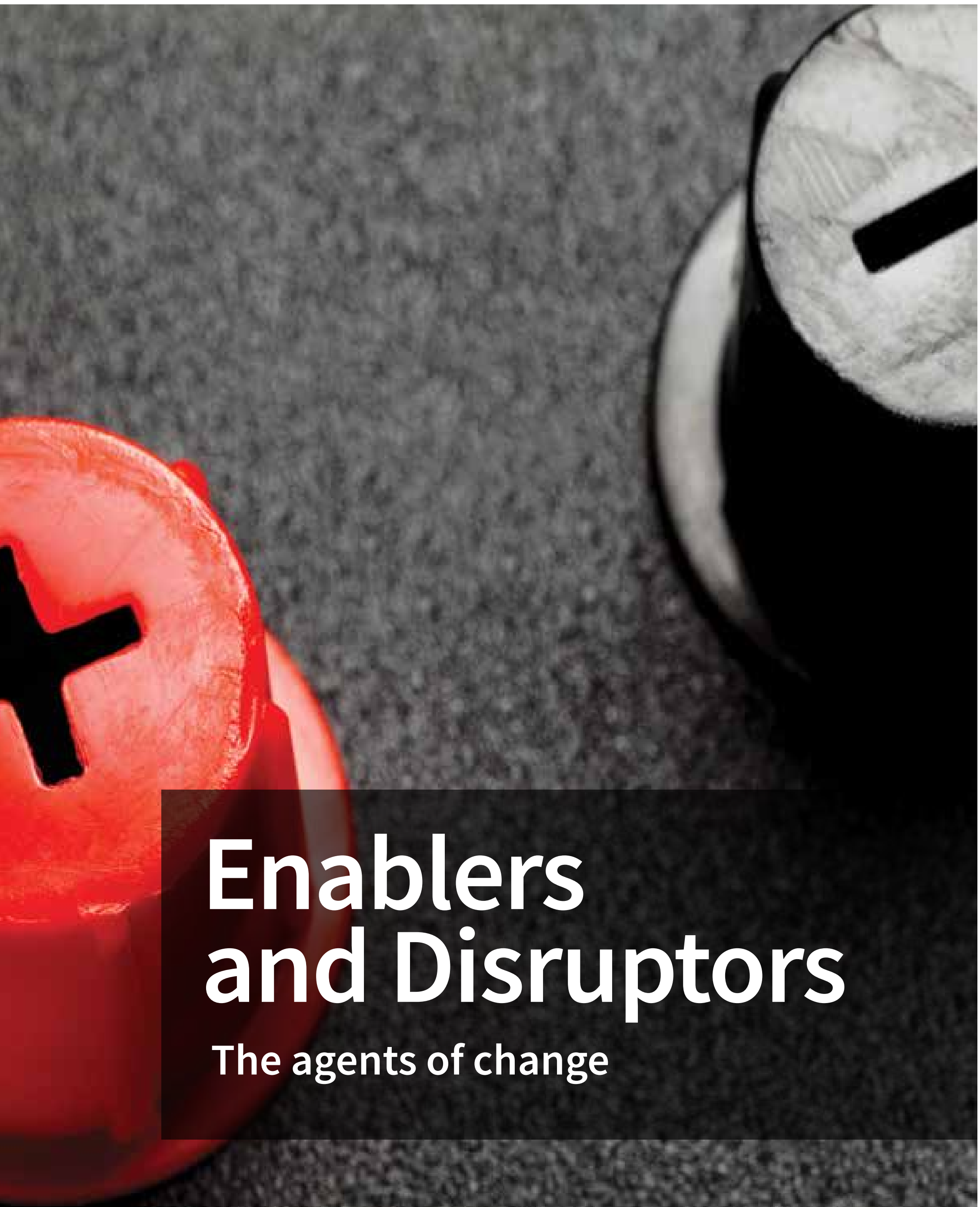

Enablers and Disruptors

The agents of change

Sustainability & energy shifts are key drivers for petrochemicals

Dewey Johnson |
Vice President, Base Chemicals and Plastics, IHS Markit
E Dewey.Johnson@ihsmarkit.com
T +128 1752 3213
L Houston

Understanding the complexity of demand for fuels and the shifting supply structure for oil and chemical feedstocks is critical to evaluate the forward risk in petrochemicals. Sustainability initiatives are likewise impacting fuel composition and economics through the so-called "energy transition," where major energy providers seek to decarbonize their portfolios with increasing investments in natural gas and renewables. Also, the plastics waste crisis in chemicals represents demand risk to chemicals and feedstocks. It also generates concern from all stakeholders by creating fundamental pressure on the social covenant for sustainable operations.

U.S. energy investment continues as major oil companies increase their investment in U.S. crude production, while the quest for advantaged feedstocks drives further global investment interest in the U.S. natural gas liquids (NGL) supply. Increasing climate change concerns are expected to drive a need for greater understanding of greenhouse gas (GHG) emissions for crude oil and chemicals through their value chains. Sustainability initiatives in chemicals extend from the need to address end-of-life management of plastics to multiple examples of the benefits of base chemicals and specialty chemicals, including improved food usage, clean water, and clean energy.

In this issue we look at the U.S. Permian Basin, where oil production is expected to nearly double in the next five years. U.S. tight oil production has been dominated by independent oil companies with funding driven by current production. These characteristics have created high price reactivity with short-cycle market behavior. The major oil companies are now investing in the Permian bringing deep balance sheets, large-scale enterprises, and high integration of assets to the mix. This change in U.S. oil production investment may enable a return to longer-cycle economics.

Looking at global crude oil, we also review GHG emissions estimates. Our review shows that estimates of GHG emissions by previous public studies vary on average by 30 percent. One critical industry need is for extensive data on crude types and refining assets. Such data is not publicly available but IHS Markit does employ it in our work. IHS Markit is seeking to bring major stakeholders together for an industry-adopted set of assumptions and framework for this important area.

Returning to the global energy supply mix, we explore the implications of the energy transition. Fuels demand is declining due to improved fuel efficiency standards and changes in mobility. Thus chemical feedstocks from conventional sources may shrink as refineries consolidate, resulting in less crude oil processing and a lower supply of naphtha from refining and NGLs from oil and gas fields. Thus, deeper integration is expected as chemicals reaches "deeper into the crude barrel" for feedstocks. For NGLs, international interest in U.S. ethane continues to increase as non-U.S. players seek diversified, low-cost feedstocks and the capital cost of ethane crackers is less than naphtha crackers.

Turning to sustainability, chemical recycling technologies are a potential game-changer for the plastics industry. We anticipate that policy directives for high-percentage plastics recycling and the need for low-cost economics will drive developments in chemical recycling. Many chemical recycling development programs are in their infancy. To that end, IHS Markit is applying commercial feasibility screening to the technology process families in this sector. In this issue, we examine some of the critical factors for success. Specialty chemicals are also a significant enabler for diverse sustainable chemical solutions. We look at the role of chemicals in clean water, wastewater treatment, and clean energy applications.

While we continue on the long-term trend line for energy transition and sustainability in energy and chemicals, the pace of change is accelerating. You can count on our experts to continue providing deep coverage of these areas based on their research and ongoing client interactions.

AMERICAS
CALGARY +1 403 213 4220
HOUSTON +1 281 752 3211
MEXICO +60 4291 921

EUROPE, MIDDLE EAST, AFRICA
LONDON +44 203 253 2330

ASIA PACIFIC
CHINA +86 21 2422 9115
JAPAN +81 3 6262 177
KOREA +82 31 8039 87795

@ihsmarkitchem
linkedin.com/company/ihsmarkit

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The next wave of Permian Basin growth driven by Majors

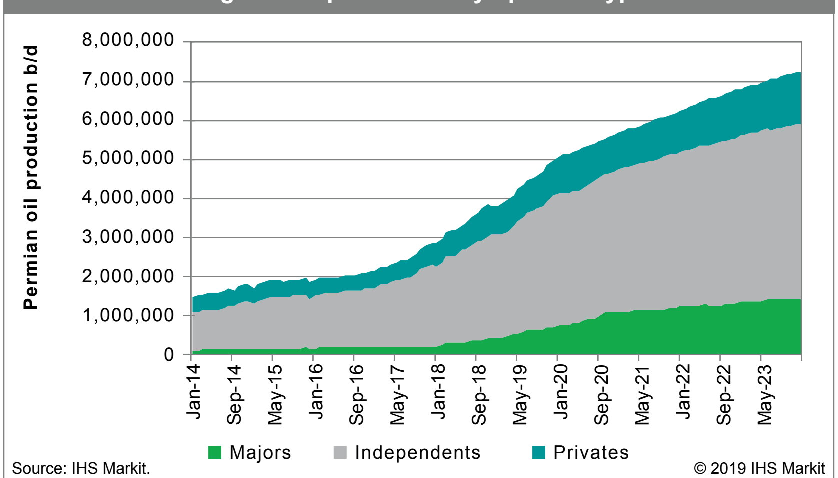
Narmadha Navaneethan | Sr. Associate, Plays and Basins, Energy Upstream, IHS Markit
E Narmadha.Navaneethan@ihsmarkit.com
T +17133690286
L Houston

The Permian fields of West Texas have a famed history and that history is still being written. The first commercial well was drilled in Mitchell county, West Texas in 1920. By War World II, the region was producing near 0.5 million b/d, supplying valuable fuel to the Allied forces. Growth continued to a peak in 1973 at near 2.0 million b/d before gradually declining to 0.9 million b/d in 2007. The initial tight oil revolution began in North Dakota and the Permian was a relatively late coming to the party, but the basin is now the primary driver of US crude oil growth. The Permian is now dominating the US oil activity with 47% of the nation's drill rigs.

The Majors were key participants in the early periods of Permian history but over time became a small part of the tight oil revolution. That is set to change in a large way. The stars of the tight oil revolution have been the Independents*, and to a lesser extent, Privates that are often funded by hedge funds.

During the tight oil boom from 2011-2017, it was common for these companies to significantly outspend their cashflow in pursuit of production growth, essentially plowing back all profits plus new money into the "drill bit". After price collapse, however, Independents were required by shareholders to prioritize capital discipline over growth, pulling back rapidly on spending and thereby growth. This response from the oil price signal through capital spend to production response is what makes the U.S. crude market so "reactive" to price. This short-cycle price-to-production reactivity now strongly influences global crude oil supply and price.

Chart 1: Permian gross oil production by operator type



Source: IHS Markit.

The Permian Basin accounts for 38% of overall US onshore capital spending in 2018 and is forecast to reach 48% by 2021, driving Permian crude production to grow from 3.8 million b/d by end of 2018 to 6.2 million b/d by end of 2021. Gas production increases 40% as well. Although capital guidance for Permian-focused Independents indicate a 5–10% cut in 2019 spending, Permian operators are forecasting a stronger production growth. Their built up drilled but uncompleted (DUC) wells will help drive growth as pipelines out of the region get completed. Producers are also seeing marginal well productivity improvements due to longer laterals, which are helping them squeeze more output per dollar spent.

(Re)Enter the Majors

ExxonMobil has announced plans to expand Permian production to more than 1,000 mboe/d by 2024, more than quadruple 2018 production. The company operated 44 rigs by year-end 2018, up from 21 rigs in 2017, and plans to run 55 rigs and 16 frac crews by year-end 2019 in the Permian. The company is expected to generate short-term production growth from its legacy Midland position while it develops its new Delaware Basin holdings. ExxonMobil is also leveraging its integrated position, including access to midstream and downstream assets. The company got the final investment decision and started construction on a third crude unit at its Beaumont, Texas refinery, to expand light crude refining capacity by 250,000 b/d. The company is linking a portion of by building a new Wink-to-Webster pipeline with Plains All American Pipeline will link key company Texas oil fields to Texas refineries and carry more than 1 MMb/d of crude and condensates from the Permian to the Texas Gulf Coast in 2021. Additional investment of $2 billion to increase the Baytown chemical plant capacity and other "Grow the Gulf" expansion initiatives will maximize the value of the company's Permian production.

Chevron has announced plans to boost its production to 900 mboe/d in 2023, nearly triple the 2018 production. The company plans to run 20 operated rigs and 7–10 net non-operated JV rigs in the basin. Chevron's 2018 Permian production is nearly 50% higher than that of ExxonMobil on a net entitlement basis, and Chevron's wells have shown dramatic productivity improvements in the past few years, requiring a lower scale of investment compared to ExxonMobil for the forecast period. Chevron's failed bid to acquire Anadarko shows the company is keen to grow yet further in the Permian. Chevron has also bought a Pasadena refinery with 112,000 b/d sweet crude capacity and other associated infrastructure from Petrobras.

BP, through its acquisition of US onshore assets from BHP, with 83,000 acres and more than 3.2 billion boe resources in the Delaware Basin. The recent BP guidance shows a high-density, multizone, long lateral development strategy across Wolfcamp and Bone Spring. The company is planning to run 5-10 rigs in the Permian during 2019–21 and growing the acquired assets (Permian, Eagle Ford, and Haynesville) from 190 mboe/d to 500 mboe/d.

Shell hasn't announced any big plans for the Permian yet. The company has around 270,000 net acres in a JV with Anadarko (now Occidental) and is targeting growth in the Permian. However, like Chevron, Shell is reportedly on the lookout for acquisition targets and may acquire additional acreage, helping drive consolidation in the play.

Production share

As the Majors enter, the competitive landscape in the Permian will change. Permian growth will be shaped by the actions of the Majors who have more flexibility on where to allocate capital and plan to increase spending over the next five years.

As Independents wrestle with a self-funding business model, which necessarily hampers growth, the Majors will gain in total production share. Privates, with comparatively less productive assets compared to the other two producer types, will still grow volumes but slowly.

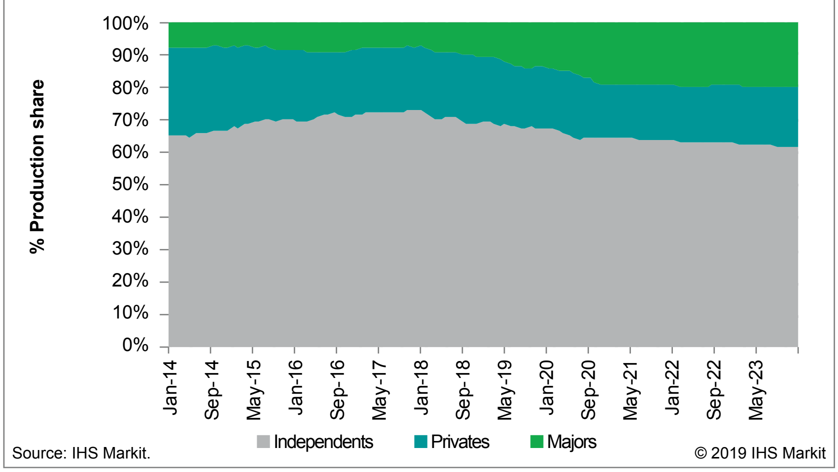
To date, the average productivity for Majors is not on a par with Independents, but it is showing continuous improvements as they leverage subsurface data to maximize growth in the play.

Majors are only a small proportion of total Permian oil production, now at around 10%, and even with aggressive growth they would only reach around one-fifth of total production in the next five years. That's because there are more than 380 operators active in the play. But as the competitive landscape changes, the competition for service sector, pipeline capacities, and other logistics will increase, creating execution risk for these smaller companies.

Majors are hoping to obtain more cost-effective service contracts and would have reduced infrastructure risk due to their large-scale operations. Moreover, majors are leveraging their integrated position with their midstream and downstream assets. Finally, from a global oil markets perspective, the large balance sheets of majors tend to make their capital budgets somewhat less sensitive to oil price. Therefore, the Permian reactivity to price signals may be tempered as the Majors revisit their roots in the fields of West Texas.

**Note: Publicly traded independent crude producers that focus solely on crude and gas production with very limited midstream/downstream integration, like Pioneer, EOG, ConocoPhillips, and others*

Chart 2: Production share by operator type



Source: IHS Markit.
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Finding the right measure: Estimating the GHG emissions of crude oil

Kevin Birn |
Vice President, North American Crude Oil Markets, IHS Markit
E Kevin.Birn@ihsmarkit.com
T +14035197804
L Calgary

Cathy Crawford |
Director, GHG Accounting & Estimation, IHS Markit
E Cathy.Crawford@ihsmarkit.com
T +14034762174
L Calgary

For more than a decade, IHS Markit has been estimating greenhouse gas (GHG) emissions associated with hydrocarbon extraction, refining, and ultimately end-use. Over this time, we've seen a growing depth and complexity of questions about GHG emissions associated with hydrocarbon production-to-use. Governments have advanced polices that make use of GHG intensity estimates in an attempt to reduce emissions over the crude oil value chain. Investors are also more interested in understanding the competitive implications of energy transition and the relative GHG competitiveness of key assets and hydrocarbon companies.

Yet understanding the competitive framework of the global oil and gas value chain is not enough. It is also important to understand how GHG emissions occur over each stage of the life of a crude oil—from extraction to processing, retail, and ultimately combustion of refined products such as gasoline and jet fuel *(see Figure 1)*.

Finding the right measure

Accessibility of GHG intensity estimates for select crude oils has increased over the past 10 years. Companies have increased disclosure, academia has produced more research, and various consultancies and non-governmental organizations are generating their own estimates. With this rising interest, the understanding of crude oil GHG emissions is improving. But much of the analysis is complex, requiring considerable technical understanding and assumptions. This can make it difficult to understand methodology differences between studies and estimates, leading to potential misinterpretation.

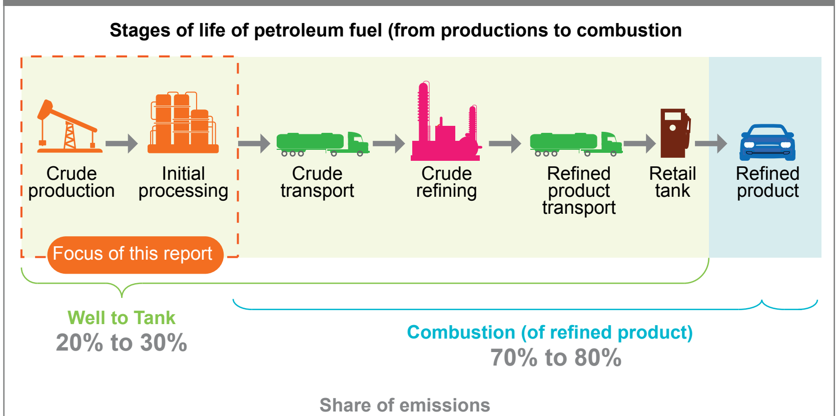
Not all life-cycle estimates measure the same thing. There are no set rules about what emissions to include or exclude. Some studies work from end-use transportation fuel up the value chain and account for all emissions that occurred to get to that fuel. Others consider all products created from a barrel of oil and account for the emissions associated with each product, regardless of where products are used.

The scope of emissions to include along the pathway can also differ, causing variance between estimates and confusion. Some methods draw a tight boundary around emissions and only include those that are a direct result of extraction, processing, and combustion. Others use a broader definition and account for other emissions that can be associated with the crude oil life cycle. For example, some analysis considers the upstream emissions of the fuels used in the extraction and processing (such as emissions associated with producing natural gas or diesel that is used to extract additional hydrocarbons). In turn, this requires an understanding of where those fuels are sourced and their own emissions pathway.

Some analysis includes all crude oil products that are combusted or have the potential to be combusted in the estimate of a crude oil pathway. Yet these estimates run the risk of unintended consequences or misinterpretation of efforts by industry to lower emissions.

Take the case of an oil production facility that consumes some associated gas for use in onsite power generation. Most life-cycle methods would include the combustion of those molecules for onsite energy use in the facility emissions (a direct onsite emission). But what if that facility installs solar panels to reduce its use of associated gas and lower its GHG emissions? In the method that attributes all emissions resulting from the barrel being produced, there would be no notable impact on the emissions intensity. There might even be an increase to account for any energy used in installation or maintenance of the solar panels. Other methods would argue the associated gas emissions should be allocated to the sector that consumes it. This sort of example has obvious implications as investors and governments seek to design portfolios and policies to reduce exposure to emission intensity sources.

Figure 1: Life-cycle GHG emissions of petroleum fuels



Source: IHS Markit.

Data is king… of uncertainties

Accounting for emissions at each stage can be complex and requires significant data. For example, extraction requires information on the type, quantity, and quality of fuels being used to produce the oil; the quality of oil and gas being produced; the extraction method used; its impact on land use; and any fugitive emissions, venting, or flaring that may occur. For downstream refining, factors such as the products being made from the crude oil, the complexity of the refinery expected to consume the crude oil, and the disposition of co-products and by-products can impact the analysis.

For many crude oils, public data may simply not exist, requiring researchers to make numerous assumptions. For these reasons, variability should be expected between estimates, and reliability is an issue. Although data availability is often discussed in research, there are seldom transparent metrics developed and published on the confidence or accuracy of emissions estimates.

Accounting for reliability

Variability and reliability are material to interpreting life-cycle GHG emissions estimates between crude oils. Because 70% to 80% of GHG emissions take place at combustion, the actual variability between estimates on a full life-cycle basis is relatively low *(see Figure 2)*. In truth, the uncertainty that can occur between independent estimates of various crude oils can be larger than the differences indicated between different crude oils.

In IHS Markit analysis, the difference between the upper and lower range of GHG intensity of crude oil consumed or refined in the US ranges from 19% to -9%. In prior research, IHS Markit compared multiple studies and found that estimates of production emissions varied by an average of 30%. Depending on the crude oil analyzed, this level of error equates to between a 5% and 15% variance in the well-to-wheels life-cycle GHG emissions estimate.

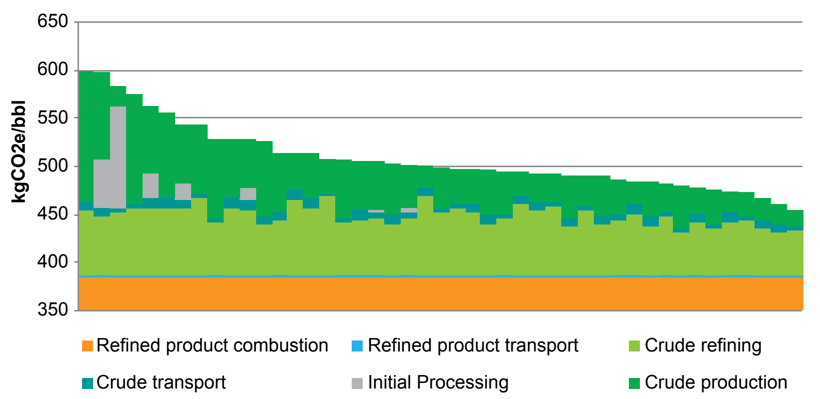
IHS Markit GHG Accounting and Estimation

Life-cycle analysis can be a very powerful tool that improves the understanding of where and how emissions occur and where the differences between crude oils exist. Interest from governments, financial institutions, and key stakeholders should be expected to drive more research in this space (including from IHS Markit) and pressure for additional oil and gas company disclosure.

However, life-cycle analysis is as much an art as a science. Assessments of the same crude oil between estimates can vary wildly due to different scopes of the emissions captured. The data requirements can be extensive and often numerous assumptions must be made. As a result, estimates can be uncertain.

Getting this right and understanding the limitations of life-cycle analysis of crude oil and natural gas is essential. Because of the complexity and integrated nature of the hydrocarbon system, the potential for distortion exists if the wrong measures are taken.

Figure 2: Well-to-wheels GHG emissions of historical crude slate consumed in the US



Source: IHS Markit. © 2019 IHS Markit

Crude oil is not homogenous, and it differs not only by emissions pathway, but also by refining intensity, availability, input cost, and value of the yield of the refined product. Even within a specific crude oil pathway, emissions can vary considerably. While it is common to see averages, such as “oil sands” or “North Sea,” these may poorly represent the actual emissions of any one facility or pathway. A complete picture requires an understanding of not only emissions, but also how the value chain interacts chemically and economically to ultimately meet consumers’ needs.

IHS Markit has launched an initiative to develop “The Right Measure.” We will be partnering with industry and financial institutions to take stock of the current state of GHG life-cycle accounting and estimation. Then we will attempt to create consensus between key institutions on best practices and methods, while shedding light on measures we can put in place to increase transparency around estimate reliability.

We hope our initiative will help shape the future of life-cycle GHG accounting. Our learnings will be incorporated into a more sustained effort by IHS Markit to estimate the GHG emissions of hydrocarbon pathways, starting with crude oil and natural gas. Our objective is to blend our deep technical capabilities with our extensive data to help clients understand where emissions arise, how various crudes compare, and why and how energy transition may change the face of the global hydrocarbon industry.

Heavy crude valuation

A case study on assessing upgrading options to maximize the value of heavy crudes

Initial situation

An international Oil & Gas company approached IHS Markit for assistance with the value optimisation of an Adriatic Sea crude, an unusually heavy crude.

The crude is a heavy (10°API) sour (5.7 wt% sulphur) crude oil grade with high mercaptans and an acidity level (0.80mgKOH/g) that is higher than what mainstream refiners tend to process.

Impact

The study provided recommendations to **maximize the value of the heavy crude.**

IHS Markit has developed potential upgrader options with respective economic models **enabling the client to evaluate the attractiveness of each configuration.**

IHS Markit approach

IHS Markit reviewed crude quality and marketability.

Using the refinery yields, operating costs and product qualities generated from the refinery models along with historical prices and IHS Markit's price forecast, refining values for the Med refining location were developed.

IHS Markit prepared an overview discussion of the long-term market and pricing outlook of crude oil and refined products that form the basis of market value analysis. A high level overview of demand for asphalt in the Mediterranean countries was also provided.

Alternative heavy crude upgrader options were developed such as standalone specialist asphalt refineries producing mainly asphalt but also other refined products; or crude oil upgraders designed to increase the value of heavy crude prior to selling to a refiner for full processing.

Contact: Spencer Welch | Executive Director, Consulting Lead – Europe, CIS | Spencer.Welch@ihsmarkit.com

308958855-0619-MT

Finding feedstocks in a quickening energy transition scenario

Kurt Barrow |
Vice President, Oil Markets, Midstream and Downstream Insights, IHS Markit
E Kurt.Barrow@ihsmarkit.com
T +18326797238
L Houston

Premasish Das |
Executive Director, Research & Analysis, IHS Markit
E Premasish.Das@ihsmarkit.com
T +65 6439 6030
L Singapore

Global energy markets are embarking on a transition to lower carbon sources. The pace of this change is uncertain, but the direction is set and undeniable. As always, petrochemical feedstock markets will be buffeted by changes in energy demand, supply, and pricing. A central challenge for petrochemical producers and "integrates" (integrated energy and petrochemical companies) will be the supply of oil-based feedstocks if oil demand declines rapidly.

The history of energy and oil markets demonstrates there are often surprises in supply, policies, and geopolitics that shape oil markets in unanticipated ways. Today there is no shortage of uncertainties in the outlook and hence scenarios are increasingly important for developing business strategies and portfolios. To help the process, IHS Markit employs a set of energy scenarios constructed from over two decades of client workshops and interactions.

The Rivalry Scenario – considered the "base case" – assumes an evolutionary energy transition over the coming decades, as policies and technologies advance to reduce the carbon content of fuel. This scenario assumes notable improvements in energy efficiency in key sectors and markets that reduce hydrocarbon fuels demand. However, it also assumes moderate levels and pacing of fuel substitution, such as electrical vehicles, natural gas-powered trucks and ships, and solar panels. The result is a relatively stable oil contribution to the global energy mix, falling from 32% today to 29% by 2040. Coal falls from 26% to 21% and natural gas increases from 23% to 26% over the same period. Gas plays a key role in reducing carbon emissions, as its lower price supports penetration into power, industrial, and transportation markets. Non-hydro renewables increase from 2% to 6%.

The Autonomy Scenario offers an alternative forecast. In this scenario, revolutionary changes in market, technology, and social forces decentralize the global energy supply and demand system. The result is an accelerated transition away from fossil fuels as low-cost renewables rapidly displace hydrocarbons from energy supply. Coal demand falls, and its share of the energy mix shrinks to 15% by 2040. Oil demand peaks sooner and declines more rapidly to 10 million barrels per day (bd) below today's level. Gas demand increases more slowly as more low-cost renewables capacity is added. While the scenario significantly reduces the growth in carbon emissions (about 14% reduction by 2040 compared with a 13% increase in Rivalry), it does not achieve the more than 50% reduction needed to reach a "2 degree C pathway."[1]

Enablers and disruptors of oil consumption

To understand how we move to tomorrow's energy market, it is important to consider oil demand trends and disruptions in key sectors. Oil demand analysis is multifaceted, complex, and quickly evolving, but a sector-wise overview provides context for IHS Markit expectations.

- Transportation, light duty – Increasingly stringent fuel economy standards dominate fuels demand for light-duty vehicles in the coming years. Compounding these trends are major mobility disruptors, including ride hailing, electric vehicles (EVs), and autonomous vehicles. For example, in China, India, the EU, and the US, we forecast EV sales to increase to 39% and 78% of total light-duty vehicle sales for the Rivalry and Autonomy Scenarios, respectively, by 2040. In Rivalry, lower EV cars (those with a charging plug) are significantly replaced by gasoline-hybrid models.
- Transportation, commercial trucking – Globalization has driven rapid growth in commercial trucking, with a two-fold increase in total global ton-kilometer of goods movements between 2000 and 2017. Policymakers and national environmental authorities have only recently started to regulate consumption and carbon emissions from this large oil sector. For example, the US implemented its first commercial truck fuel economy standard in 2010. These standards will reduce diesel consumption in medium- and heavy-duty fleets through a combination of more efficient diesel-power platforms and fuel substitution with liquefied natural gas (LNG), compressed natural gas (CNG), and electricity.
- Aviation –Aviation growth is expected to increase about 130% by 2040. As tough long-term carbon reduction targets are established, aircraft manufacturers are focusing growing research and development on reducing fuel consumption.
- Marine – The underlying demand for ton-kilometer of waterborne freight has increased at an astonishing compound growth rate of nearly 8% per year from 2000 to 2017. The International Maritime Organization has set a 50% carbon emissions reduction target for 2050 with an interim intensity target in 2030. While the industry has demonstrated substantial

efficiency gains in recent years, in part due to trends in reduced vessel speed and larger vessel size, it will be a challenge to achieve carbon targets given increasing demand for shipping.

Policy and technology changes will strongly influence these industries, the markets they serve, and the fuel they consume. Not all of the oil consumption and carbon reduction targets will be met, but regulations will change these and other oil demand sectors. In Autonomy, oil consumption peaks in five years. By 2026, the decline rate is 400 thousand barrels per day (kbd) per year, accelerating to one million bd per year by 2037. This is a rapid pace of change, given that oil demand has been growing at over one million bd per year over the past decade.

Contrast these fuel sector trends with petrochemicals. Base olefins plus aromatics demand, the majority of oil feedstock demand, is forecast to increase by 65% by 2040 in the Rivalry Scenario. That growth rate should be less in an Autonomy Scenario, where more effective recycle and reuse of petrochemical products can be assumed and chemical recycling technology advances more rapidly. However, IHS Markit analysis on the plastics sustainability issue demonstrates that reasonably strong growth will remain[2].

Feedstock supply

Natural gas liquids (NGLs) such as ethane, propane, butane, and natural gasolines have contributed notably to the global feedstock supply. For example, NGLs now contribute 55% of global ethylene production. These feedstocks have come to market largely as by-product of crude oil and liquids-rich natural gas fields, spurred by growth in transportation fuels. Lower demand growth and an eventual decline in transportation fuels demand would result in consolidation of the refining industry and reduction of crude oil processing and petrochemical feedstock production in the long term.

Crude production is one-quarter lower in the Autonomy Scenario than Rivalry and gas production is lower by 9% by 2040. In the Autonomy scenario, the appetite for residential and commercial LPGs continues to rise, reducing NGL feedstock availability to the petrochemical industry and causing petrochemical producers to rely more heavily on naphtha feedstocks.

In fact, petrochemical feedstock buyers will be confronted with shrinking supplies from both traditional sources – straight-run naphtha from refineries and NGLs from oil and gas fields. These supply constraints are present in the Rivalry Scenario forecast but are exacerbated by rapidly falling transport fuel demand in the Autonomy Scenario.

Going deeper into the crude oil barrel

Divergent trends in naphtha and NGL feedstock supply versus demand create the need to go "go deeper into the crude oil barrel" to find feedstocks. Today, most refinery-sourced feedstocks are naphtha, which trades at a price lower than crude oil. The technology exists to convert other refinery products, such as diesel and vacuum gas oil (VGO), to petrochemicals – either directly or by processing in a catalytic conversion unit. At today's refined product price structure, however, these feedstocks are not as economically attractive as naphtha or NGLs.

As an Autonomy Scenario unfolds, integrates and refiners will need such deeper integration steps.. Some new integrated projects are already designed for a production yield of 25% to 40% chemicals versus the "traditional" 10% to 15%.

Today, the production of nearly all chemicals from the global refining system, even the new deeper integration projects, uses traditional refining and petrochemical process configurations. Crude-oil-to-chemicals (COTC) technology has the potential to completely reconfigure the process for converting crude oil into chemicals, producing 70% to 75% chemicals. This technology could revolutionize the industry due to the refinery-sized scale and very low cash cost of production.[3]

Feedstock implications

The exact path and pace of the energy industry's transition is uncertain. However, the prospect of falling oil demand and refinery runs has sparked an intense conversation around the future of petrochemical feedstock supplies and the strategies to address inherent risks. As no one solution will be fit for all, petrochemical producers need to consider revisiting and testing their strategy to address this feedstock challenge.

Footnotes:
1) The Paris Agreement among international parties proposes to keep the global average temperature to below a 2 °C increase relative to pre-industrial levels. IHS Markit 2 Degree CCUS case: SDS.
2) IHS Markit Plastics Sustainability Study
3) IHS Markit Process Economics Program: Crude Oil to Chemicals and Oxidative Coupling of Methane

Dr. Yanyu He |
Executive Director,
Midstream & NGL Markets,
IHS Markit
E Yanyu.He@ihsmarkit.com
T +18326797260
L Houston

Keefer Douglas |
Director, Midstream & NGL
Markets, IHS Markit
E Keefer.Douglas@
ihsmarkit.com
T +12024813744
L Washington DC

William Chen |
Director, Light Olefins
Market, IHS Markit
E William.Chen@
ihsmarkit.com
T +861065334529
L Beijing, China

Why international buyers import US ethane

Current landscape of US ethane exports

Over the past decade, rapid unconventional oil and gas development in the US resulted in significantly increased ethane availability. Increased ethane rejection reduced ethane prices to parity with natural gas, incentivizing a wave of investment in both domestic consumption and exports. The US began exporting ethane via pipeline to Nova Chemicals' Sarnia plants in Canada in early 2014. The first waterborne cargo was loaded for Norway in March 2016, and ethane began reaching Reliance Industries' facilities on the west coast of India in late 2016. Other countries currently importing US ethane include UK, Sweden, Mexico, and Brazil.

Some international buyers import US ethane to fill the void left by dwindling domestic ethane supply. Others take advantage of the lower cost of US ethane to diversify, making additional investments to accommodate the more economical feedstock. Figure 1 breaks down the ethane imported by each company in 2018, along with the capital spent on related projects.

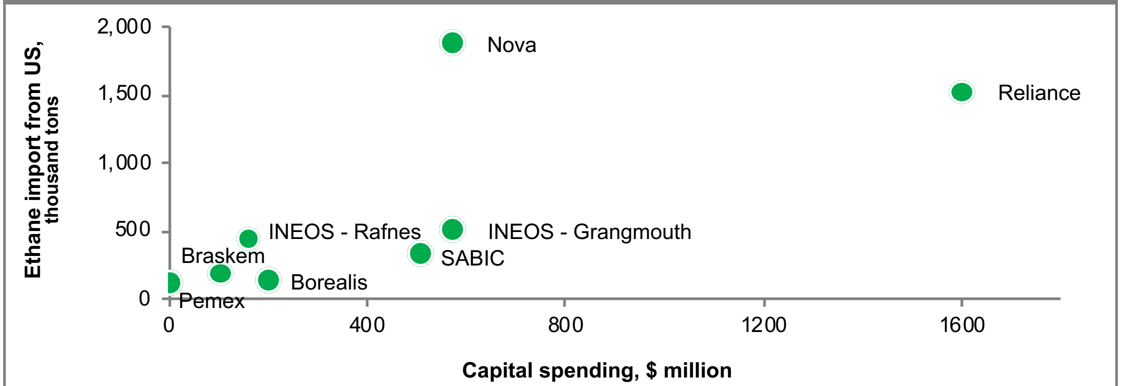
INEOS owns two gas crackers at Grangemouth, UK and Rafnes, Norway. Feedstock for these facilities traditionally relied on North Sea production. Declining ethane production in the UK caused INEOS to close the Grangemouth cracker in 2008. Production in Norway has been more stable. To capitalize on its early-mover status in securing US ethane, however, INEOS decided to expand capacity by investing in a new furnace at Rafnes. With eight dragon-class ships, the INEOS fleet acts as a virtual pipeline to bring US ethane to Europe.

Borealis soon followed INEOS into the waterborne ethane trade. Borealis still has an ethane supply contract with Equinor. Yet in 2017 when the company saw an opportunity to secure feedstock long term for its Stenungsund, Sweden cracker, Borealis started importing from the US. In 2018, this flexible gas cracker imported 450,000 tons of ethane, higher than the annual average of 350,000 tons per year used during the prior five years.

In order to enhance its competitiveness, Reliance revamped its existing ethylene crackers at Nagothane, Hazira, and Dahej to increase capacity. It also built a 480-kilometer pipeline connecting the facilities. And Reliance set up an even larger virtual pipeline than INEOS, commissioning the world's first very large ethane carrier (VLEC) fleet to supply US ethane to its crackers. The sourcing of ethane at these facilities plus integration with Reliance's Jamnagar refinery provides the company with feedstock security as well as optionality in feedstock usage.

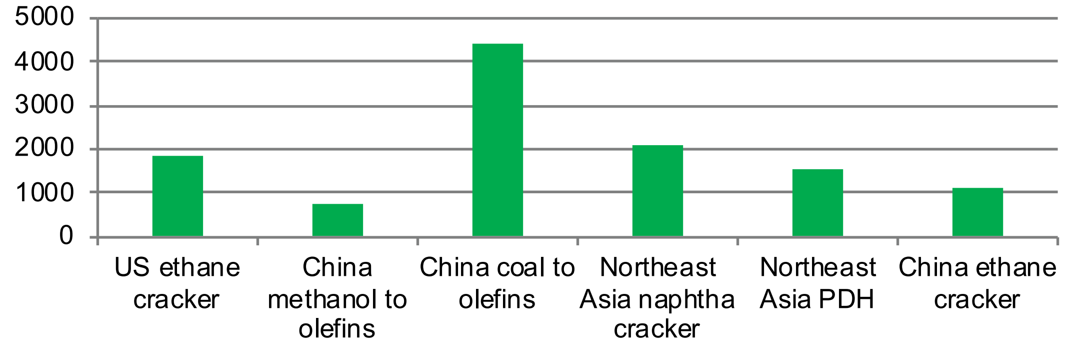
Similar arrangements were made by several other international chemical firms. Brazilian petrochemical player Braskem signed a 10-year contract with Enterprise Products Partners and started lifting ethane in 2017. Underpinning the plan is a US$105 million upgrade project at its cracker in Camaçari, Bahia to use the ethane. Improvements will also be made to allow the Port of Aratu and the connecting pipeline to receive ethane. In addition, SABIC upgraded its Olefins 6 plant at North Tees and added ethane offloading and storage facilities at the port.

Figure 1: Estimated capital spending vs. ethane import in 2018



Source: IHS Markit

Figure 2: Total fixed investment of various olefins projects ($/ton, 2018)



Source: IHS Markit

Anticipated interest in importing US ethane

The countries currently importing US ethane are not alone in their interest. In our view, there are three types of players that might consider importing US ethane:

- Those currently cracking domestically produced ethane, thus having potential to diversify supply or crack more ethane
- Non-ethane crackers that could potentially be re-configured to use ethane as a feedstock
- Countries that are short in ethylene and willing to invest in greenfield projects to use ethane as a new feedstock

Looking beyond existing importers, more than a dozen other countries also use ethane as part of their ethylene feedstock. A number of these countries are located in the Middle East and Commonwealth of Independent States regions, where vast local oil and gas resources typically limit the need for US imports.

Some other countries with ethane access could consider US ethane, however – either for supply diversity or to crack more ethane due to favorable economics. For example, declining ethane supply in Europe could eventually lead to expansion of US imports there. Both Borealis in Sweden and TOTAL in Belgium currently have contracts with Equinor to provide ethane feedstock, but US ethane might find its way into Belgium as Norwegian oil and gas production matures. In Asia, Thailand and Malaysia currently use ethane from domestically produced natural gas. However, declining domestic gas production may cause both countries to reconsider their options.

If US ethane remains competitive against naphtha, we could expect additional companies to upgrade to allow ethane cracking. This opportunity is mostly relevant to crackers located in coastal areas, which allow easy access to waterborne ethane. For example, Repsol at Tarragona, Spain has increased its use of lighter feeds (propane and butane so far), but the company could be enticed by plentiful lower-cost ethane. Versalis in Italy might be a candidate for retrofitting its own traditionally naphtha-based coastal crackers. As South Korea actively optimizes its crackers, which are largely based on naphtha feedstock, ethane could become another option.

For greenfield crackers that use US ethane, China has the largest potential. The first of such projects will be SP Chemical's new ethane/propane (E/P) cracker in Taixing, China, which is expected to be in service by Q4 2019.

Building an ethane cracker in China offers many benefits. Based on IHS Markit estimates, a Chinese ethane cracker requires about $1,000 of total fixed investment (TFI) per metric ton of ethylene, which is much lower than coal-to-olefins (CTO) or naphtha-based ethylene plants and propane dehydrogenation (PDH) projects (see Figure 2). Ethane crackers also have the highest ethylene yields. In China, ethylene self-sufficiency is still low, while propylene self-sufficiency is much higher. A higher ethylene self-sufficiency would be economically and operationally beneficial to balance ethylene and propylene market fundamentals and requirements.

However, China is not the only place where greenfield ethane crackers are being considered. INEOS is planning an ethane cracker in Antwerp, Belgium to go with its greenfield PDH plant at the same site. This investment is at least in part underpinned by INEOS' unique position: the ability to access large volumes of US ethane while still being Europe's largest net buyer of ethylene, which helps it feed its polyethylene and other derivatives businesses. Few other European players are likely to be in a position to add greenfield capacity, but there are likely markets in other regions where a new cracker could make sense.

Kaushik Mitra |
Director EMEA Polyolefins Market Research, IHS Markit
E Kaushik.Mitra@ihsmarkit.com
T +4920118579165
L Essen

Mark Morgan |
Vice President, Chemicals Consulting, IHS Markit
E Mark.Morgan@ihsmarkit.com
T +441344328341
L UK

Is chemical recycling a game changer?

Chemical or feedstock recycling is being touted as a game changer that can transform recycling. With chemical recycling, innovative technologies – such as pyrolysis, gasification, chemical depolymerization, catalytic cracking and reforming, and hydrogenation – convert plastic waste into chemicals. These technologies produce feedstocks such as monomers, oligomers, and higher hydrocarbons that can in turn be used to make virgin polymers.

Considering the steep recycling targets introduced by European Union regulators and the inadequacy of mechanical recycling to meet those goals, it makes sense that chemical recycling could play a complementary role. However, chemical recycling operations have yet to reach industrial or commercial scale.

Beyond cost

Cost and complexity are major negative factors: a chemical recycling plant has a much higher CAPEX than a comparable mechanical recycling operation. Chemical recycling also has an adverse carbon lifecycle assessment (LCA) footprint. A carbon pricing regime would raise the cash cost of virgin resin production to a higher level than today. Even so, a typical chemical recycle project would struggle to meet the internal rate of return for most businesses

However, looking purely at economic viability from cost perspective misses the bigger picture. Business leaders should focus on balancing economic viability, environmental impact, and regulatory compliance. Yet producers need to overcome many hurdles before establishing chemical recycling programs, and having authorities adopt a balanced approach to computing the value of chemical recycling would help.

Ironically, the escalating cost of unrecycled plastic may positively affect the case for chemical recycling. All EU countries have pledged to increase Extended Producer Responsibility (EPR) fees charged to consumer packaging companies for plastic waste. These fees are used to build recycling infrastructure. Also under consideration is the idea of imposing a steep tax of €800 per metric ton of unrecycled plastic on producers under the EU's Multiannual Financial Framework.

Another factor that could help companies embrace chemical recycling is product differentiation. Chemically recycled polymer would be as pure as virgin polymer. It also would avoid the pitfalls of mechanical recycling, such as contamination and potential risks to health and safety - thereby offering a superior product while providing circularity. Products made in this environment would be easy to differentiate.

Technology approaches

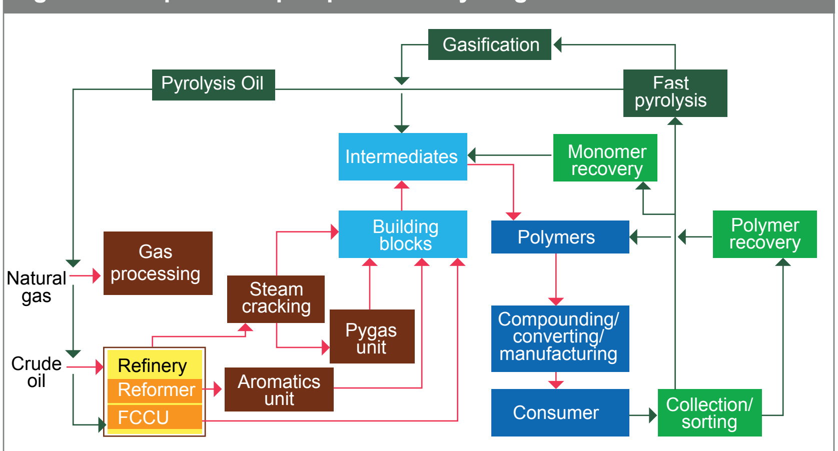
In recent consulting work, IHS Markit has seen common themes emerge in plastics recycling, especially the circular economy. How circularity is achieved varies. Figure 1 maps the conversion of hydrocarbon feedstocks into petrochemical building blocks that can include olefins and aromatics or their derivatives. Most polymers made today are processed with additives, fillers, and fibers to meet specific end-use customer needs, ranging from barrier films to keep food fresh to rigid components in automobiles.

Many municipalities collect and sort plastics waste, often alongside green water, paper, cardboard, and glass. Plastics must be sorted for subsequent processing. Techniques such as near-infrared systems that can "see" different plastics help with this. If manufacturers can be convinced to rethink the design of common household items – using a single polymer such as HDPE instead of a mix of polyethylene, ethylene-vinyl acetate (EVA) copolymers, or polyacetal – recycling could be simplified.

Once sorted, polymer articles can be cleaned and baled, ready for downstream use. Polyolefins and polyesters can be mechanically recycled and re-incorporated into select packaging solutions or made into fibers for fabrics.

The simplest way to chemically recycle polyolefins is to use pyrolysis, heating the polymers in an anaerobic atmosphere and generating an off-gas for use as fuel, a solid "char" for fuel use, and a core

Figure 1: Simplified map of plastics recycling via chemical conversion



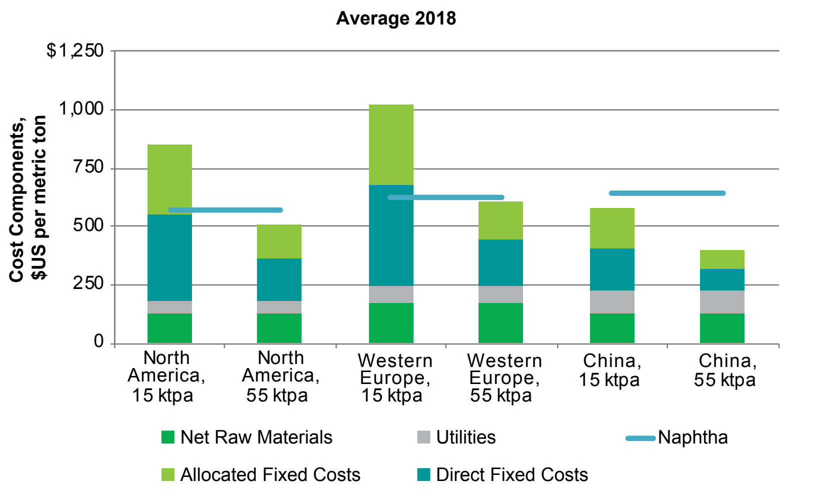
Source: IHS Markit.

product of mixed liquid hydrocarbons that is composed similar to naphtha. The output can be sent to a steam cracker or a fluid catalytic cracking (FCC) unit for olefins and fuel component production. SABIC and Plastics Recycling recently struck a deal to adopt this approach. Circularity is achieved by making hydrocarbons for use in the existing supply chain. Pyrolysis can be installed on a low scale close to sorting operations. Operations can also be integrated with sorting and mechanical recycling.

Some plastics waste can be gasified or co-gasified. Enerkem is part of a consortium with a project that is converting mixed waste into synthesis gas (syngas) and ultimately methanol, mainly for fuel use. In China, plastics and pyrolysis oils could be co-gasified using existing large-scale operations for methanol, olefins, and mono-ethylene glycol (MEG) production from syngas. In this case circularity can be achieved through monomer production.

PVC is challenging to recycle chemically due to its chlorine content. It generates hydrogen chloride during, for example, the pyrolysis reaction. Although these processes can handle small volumes of PVC when precautions such as guard bed systems are in place, it is far from ideal. It is important to remember that most plastics contain additives and that efforts are needed to sometimes clean up polymers beyond basic cleansing. Technologies such as supercritical carbon dioxide could be used to remove many additives from recyclable polymers, but such approaches are costly.

Figure 2: Manufacturing costs for pyrolysis hydrocarbon oil PHO



Source: IHS Markit. © 2019 IHS Markit

Responsibility for change

Another controversial area is the cost of chemical recycling and who pays. IHS Markit has an approach to validate costs and the affordability of feedstock. By modeling the appropriate process – considering utility needs, labor hours, maintenance, overhead, capital, and scale of operation – we can compute the price of feedstock to give a zero margin on the product. This approach can be applied to pyrolysis for making naphtha as well as depolymerization for making MEG.

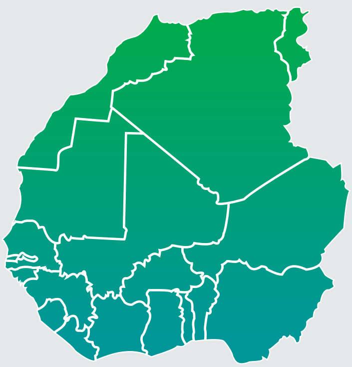
Figure 2 illustrates the range of costs involved. Pyrolysis is a simpler process that operates at the local municipal level, creating a relatively low-value hydrocarbon stream with a known price. The MEG approach is more cost-effective using a polyester feed.

For plastics recycling to be financially attractive, there must be a workable margin for everyone in the recycling chain – including municipalities, sorters, processors, and mechanical and chemical recyclers. And the best solution may vary by geography. The mega-cities of China could favor an approach for polyester linked to the existing gasification infrastructure. In Europe, certain major cities are located near petrochemical production, which may lead them to polyethylene pyrolysis for liquids cracking.

If government-established recycling targets are to be achieved, the links between consumers, municipalities, and petrochemical production must be improved. After all, public opinion is moved by media images of a threatened planet and eco system. Only through the collaboration of people, municipalities, and industry – supported by improved technology along the recycled plastics supply chain – can we begin to find a solution for this global crisis.

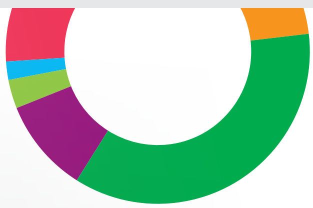
A case study on assessing new refineries and local markets in West Africa

Initial situation



IHS Markit's overall objective was to assist the client with an understanding of the West African regional refined product market and screen potential refinery configurations that might be best address the needs of the refined products market.

Impact



The study provided the client with an independent market study of the local refined products along with a **crude oil availability study for such new refinery in West Africa**.

IHS Markit has developed potential configurations for the new refinery with respective economic models **enabling the client to evaluate the attractiveness of each configuration.**

IHS Markit approach

IHS Markit provided a refined product market review for the region together with a crude availability outlook.

A consistent crude and product price forecast was provided to the client for use in economic analysis of the project. Price forecasts were provided at refinery gate based on import parity and export parity pricing to/from relevant markets.

Potential refinery configurations were evaluated to simulate consumption of chosen crude oil(s), determine the resulting product slate and overall material balance.

IHS Markit provided a cash flow projection for each configuration to evaluate the rate of return and potential refinery margin.

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Impact of the US-China trade war on the MDI market

James Elliot |
Principal Analyst,
Polyurethane Feedstocks,
IHS Markit
E James.Elliott@ihsmarkit.com
T +442031593270
L London

The polymeric methyl diphenyl diisocyanate (pMDI) market has been impacted by the latest developments in the United States-China trade war. pMDI, a key polyurethane feedstock, was initially included in the list of $200 billion of Chinese imports that were tariffed by the United States Trade Representative in response to China's trade practices. US pMDI imports from China were subject to a 10% import tariff beginning September 24, 2018. This rate was subsequently increased to 25% on May 10.

The main polyurethane feedstocks – including pMDI, monomeric methyl diphenyl diisocyanate (mMDI), toluene diisocyanate (TDI), and polyether polyols (produced via the intermediate propylene oxide) – are reacted in different combinations to produce polyurethanes. The most common product is flexible and rigid polyurethane foam.

Polyurethanes are used in a myriad of applications. The buildings we live in, the mattresses we sleep on, and the shoes we wear can all contain polyurethanes. Even surfboards are made from rigid polyurethane foam. Polyurethanes are everywhere.

The global pMDI market has been volatile lately. In 2017, supply shortages triggered by plant outages and insufficient capacity investment led to a pMDI price surge. Prices collapsed in the second half of 2018, as supply significantly improved and demand waned amid product substitution and the cooling global economy. In late-Q1 2019, the pMDI market picked up with reinvigorated demand thanks to the peak spring construction season.

However, the escalation in the US-China trade war and implementation of the 25% trade tariff will impact global pMDI demand growth and in the United States. Slower global economic growth is now forecasted. One upshot is a weaker outlook in construction activity, including in the United States, moderating growth in building insulation demand; the largest pMDI end use in the United States is in rigid polyurethane and polyisocyanurate foam based insulation. In general, IHS Markit forecasts softer pMDI demand growth compared to the healthy growth exhibited in recent years. Weakness in other sectors such as the automotive industry - an industry facing its own challenges - is also projected to stifle US pMDI demand growth.

The United States, the second largest pMDI-consuming country, has seen its pMDI trade position shift in recent years. Historically, the US was a net exporter of pMDI. Today the country still exports a substantial volume of pMDI, including more than 200,000 metric tons (mt) in 2018.

The US pMDI market has recently exhibited high demand growth rates. Yet there has not been a major greenfield MDI capacity investment in the United States for many years. As the US import requirement grew and the pMDI market structurally tightened, the US became a net importer of pMDI in 2018.

Subsequently, the US market has become dependent on imports to meet demand. Approximately 71% of the 300,000 mt of pMDI imported into the US was sourced from China. Based on IHS Markit's US pMDI monthly index and the monthly import volume, this equates to just under $500 million worth of imports.

The introduction of the 25% tariff will ensure that volatility continues in the pMDI market, especially in the US. US pMDI prices are forecast to rise not just because the tariff increase, but also because Chinese supply is expected to moderate as exporters reduce US shipments.

The United States trade position will rebalance. pMDI imports will decrease in 2019. Exports are also projected to drop as more domestically produced material remains in the US market to meet the deficit arising from reduced Chinese supply. Agreed contractual volumes will continue to flow from China to the United States. In such circumstances, pMDI consumers will face rising prices where contracts allow. The impact a trade rebalance will have on the market is one factor amongst others contributing to upward price momentum anticipated in the second half of 2019. It is unlikely direct long-term supply shortages will be experienced due to the consequences of the tariff introduction. Instead major end users in the construction, appliance and wood composite industries will not have to moderate end use production, rather face higher polyurethane material costs.

Other polyurethane feedstocks are also impacted by the US-China trade war. The US implemented the 25% tariff on TDI and propylene oxide. On May 13, China applied retaliatory tariffs of 25% on pMDI, mMDI, and TDI as well as a 10% tariff on propylene oxide.

IHS Markit launched its new Global Polyurethane Feedstocks Market Advisory Service in March. This service helps clients navigate pricing, supply, and demand volatility in the polyurethane feedstocks markets. It also provides deep insight into the latest market developments, such as the impact of the US-China trade war on the polyurethane feedstocks markets.

Specialty chemicals: Enablers of sustainable development

Marifaith Hackett |
Research and Analysis Executive Director, Renewables & Nutrition, IHS Markit
E Marifaith.Hackett@ihsmarkit.com
T +14083434813
L Freemont, California

We live in chemophobic times: The media and general public view chemicals as enemies of the environment. But this perspective is flawed because it overlooks the essential role of chemicals – particularly specialty chemicals – as enablers of sustainable development.

Produced responsibly - as the vast majority of chemicals are - specialty chemicals and polymers support key sustainable development goals, including clean water, clean energy, and the preservation of life below water. They enable society to satisfy its current needs without compromising the ability of future generations to meet their own requirements.

Clean Water

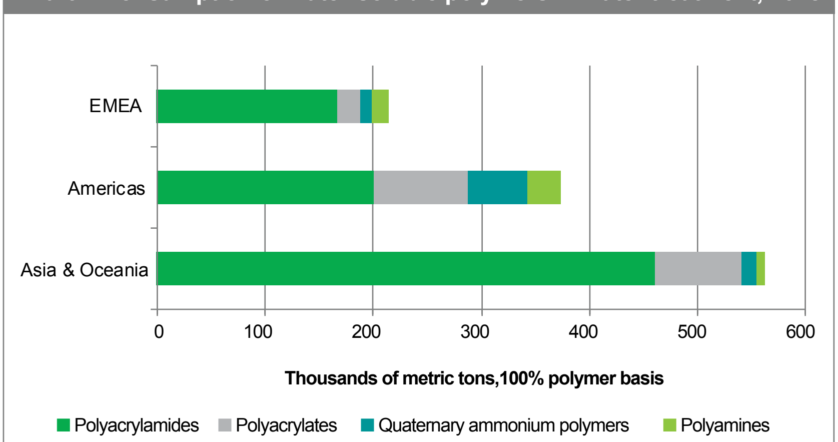
Clean water is the foundation of a healthy society. But clean water doesn't just happen. All water – even water from a pristine mountain reservoir – requires treatment before it is suitable for human consumption or industrial use. And water also requires treatment after use so it can be safely returned to the environment.

Specialty chemicals – and specialty polymers in particular – play important roles in a range of water treatment processes (see Figure 1). These processes include drinking water production, wastewater treatment, and industrial water treatment. Specialty polymers:

- Reduce turbidity and accelerate the settling of suspended particulates in the production of potable water
- Thicken and dewater sludge in wastewater treatment
- Inhibit the formation of scale (mineral deposits) in boilers and cooling towers

Worldwide consumption of specialty polymers in water treatment exceeds one million metric (mm) tons per year. Polyacrylamide, the largest volume water-soluble polymer used in water treatment, plays important roles in drinking water production and wastewater treatment. Polyacrylate, the second largest volume polymer, prevents scale formation in industrial equipment. Quaternary ammonium polymers and polyamines are used primarily in the production of potable water.

Chart 1:Consumption of water-soluble polymers in water treatment, 2018



Source: IHS Markit.

Clean Energy

Wind is crucial to today's global energy market, and its importance as source of clean, renewable energy continues to grow. In 2010, wind made up less than 4% of global power capacity. In 2018, wind accounted for more than 8%.

The turbines that transform wind into clean electricity depend on specialty materials. Each wind turbine incorporates 25 to 100 metric tons of specialty resins and reinforcements. Unsaturated polyester resins, epoxy resins, glass fiber, and carbon fiber are standard construction materials for wind turbine blades.

Size matters in wind energy. Turbine height, blade length, and power output are increasing, and so is the amount of resin and reinforcements required to produce a wind turbine. The largest turbine blades in commercial production are more than 88 meters long (about the length of a football field) and require more than 100 metric tons of resins and reinforcements.

Economics is driving this trend. Larger wind turbines are more efficient, resulting in lower power generation costs. Energy from a modern wind farm with large turbines is cost-competitive with energy from conventional sources such as coal and natural gas.

Preserving Life Below Water

Nutrient pollution is the enemy of underwater life. Surplus nutrients, typically nitrogen or phosphorus, lead to algae blooms in lakes, rivers, and coastal waters. Excessive algae growth creates dead zones – depleting oxygen and blocking sunlight from underwater plants – making life below water untenable. Some algae blooms also produce toxins that are harmful to humans.

Excess nutrients can come from many sources, including laundry detergents. Traditionally, laundry detergents included phosphate "builders" for improved performance, especially in hard water. Phosphate builders are inexpensive and effective, but they also serve as nutrients. In contrast, specialty chemical builders – zeolites, citric acid, and polyacrylates – enhance detergent performance without causing algae growth. These specialty chemicals do everything that builders are supposed to do – soften water (by sequestering calcium and magnesium ions), disperse dirt, and prevent soil redeposition – without nourishing algae blooms.

Global consumption of zeolites, citric acid, and polyacrylates in laundry detergents is about two mm tons per year. Developing markets are driving demand growth for these specialty builders. In contrast, demand for specialty builders in the mature markets of North America, Western Europe, and Japan is expected to be flat, in part because these regions are moving on to new and greener formulations. Increasingly, mature markets are turning to liquid and unit-dose formats instead of powder laundry detergents. The new formats rely on greener builders, such as sodium gluconate and the sodium salt of glutamic acid, N,N-diacetic acid (GLDA). These chelating agents are both biodegradable and bio-based, as their raw materials include glucose and glutamic acid, respectively.

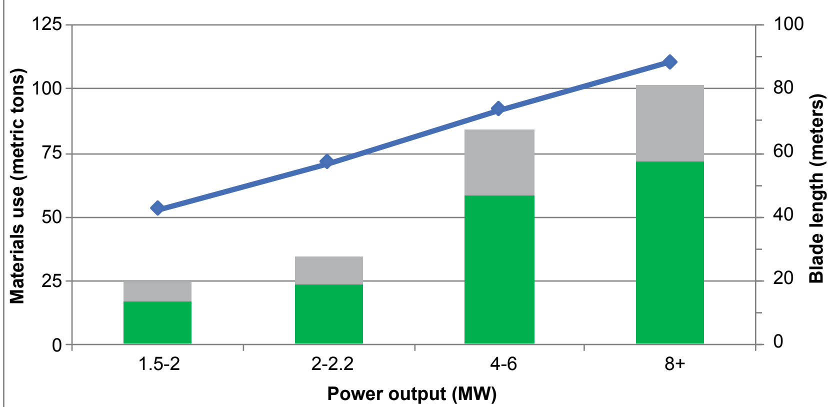
Looking Ahead: Opportunities for Green Innovation

Specialty chemicals may play an even larger role in sustainable development in the future. Opportunities for green innovation are substantial. Specialty chemicals are sold on the basis of performance or function, not chemical composition. Consequently, price is important but not imperative. In addition, specialty chemicals are closer to the consumer than commodity chemicals. Products that include "green" specialty chemicals can tap into consumer interest in the environment and bio-based ingredients.

Paths to greener specialty chemicals include the use of:

- Sustainably produced renewable feedstocks. In general, bio-based materials have smaller carbon footprints (cradle-to-factory-gate greenhouse gas emissions) than their petrochemical counterparts. But there is a caveat: Feedstock provenance matters. Land use changes can have a major negative impact on carbon footprint. Specifically, the drainage and deforestation of peatland to make way for oil palm plantations increases the environmental burden of palm oil, palm kernel oil, and their methyl ester derivatives. Because of land use change, these materials have large positive carbon footprints. In contrast, coconut oil and coconut methyl ester have negative carbon footprints – that is, their production removes carbon dioxide from the environment.

Chart 2: Blade materials use per wind turbine



Notes: Combined materials use for all three blades of the wind turbine.
Source: IHS Markit.
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- Biocatalysts and biotechnology. Biotechnology offers a sustainable route to value-added products. A case in point is stevia sweeteners. First-generation stevia sweeteners are extracted from the leaves of the stevia plant. The extracts contain many components but only traces of the best tasting sweeteners. Next-generation stevia sweeteners (such as Reb M and Reb D) are produced from corn or sugarcane by yeast fermentation. Reb M and Reb D are intensely sweet with zero calories and no aftertaste. They show great promise as sugar replacements in soft drinks and other beverages.
- Waste materials as feedstocks. Using waste materials as feedstocks supports the circular economy by recycling "waste" into useful products. Examples of specialty chemicals that can be produced from waste materials include polyols from waste gas (such as flue gas from steel mills and off gases from refineries); furfural from biomass (such as corn stover, corn cobs, and sugarcane bagasse); and polyhydroxyalkanoates – biodegradable polymers – from biogas (through anaerobic digestion).
- Sustainable development matters. To paraphrase Moses Henry Cass: We have not inherited this planet from our parents – we have borrowed it from our children. Specialty chemicals can help us preserve this world for future generations.

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