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INSIGHTS

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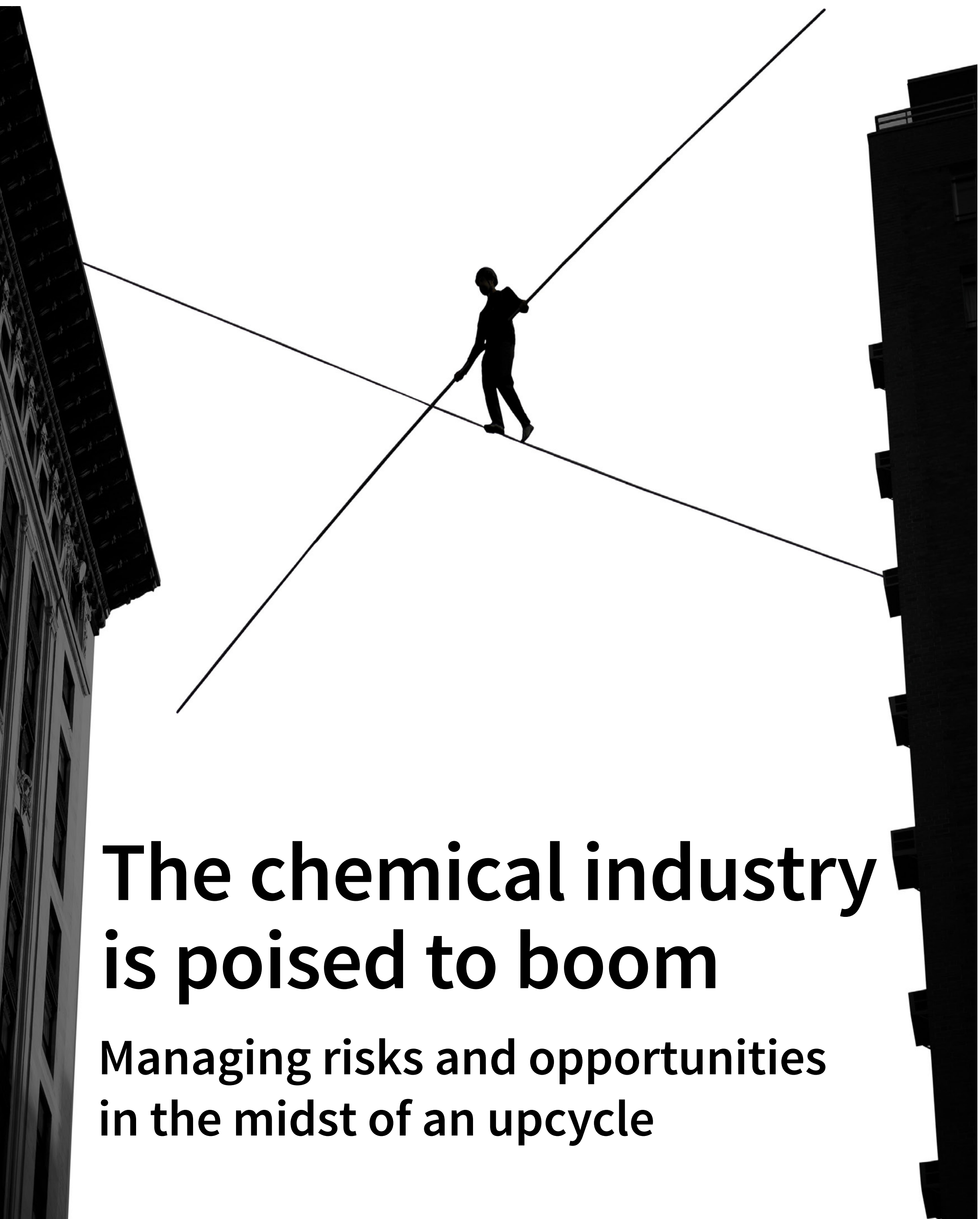

The chemical industry is poised to boom

Managing risks and opportunities in the midst of an upcycle

Energy & value chains - bringing clarity to an uncertain world

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The refining and petrochemical industries are shaped by a complex set of market, regulatory, technological and economic forces. Our job at IHS Markit is to provide our clients with the best set of data, insights and analytics that helps create clarity from complexity. As we look forward through 2018 and beyond, we see these forces creating a set of industry dynamics with an unprecedented level of uncertainty with implications for industry pricing and profitability.

Specifically, here are some of the key issues and trends:

Economics – After spending much of this decade mired in mediocrity with alternating strength between developing and developed economies, and barring the ever-present policy or geo-political risks, it now appears the world economy is poised for synchronicity and unified strength. Economies that had been mired in weakness or risk attributable to high debt or weak commodities are now strengthening along with the traditional larger economies of Japan, the United States, Europe and China. The implications on global demand for chemicals and petroleum are substantive and build additional momentum for growth on what has been extremely strong and consistent expansion in demand over the past several years.

Regulatory – the regulatory pressures on the industry are an acceleration and broadening of the trends that have been underway. From reduced sulfur in gasoline and bunker fuel, to increased plastic recovery and recycling, the industry continues to drive toward product-specific changes that allow the full deployment of all the commensurate benefits that our industry provides.

More directly, the drive to reduce pollution and extend decarbonization will impact specific countries and value chains differently. For example, China's push to demonstrate leadership and alignment with the Paris Accords while specifically addressing citizen concerns of air quality means potential rationalization of capacity and an impact on gasoline markets from mandated ethanol content and a longer-term focus on EVs.

Technology – Technological changes are accelerating. Shale continues to create waves in the fabric of the energy markets. OPEC is still adapting shale's ability to quickly and substantively deploy as a flexible and lower-risk route to incremental petroleum production. This creates volatility and the potential for supply dislocations.

Meanwhile other and even more transformative transportation technologies are moving to the fore. Specifically, the intersection of environmental trends and technological changes such as autonomous vehicles, low-cost battery technology, and ride-sharing via platforms like Uber and Lyft create both risk and opportunity for the refining and chemical industry. This has implications for the gasoline, trucking and chemical markets; implications that are often counter-intuitive. At IHS Markit, we have leveraged our leading energy and transportation businesses to bring clarity to this complex subject.

Market – despite the evolving economic and regulatory framework and uncertainty/volatility in energy, the chemical and refining markets have been remarkably stable in terms of profits. This stability belies rapid structural changes that have been amplified by weather-related production outages. We see the near-term markets remaining tight. Depending on realized demand growth and operational reliability, some value-chains are balanced on a knife's edge. This tightness is likely to be exasperated by coming changes in the environmental/regulatory framework.

The articles contained in this publication deal with a number of these macro issues. Our experts are always available to help translate these rapidly changing forces to mitigate the risk and capture opportunity for your company.

I hope you enjoy.

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Are electric vehicle makers putting the cart before the horse?

Limited battery raw materials could impact EV deployment

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The dramatic impact of global warming on the environment has finally led governments to begin establishing strict targets to lower CO_2 emissions. Achieving these governmental goals will require greener transportation modes that are powered by clean electricity and stored in batteries.

There are a number of factors that will influence the adoption of electric vehicles (EVs), including legislation, charging infrastructure, fuel cost, and tax incentives. The most important issue is the battery, in terms of both cost and efficiency. The lithium-ion battery (LIB) is the most important cost component of an electric car and its cost has dropped by 80% since 2010. However, one cost that has not dropped is that of raw materials such as lithium.

Lithium, the lightest metal, can be found in phones, computers, and EVs. It allows batteries, along with other materials, to store energy efficiently. Lithium supply has been tight over the last two years. An increase in demand in an unprepared market led prices to surge.

As the industry slowly wakes up, we are seeing investments that will bring new lithium capacity on stream. Developing lithium mining projects can take as long as 10 years. To overcome delays, a number of junior lithium producers are finding partners in the industry with available expertise and funding, both of which are crucial to developing a successful project.

Lower CO_2 emissions targets push faster EV adoption

In the coming years, the EU, China, and the US are expected to reduce transportation-related CO_2 emissions. Selling more EVs is essential to meeting these targets, and some governments are proposing a rapid phase-out of the internal combustion engine. In China, 20% of all vehicles sales are to have some form of electrification by 2025, while France and the UK propose to end the sale of all cars emitting greenhouse gases by 2040.

In 2017, most traditional auto manufacturers announced new EV models. Volvo announced that all models will be electric or hybrid beginning in 2019. IHS Automotive estimates that hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and EVs will represent around 45% of all car production by 2030, with pure EV representing 5%.

EV production drives lithium demand

Lithium demand was estimated to be more than 220,000 tons LCE (lithium carbonate equivalent) in 2017. Historically, industrial applications including glass and ceramics, grease, polymers, pharmaceuticals, and air treatment consumed the most lithium. Recently, batteries for portable devices became important, and today, lithium demand is led by electric mobility.

Our base case scenario is that total lithium demand will grow at 14% per year by 2025, when it will reach more than 600,000 metric tons (mt). Our high case scenario assumes an 8% penetration of EV by 2025 instead of 4%, creating an increase of 18% per year in lithium demand.

LIB market chain concentrates in Asia

Until 2016, the LIB market was powered by demand in portable devices. In the near future, growth rates will be driven by EV demand. Auto and battery manufacturers are making substantial investments in new production facilities. Although Tesla's gigafactory in Nevada receives substantial attention, the most ambitious company is CATL in China. CATL plans a tenfold increase in LIB capacity to 50GWh by 2020. Around 95% of all LIB capacity is currently located in China, Japan, and South Korea. Most investments will be in this region, but several producers have announced plans to build factories in Europe. For example, LG wants to open Europe's largest EV battery factory.

Most EV makers do not actually produce batteries. Battery cells are produced by Japanese, Korean, and Chinese companies such as Panasonic, Samsung, LG and CATL. Only in China do EV makers such as BYD produces their own battery cells. So far, car makers are prioritizing strategic partnerships with battery manufacturers rather than investing in making the batteries themselves. Daimler and Nissan used to produce batteries, but have stopped in the last two years because costs and technology could not compete with Asian manufacturers.

The main cost component of an EV is its battery pack. Battery cost decreased from around $900 per kWh in 2010 to approximately $200 per kWh in 2017, a drop of 80%. Battery costs are expected to decline further, albeit at a slower rate, as manufacturers build large battery factories and achieve economies of scale.

Decreased costs have allowed LIB technology to become much more competitive recently, but there is still much discussion about new types of batteries that could replace LIB.

New battery technologies appear on the horizon

Until 2015, nickel metal hydride was the preferred technology for hybrid vehicles. Since then, LIB technology has cornered the market. In 2025, LIB will represent more than 95% of all EV battery types. However, some new technologies could compete with LIB in the future, such solid-state batteries that eliminate the liquid electrolyte and improve energy density. Most of those new technologies are still at a very early development phase, however, and it will take years before they can replace LIB.

Cathode evolution dominates in the short term

The cathode is the battery component that consumes lithium. Cathodes are a sintered blend of lithium, cobalt, nickel, manganese, and other materials. In the next five years, nickel, manganese and cobalt (NMC) will represent more than 60% all cathode types used in e-mobility. Some manufacturers favor nickel-rich NMC in order to reduce the amount of cobalt required for production. Most cobalt originates from the Democratic Republic of Congo, where a portion of production comes from artisanal mining that sometimes employs child labor.

Lithium supply questions arise

Do we have enough lithium to power electric cars? Measured and indicated lithium resources are estimated at over 250 million tons LCE. Proven and probable reserves that are economically extractable are closer to 60Mt LCE. This does not include lithium deposits that have yet to be explored. If all cars were EVs by 2050, this would represent a cumulative consumption of 60Mt LCE. When we look beyond cars and add other battery applications, future lithium demand could be larger than today's lithium reserves.

Potentially limited lithium reserves could be augmented by recycled lithium from LIB. The LIB recycling process is still uneconomical and years from reality. Using batteries in second-life applications, such as home energy storage, could be a practical first step in recycling.

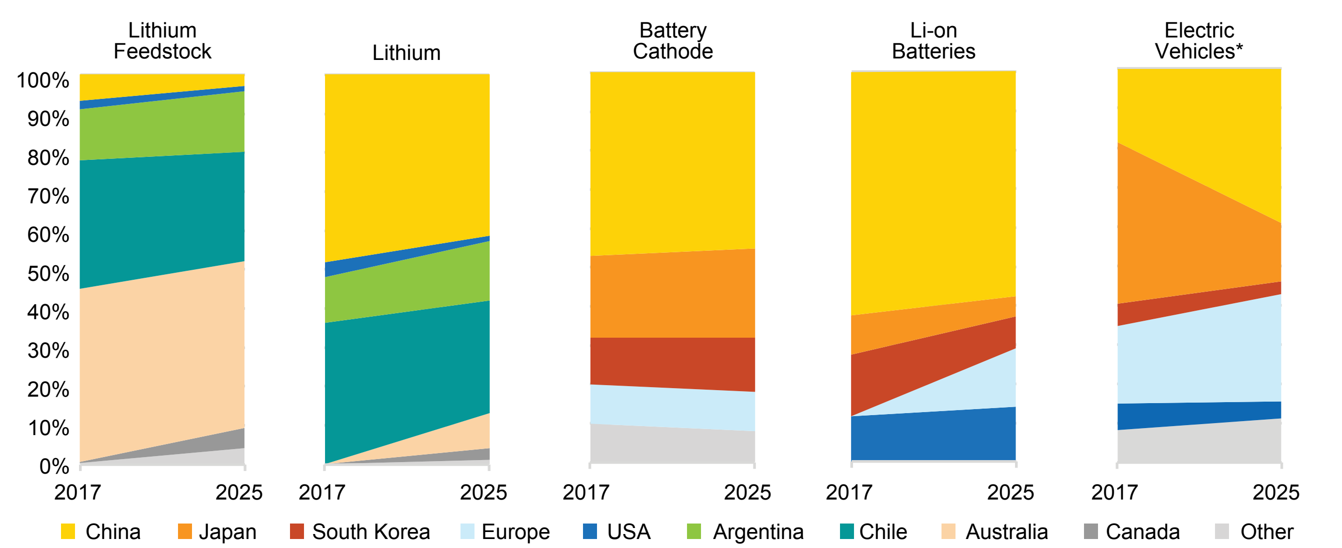
Lithium is produced from either brine-based deposits or from hard-rock mineral deposits. Brine production comes mostly from South America. Lithium brine is extracted from beneath salt flats and pumped into ponds where it is concentrated for up to a year before being refined to make lithium chemicals. Lithium can also be produced from rock mining, mainly spodumene. Almost 100% of all lithium rock mining occurs in Australia, but spodumene processing into lithium chemicals is done in China.

The main refined product is lithium carbonate. Lithium hydroxide has mostly been used in the production of grease, but it is becoming the preferred lithium chemical for cathode manufacture. Demand for lithium hydroxide is anticipated to grow faster than lithium carbonate.

Control over the lithium supply creates challenges

Lithium raw material production is dominated by

Who Really Controls the Lithium-ion Batteries Supply Chain?



*Including HEV, PHEV & EV
Source: IHS Markit

Australia, Chile, and Argentina, which represented 90% of global production in 2017. Albemarle, SQM, Tianqi, and FMC accounted for approximately 70% of global supply. As numerous new producers enter the market, the market share of existing players will decline.

Because the entire conversion of rock to lithium chemicals takes place in China, fully half of all global lithium chemical production takes place there. By 2025, Australia will have developed some domestic rock conversion plants, but a majority of the spodumene will still be exported to China.

China has been investing in foreign lithium assets for many years. The largest investment occurred when Tianqi secured a 51% share in Talison Lithium in Australia in 2013. Since then, Chinese companies continued investing and securing offtake agreements, mostly in Australia and in South America. In 2016, a surge in prices saw continued activity. In 2017, many Chinese companies – from lithium players to battery manufacturers, automakers, and traders – invested in numerous assets and secured a many offtake agreements. In fact, two-thirds of all offtake agreements concluded in 2017 were negotiated by Chinese companies.

Offtake volume represented less than 20,000t LCE in 2017, but by 2025 it could represent more than 300,000t LCE. Offtake agreements allow suppliers to mitigate risk because they can count on the ability to sell future production. These agreements also allows buyers to secure volume in a potentially tight future market.

Lithium supply dreams and reality loom large

Existing lithium producers have announced significant expansion plans in Chile, Argentina, the US, and Australia. A number of new producers are also willing to enter the market. New Australian players are ramping up production and increasing exports to China. Three plants in Australia are likely to start production in the second half of 2018.

In order to meet 2025 demand, producers need to build a supply of approximately 500,000 mt of lithium – three times more than we have today. With an average capex of 16,000US$ per ton, the industry requires an investment of at least $7 to 8 billion during the next 10 years. Yet bringing a lithium plant on stream is a complex, time-consuming process. The average lithium brine production site requires an average of seven to 10 years to come on stream. A new rock mine takes four to six years to become productive.

In 2017, there were more than 400 known lithium operations and development projects. However, only 3% of all those assets are operational, while 2% are in the construction phase and another 5% are in a feasibility stage. Being at a feasibility phase does not guarantee that lithium production will start. The remaining 90% of operations are either at an exploration or pre-exploration stage, which means they are many years away from potential production. In order for any of these projects to be developed, lithium must be extracted economically and financing must be secured. The best case is that production will expand from 230kt today to around 700kt LCE by 2025, growing at 16% per year.

Lithium supply balances and prices will take time to stabilize

In our base case scenario, which assumes that demand grows 14% per year to 2025, the lithium market will not be fully balanced despite supply that exceeds demand. This is due to a number of factors, such as potential operational issues at lithium plant, plants that deliver non-battery grade lithium, delays in plant start-ups, and lower-than-expected production.

However, if EVs reach 10 million units instead of five million EVs by 2025, the lithium market will be undersupplied. Supply has been tight over last the two years, leading to price increases and supply anxiety from car and battery producers. Contract prices more than doubled during the last two years. Large lithium players have shortened contract lengths due to the uncertainty of upcoming supply.

In the short term, lithium resources are tight and will struggle to keep up with strong demand from the battery sector. We expect prices for lithium chemicals to remain at a high level for at least two to three years before significant new capacity comes on stream and prices strat eroding. However, we do not expect prices to be restored to their historic levels.

Conclusion

The lithium industry will require significant investment to allow a smooth transition to EV mobility. China accounts for only 7% of lithium extraction, but controls 48% of lithium chemical production and 62% of LIB capacity. China is also the largest EV producer today.

Chinese lithium, battery, and car producers have been negotiating foreign investment and offtake agreements to secure lithium supply, mainly with Australian projects. Approximately 70% of recent off take agreements were with Chinese lithium converters and battery manufacturers. In early 2018, only one site was sending product to its off-taker.

Automakers will continue trying to develop long-term deals to secure lithium, but pricing discussions will be complex. Lithium prices are not likely to return to their historic levels but will likely remain high for some time.

Coming Soon!
Global Lithium Market Advisory Service

IHS Markit is pleased to announce the upcoming introduction of an integrated Market Advisory Service (MAS) covering the lithium industry and its downstream applications.

The MAS will provide a wide range of market information and analysis to assist clients in making smart tactical and strategic decisions in the fast-moving Lithium market:

- Market analysis and forecasts for lithium and end uses
- Market prices for a range of lithium chemicals
- Supply and demand updates
- Lithium production economics
- Global and regional economic trends
- Trade data and trends
- Investment and technology updates for lithium and end uses

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Disruptive forces promise to reshape the trucking industry

Transportation demand accounts for over 50% percent of the world's refined product demand, and the medium/heavy trucking sector accounts for almost half of this. But the trucking industry is increasingly exposed to disruptive forces that could alter longstanding trends and impact diesel demand globally. How these forces unfold and interact will determine the answers to the big questions facing the logistics, trucking, and energy industries. IHS Markit's current study, "Reinventing the Truck" , examines these changes, taking into account the impact on adoption of new power-train technologies as well as deployment of autonomous technologies.

The first driver of change is new patterns of distribution and consumption. Historically, growth in trade has mirrored economic activity, but this relationship may be disrupted by changes to the way we manufacture and distribute goods. Innovations such as 3D printing shorten supply chains and may diminish demand for freight carriers, reducing shipping costs to zero in some cases.

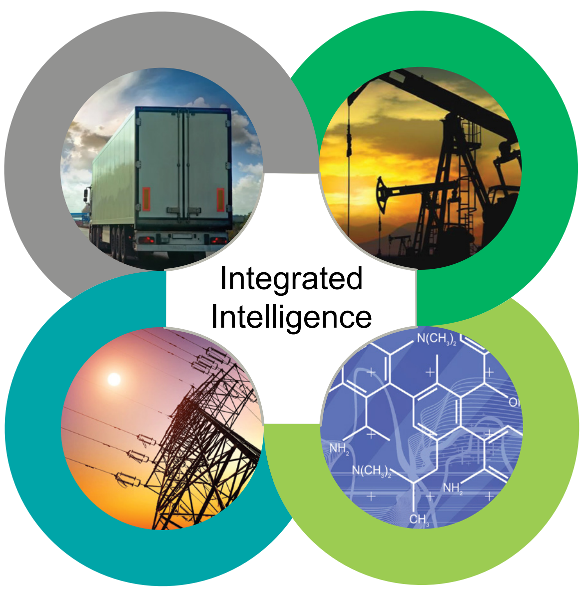
The second driver of change is technology. There are three key ways that new technologies will change the trucking industry. First, new technologies will spur efficiency gains in the supply chain through electronic logging devices and increased access tov data, which facilitate better network optimization. Second, adoption of new drive-train technologies will alter fuel consumption patterns as electric vehicles become more numerous, particularly in urban environments. As electric drive trains allow for quieter vehicles, service hours can be extended in urban and suburban areas, altering established patterns of vehicle deployment. Third, increased levels of automation will lead to cost reductions through increased efficiency, which will be achieved via higher levels of connectivity and communication.

The third and perhaps most immediate driver is regulation at the national, state, and local level. Whether policies are designed to promote

Forces of change will impact industries beyond the automotive sector

Trucking OEMs & Suppliers
- How will changes in technology impact suppliers?
- Will today's supply chain endure?
- How will business models evolve?
- How will economics be affected by the transformation in the trucking sector?
- Are cross-industry partnerships the key to success, or even survival?

Oil & Gas
- What will be the impact on the downstream industry and when will peak oil demand arrive?
- How will crude oil prices be impacted by changes in the automotive eco-system?
- Upstream implications: What will the global oil supply curve look like?
- What will be the balance between gasoline and diesel, and can natural gas expand its niche in transportation?



Power
- What wil be asked of the electric grid infrastructure and how will it evolve?
- How will the recharging infrastructure develop in the medium and heavy commercial vehicle sector?

Chemicals
- What will be the impact of changing feedstocks on chemicals production?
- How will design changes in the automotive sector affect the demand for chemicals and materials such as thermoplastic polymers and synthetic elastomers?

Source: IHS Markit.

environmental sustainability, enhance fuel economy, or address labor issues, there is considerable uncertainty about the impact legislation will have on the future of the trucking industry. Germany's recent decision to allow individual cities to ban diesel vehicles highlights the potential for additional complexity for fleet operators working in and between urban areas, each potentially with its own regulations.

These three key drivers will not only transform the trucking industry, but will also have a significant impact on the energy and chemical industries. The substitution of oil demand via transitions to alternative drive trains and the strengthening of fuel economy standards is expected to erode diesel demand globally. In turn, this will impact refinery operations with a knock-on effect for feedstock availability for the petrochemical industry. Subsequent changes in chemical feedstock price and availability will affect the relative competitiveness of chemical feedstocks, and regional chemical investment opportunities may shift toward Asia and the Middle East. Trade patterns will shift as the North American cost advantage is eroded, thereby reducing derivative exports to Asia, where more local production capacity will be built.

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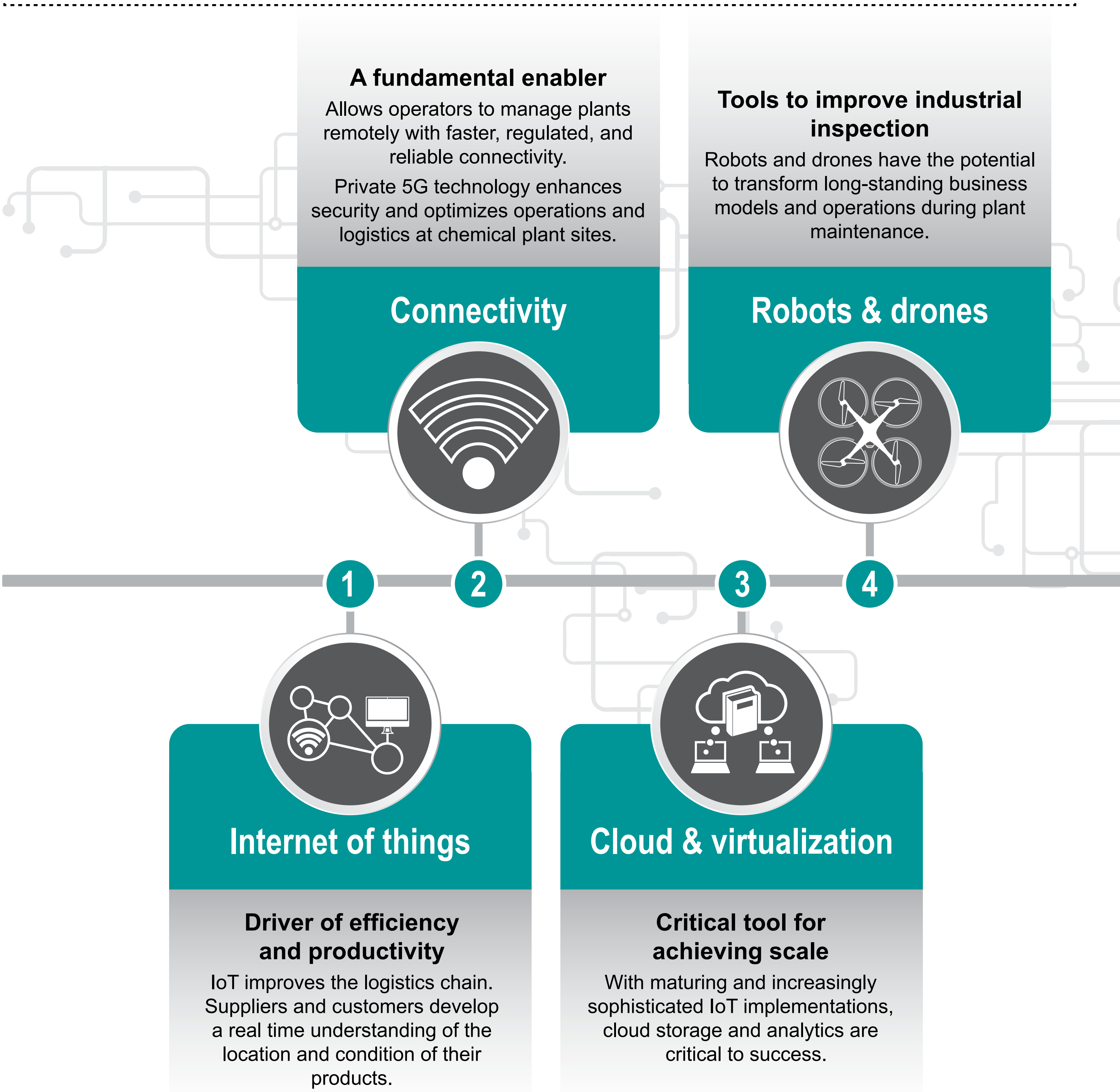
Transformative technologies

These technologies have seen significant development and evolution over the past few years, and the pace of innovation is increasing. As innovation accelerates, transformative technology trends start to converge. Synergies between these technology trends drive exponential, rather than linear, change.



Source: IHS Markit

25 minutes

The time it took a bank to verify crude oil transaction using a blockchain-based platform. This task usually takes

3 hours

Dow received FAA approval in 2015 to fly drones though their chemical sites; **reducing costs** while enhancing employee safety

Increase transparency

Blockchain solutions can be used to improve reliability of logistics across supply chains using a de-centralized ledgers. This eliminates the need for intermediaries when paying for transactions using smart contracts, with a pre-programmed set of conditions.

Other applications are also under trail for smart contracting by commodity trading companies-- reducing transaction costs, increasing speed and adding transparency.

Blockchain

Manufacturing processes in the chemical industry, as well as the types and volumes of products that will be produced, could be significantly impacted by these transformative technologies.

But how aggressively are manufacturers moving to adopt?

Understanding the opportunities and the impacts of these technologies in today's world, requires an understanding of the various technologies and the pace at with they are developing, to be better prepared.

5

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Artifical intelligence

Essential for data processing

AI can help the chemical and refinery industries improve their predictive maintenance reducing downtime and unplanned outages.

Machine vision

Continuous monitoring

Machine vision systems can be used to cost-effectively increase production speed and efficiency - from defect and contamination detection, to facial recognition software, self-driving vehicles, advanced robotics, and surveillance. Helping a wide range of businesses to achieve better results.

Energy cycle realities: implications for chemical industry investment strategies

Getting both location and technology “just right” keeps business competitive through the cycles

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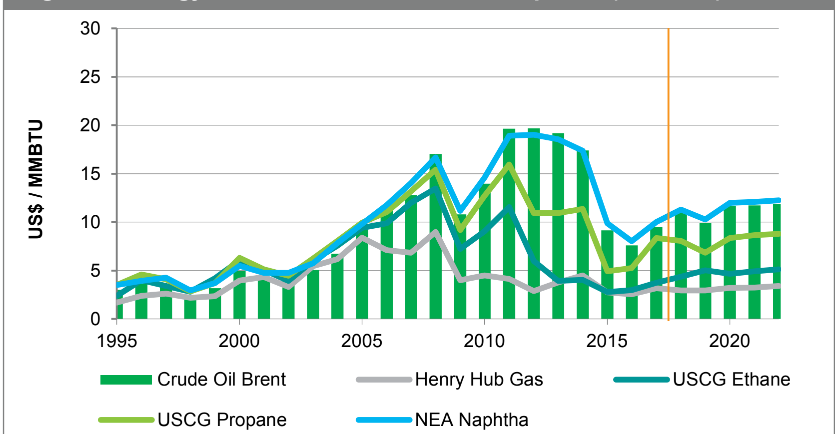
Every energy cycle has resulted in certain feedstocks becoming more or less advantageous to petrochemical producers — depending on individual products, locations, and processes. The most recent example of an energy market shift that resulted in high-cost producers becoming competitive and profitable was the sharp collapse in crude oil prices in second-half 2014. As crude oil prices fell from over $100 per barrel of oil (bbl) to less than $40/bbl (Brent), ethylene operations consuming naphtha feedstocks became profitable assets “overnight.”

Earlier, during the 1990s and the first decade of the 2000s, raw materials favored to produce ethylene and propylene cycled between light and heavy feedstocks. These cycles were driven by changing energy markets as well as regional availability and cost. Regional competitiveness has changed dramatically through these cycles, resulting in shifts in focus for new capital investment decisions. Understanding the implications of energy cycles on competitiveness in the industry is critical to long-term success.

Assumptions regarding energy and feedstock price trends for the future influence location and technology decisions for new capital investments. Companies must also consider other factors, including market access for derivative products and vertical integration strategies. If a downstream business relies mainly on ethylene chemistry, then ethane-based ethylene would seem an obvious technology choice. An investment in naphtha-based ethylene capacity would suggest the company has downstream businesses that rely heavily on the full slate of higher-value hydrocarbons.

Knowing whether to pursue investment planning decisions that involve heavy or light feedstocks is a challenging task. How can the planning team assess both current and coming energy cycles and use that insight to inform investment decisions? It all starts with assessing scenarios to better comprehend feedstock competitiveness over time.

Figure 1: Energy & Feedstock BTU Value Compariso (Current$)



Source: IHS Markit

Reviewing a history of feedstock competitiveness

Figure 1 provides a historical perspective on the changes in energy markets over time, as well as the most current forecast from IHS Markit Energy teams. The energy and feedstock products shown are all converted to a BTU basis to provide a relative comparison of value or cost.

From a chemical analysis viewpoint, there are two distinct historical periods:

1990 – 2004: Prices were low and stable compared to today, providing an almost neutral incentive from a pure cost perspective. The selection of heavy versus light was driven mainly by location or availability, capital cost, and downstream business needs.

2005 – 2014: This period represents “energy at the extremes,” during which a significant increase in the price of crude oil raised the cost basis for heavy feedstocks. During the pre-shale renaissance, this period was also defined by elevated, volatile natural gas and natural gas liquid (NGL) prices. Next was a shale oil and gas renaissance period for the US, which brought an abundant supply of crude oil, associated natural gas, and NGL feedstocks to the US market. A significant differential developed between light and heavy feedstocks, and the industry began a period of conversion to lighter feeds.

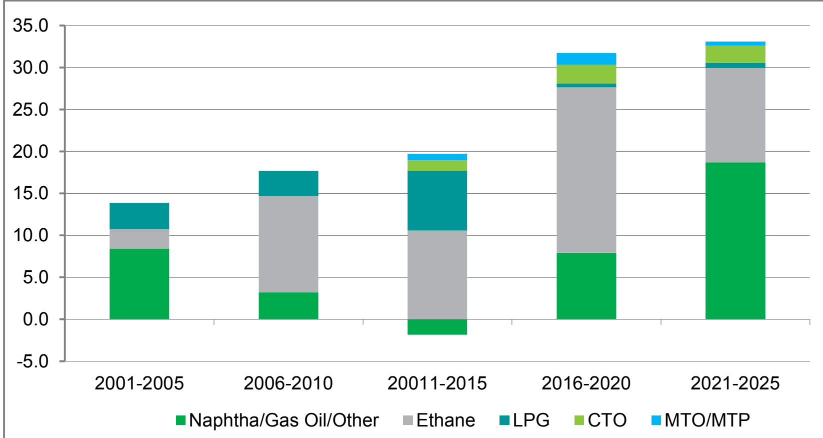
Responding to the energy cycle of the 2000s, chemical companies have invested in ethane-based feedstock and non-conventional, “on-purpose” technologies to support growth. Since 2010, the North American market has experienced a chemical industry investment renaissance. The surge in energy development resulted in a clear pricing advantage for North

American-produced ethane, to the disadvantage of heavy feedstocks. New assets began coming online in 2016 and additional investments in the region are expected to continue well into the 2020s.

Figure 2 represents the total amount of ethylene supply growth (by feedstock) in five year periods, from 2000 through 2025. The incremental supply of ethylene globally was dominated by ethane and liquefied petroleum gas (LPG) feedstock, with naphtha-based feed decreasing from 2006 to 2015.

The use of naphtha as a feedstock begins to increase in the 2016-2020 period. This shift is based on lower (crude oil) prices that make naphtha more competitive. In addition, strong demand growth for ethylene will press all available ethylene production to maximum utilization during this period. The 2021-2025 period shows continued growth in the demand for naphtha as the availability of low-cost ethane begins to slow. Naphtha remains high-cost, although readily available and necessary to meet overall demand growth.

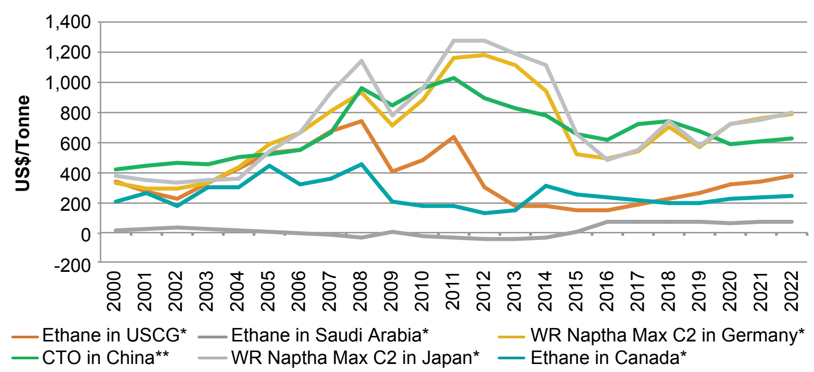
Figure 2: Ethylene Supply Growth By Feedstock (Million metric tons)



Source: IHS Markit © 2018 IHS Markit

Figure 3: Plant cash costs by process and region

(Basis = IHS Markit, Product Basis = *Ethylene, **Light Olefins)



Source: IHS Markit. © 2018 IHS Markit

Analyzing the best feedstocks for each business

Each company must evaluate its feedstock possibilities based on product mix and integration, energy cycle expectations, investment timeframes, and appetite for risk. Simply stated, heavier feedstocks support a broader mix of products and a higher capital investment while lighter feedstocks tend to narrow the product portfolio but reduce capital cost.

Of course, projections and assumptions are always more powerful when decision makers can visualize potential results. Using a new IHS Markit-developed tool called Project Comparison Cost Tracker (PCCT), clients can compare the impact of choosing different feedstocks for specific energy scenarios. The tool projects varying levels of cost competitiveness per feedstock over time. Clients can compare the bottom-line impact of choosing heavy versus light feedstocks and compare them with on-purpose technologies. These comparisons enable insight into cost-competitiveness for each feedstock and assess potential implications for the business over an energy cycle.

Figure 3 shows sample outputs of the tool, comparing plant cash costs for six different technologies, for six locations, over a full energy cycle. Key insights from this analysis show ethane-based feedstocks remaining low-cost while naphtha and coal are disadvantaged. A further comparison to production costs (including depreciation and overhead) can provide insights for predicting market behavior through energy and supply-demand cycles.

The cyclicality of energy markets will continue to heavily influence capital investment decisions for the chemicals industry. Getting both location and technology "just right" to meet the needs of a business over the long term is a difficult task. Today, scenario planning seems to be the best option for assessing the opportunities and risks that are associated with a given set of energy and supply-demand assumptions. The use of advanced analytics and tools such as PCCT has become essential to help planning teams frame a picture of the future so that final investment decisions can be made with the best available information.

Make responsible capital deployment decisions by "disrupting" volatility

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Deciding how and where to deploy capital may be one of the most challenging tasks for chemicals executives. Responsible deployment of capital and the sustainable use of ongoing resources is critical to successful mega-project development.

Yet investments that seem solid today can go sideways tomorrow. Dynamic energy markets and disruptive production technologies can radically change the industry, seemingly overnight.

For these reasons, it's not enough to understand past successes or failures. To plan investments that will meet your near- and mid-term goals, you also need to be able to anticipate potential outcomes catalyzed by factors such as feedstock, technology, and regions. Only then can you "disrupt" volatility, using each variable to maximize return on investment and achieve long-term sustainability.

Factoring feedstocks into the mix

Technology developments and innovations have been driven both directly and indirectly by changing energy feedstock dynamics. To realize maximum return from feedstock resources, producers of base chemicals must focus on:

- Converting low-cost molecules to high-value molecules
- Maximizing tons of output per unit of capital invested
- Minimizing environmental impact and maximizing safety

Positioning the best feedstock – especially when developing technology offers an opportunity to use alternatives – is critical to meeting these business goals. After all, refinery and production facilities cost billions of dollars to build, and they typically operate for several decades. Petrochemical companies must build and operate plants cost-effectively. Choosing cost-advantaged feedstocks is key to success when deciding which types of plants to build or retrofit.

Over time, however, process and feedstock cost-effectiveness can vary significantly (See Figure 1.) In early 2008, for example, there was no question that naphtha was more cost-advantaged than a coal feed for China.

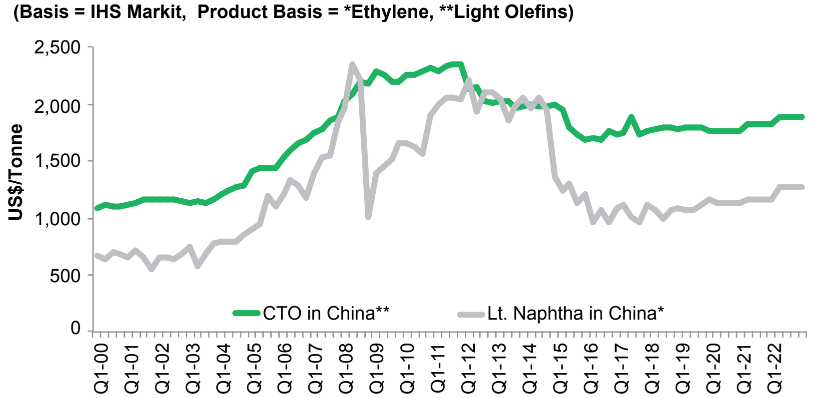
Typically, coal offers lower raw material costs. Between 2012 and 2015, coal-based ethylene production was essentially competitive with naphtha-base routes. Beginning in 2016, however, net feedstock costs for naphtha-based plants declined and the product value (including a capital cost component) for coal became a disadvantage.

Beyond process and feedstock, decision makers also need to balance local capital and operating costs. Building a coal plant is about five times more expensive per ton of product produced than more conventional technology. To determine true product value, companies must balance low-cost feedstock with high-cost capital, considering both production cost and return on capital investment (see Figure 2).

Considering the abundance of coal in China and the shortage of naphtha, investment choices can be complex. The good news is that developers are working on innovations designed to use coal in ways that maximize capital and cost while minimizing environmental impact.

Figure 1: Product value by process and region

(Basis = IHS Markit, Product Basis = *Ethylene, **Light Olefins)



Analytics powered by Process Comparison and Cost Tracker.
Source: IHS Markit.

Using technology to maximize innovation

Chemical engineers, chemists, and other researchers are regularly introducing new innovations. The development and commercialization of these new technologies – which are disruptive by definition – will impact capital deployment decisions.

For example, a number of companies are finding new ways to support molecular valorization, the practice of enhancing the value of feedstocks, a key goal of disruptive technology development. Integrated refineries and petrochemical facilities offer clear examples of this practice. Producers such as ExxonMobil, Hengli, Saudi Aramco, and Sabic JV in partnership with Chevron Lummus Global (CLG) are in the planning or near-deployment phase of innovative new technology that cracks crude oil into significantly higher volumes of petrochemical feedstocks than traditional refineries.

With these advances, refineries can be configured to convert more than 40% of each barrel of oil into targeted chemicals. Where light crude oil is processed, up to 20% of the crude feed can be processed into naphtha. Roughly half of the naphtha produced can then be converted to prime olefins.

Crude-to-olefins technology is expected to have a significant impact on the chemical industry. Companies such as Saudi Aramco with CLG are using it to convert material from the bottom of the crude oil barrel to a substance suitable for fluid catalytic cracking. The technology produces feedstock that is optimal for steam cracking, because it is high in paraffin and low in aromatics. Our independent assessment has shown an increase in prime olefins to approximately 40% of crude feed and 72% for chemical feedstocks in total (including pygas).

Building on regional strengths

Advantages and disadvantages in regional construction can also impact capital deployment decisions. Perhaps the most dramatic example is a shift in regional competitiveness in China.

Traditionally, Chinese productivity was considered to be half that of US workers, requiring twice as many hours to complete the same construction tasks as US workers. Today, productivity is roughly equal, but the US wage rate is roughly seven times higher that of China.

China's cost-to-build is now 50% of that in the US – thanks to efficient construction methods, high productivity, low skilled-labor cost, and extensive domestic equipment manufacturing capabilities. With the lowest investment capital intensity (as measured by investment per ton of capacity) and innovative petrochemical technology, China is responsible for what we call a double disruption. Vast plant scale, speed of technology implementation, productivity enhancements, and the ability to manufacture complex equipment domestically have helped China spearhead a dramatic shift in regional competitiveness.

Market drivers will undoubtedly close this advantage over time. Producers in the rest of the world will reduce the cost of construction through equipment sourcing and modular construction methods. They are certain to find new ways to enhance productivity, thereby boosting competitiveness. (Although U.S. steel tariffs, if implemented, will add another level of competitive complexity.) Until then, double disruption needs to be considered in capital deployment planning.

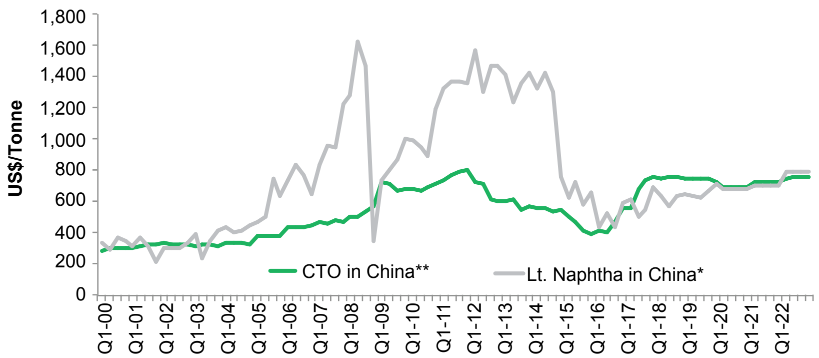
For now, China is highly dependent on imported feedstock. If lower construction costs combined with disruptive technologies allow China to cost-effectively boost production volumes or increase capacity, the country could become more self-sufficient, reducing the volume of feedstocks imported from North America, the Middle East, and other regions.

How might this global trade shift affect the investment decisions of US energy producers? How would it impact the decisions of companies that import feedstocks from sources other than the US? Answering these complex questions requires consideration of multiple interrelated variables and requires individualized analysis.

Weighing these decisions can require expert guidance supported by powerful analytics and visualization tools. IHS Markit now offers the Project Comparison and Cost Tracker (PCCT), an analytical tool that helps clients assess the impact of choosing different investment options for specific business scenarios. To learn more about PCCT or find out how IHS can help you minimize disruption and optimize capital deployment decisions, contact IHS.

Figure 2: Variable costs by process and region

(Basis = IHS Markit, Product Basis = *Ethylene, **Light Olefins)



Analytics powered by Process Comparison and Cost Tracker.
Source: IHS Markit.
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Cracker dynamics and the impact of feedstock developments

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Assuming that crude oil prices strengthen over the next decade, certain cracker operators in Europe may again consider an increase in natural gas liquids (NGL) cracking and plan investments to retrofit existing facilities for this purpose. There will be consequences in the supply of cracker by-product streams, which are important to many downstream industries. More recent cracker developments have already led to the tightening of supply of intermediate C4 streams like raffinate-1 and raffinate-2. Future cracker developments could create an even greater impact on merchant by-product stream consumers.

Cracker Feedstock Developments in Europe

IHS Markit forecasts that by end of 2018, Western Europe will produce around 20.0 million metric tons of ethylene. Over the short term, production will grow at around 0.3x average GDP. However, it is important to note the impact of changes in cracker feedslate over this period and beyond.

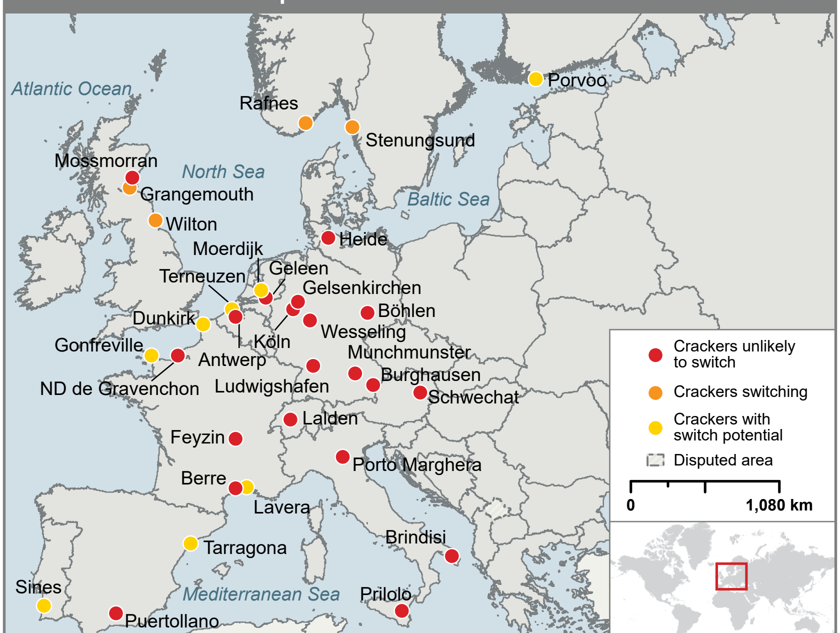
As crude oil prices strengthen over the next decade, there is likely to be a move toward cracking lighter feedstocks. Ineos at its Grangemouth facility in the UK already consumes imported ethane from the US, sourced from shale gas. Borealis has also invested in ethane logistics at its Stenungsund cracker and is currently modernizing its furnaces. Converting NGL crackers for enhanced ethane use is more straightforward than the original intentions of Versalis, which sought to retrofit its Dunkirk facility in France from naphtha to at least partial ethane use. This project is reportedly on hold.

While a wholesale retrofit of regional cracker capacity is unlikely, there are a number of operators looking to increase their flexibility to use price-competitive, shale-derived NGLs sourced from the US. A number of candidates enjoy coastal locations, which provide ease of logistics (see Figure 1). Even crackers in the Mediterranean could move to lighter feedstocks. Within 10 years, naphtha will make up 54% of Western European cracker feedstock supply, down from as high as 73% in 2010.

Changing feedslate impacts the distribution and volume of co-products. The greatest impact of moving to lighter feedstocks is found in the heavier by-product components of the cracker.

Recently our Chemicals Consulting team within IHS Markit has aided companies who consume some of these heavier components and various resulting intermediate streams. There is grave concern, especially among merchant consumers, for future availability. These companies have approached IHS Markit for help in solving potential future supply problems.

Locations of West European steam crackers



Source: IHS Markit/1722828

Potential Impact on the C4s Industry

Management of the C4 chain is complex, given that a strategy is needed to valorize each component. A naphtha cracker will generate around 0.338 metric tons of crude C4 stream per ton of ethylene made. The yield of C4 stream reduces significantly when moving to lighter feedstocks; in addition, the process results in composition changes. This year, Western European steam crackers could generate around 2.3 million metric tons of contained butadiene. IHS Markit forecasts that around 90% of this will be extracted to serve the synthetic rubbers industry, the polyamide value chain, and other markets.

There are other ways to process crude C4s. In the early 1990s, selective and full hydrogenation technologies were introduced on certain cracker sites to process contained butadiene. Previously butadiene could be extracted, or crude C4s recycle could be co-cracked or even fueled. Hydrogenating contained butadiene provided mainly butylenes for downstream chemical conversion (see Figure 2). The contained isobutylene remains virtually unchanged. The increased volume of butylenes served applications like butene-1, MEK, and higher oxo alcohols. Butylenes also help in refinery processes like alkylation to boost octane in gasoline.

In 2011, flexible cracker operations in the US moved to much light shale-derived NGLs, thanks to their competitive price. This shift in turn severely reduced the availability of domestic Crude C4s and contained butadiene. In Europe, cracker operators such as BASF and OMV – that possessed an existing selective hydrogenation infrastructure – constructed butadiene units. Evonik, a company which "collects" C4 streams of various forms, also invested in new butadiene capacity in Antwerp.

These developments have caused a considerable upheaval in C4 market dynamics, reducing the availability of selected butylene streams for chemical conversion. A number of consumers of butylenes have had to develop new strategies for feedstock supply or adapt their operations.

Putting butadiene aside, the refinery FCC unit does generate a C4 stream that can serve the production of octane boosters such as MTBE, alkylate, and polygasoline. Companies like ExxonMobil, which have developed extensive refinery-petrochemical integration, will also use such streams in chemicals production.

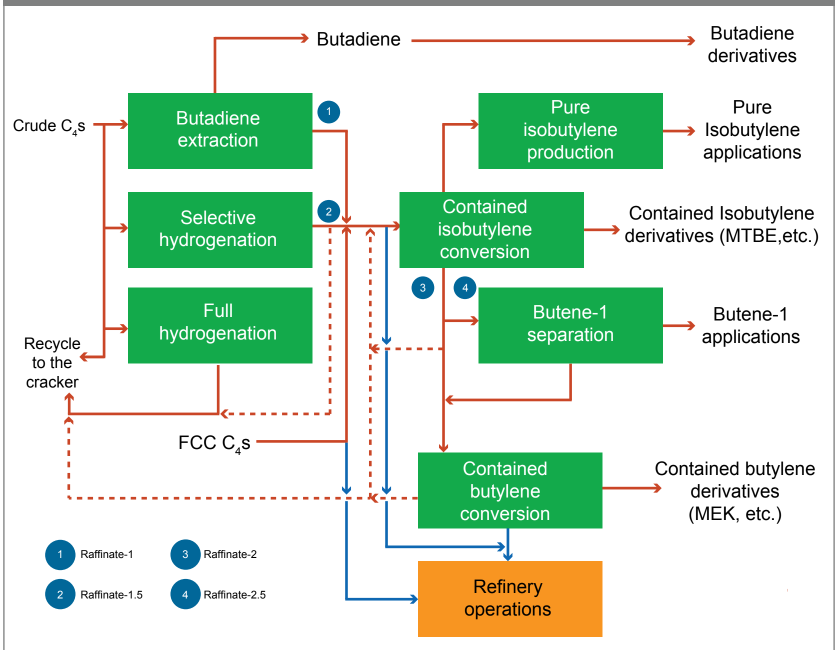
Looking forward, however, there is concern that the move to lighter feedstocks by certain crackers will create a secondary effect on C4 supply. In the case of butadiene alone, Europe will need to recovery 96% of available butadiene from cracker operations to meet demand and supply export markets. There will likely be an ongoing impact on merchant consumers of isobutylene and butylene-containing streams for applications like polyisobutylene and MEK. Some consumers are already looking to source the streams needed from outside the region.

Can Technology Provide a Solution?

Over the last few years, technology played a role in supporting C4 stream availability. In the early 1990s, crude C4 selective hydrogenation helped manage the situation. Other C4 management technologies like BUTENEX® from Krupp-Uhde and C4 OLEX® from UOP were also commercialized.

The 2010-2012 "shale-gale" encouraged the revisit of deep and oxidative hydrogenation processes to supply

Chart 2: Simplified view of process with C_4 value chain



Source: IHS Markit.

butadiene. Today technologies such as C4 skeletal isomerisation, also developed in the 1980s and 1990s, may need to be revisited to provide more isobutylene in Europe.

While the refinery can provide a source of isobutylene and butylenes, their content falls far below that of cracker-sourced materials. Certain applications can be very sensitive to C4 composition, such as polyisobutylene. However, innovations in Argentina allow isobutane dehydrogenation on the small scale, providing an isobutylene concentrate for polyisobutylene production.

Technology solutions are possible with alternative feedstocks. However, there is clearly a need for considerable investment to make this happen.

Conclusions

With a strengthening crude oil price, IHS Markit believes that the regional cracker feedslate in Western Europe will likely move lighter. The impact of this change will be keenly felt in value chains like C4s and more specialised cracker by-product streams. Merchant consumers of isobutylene and butylene streams may face considerable supply challenges. They may need to look outside of the region for new supply sources. However, investment in certain technology solutions could help alleviate supply. Consumers of more esoteric cracker by-products will also find local supply challenges emerging and continue to rely on deep-sea or out-of-region supplies of C5 and C9 components.

Refinery-petrochemical integration trends

Better together? Assessing the value of integrated refinery and petrochemical operations

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Facing flat or declining market demand for refined products, refiners are bracing for lower sales and profits. In contrast, petrochemicals market demand continues to rise – thanks to numerous demographic, economic, and consumption trends. How can refiners use growing petrochemical demand to help their businesses survive and thrive? One possible solution involves finding new ways to integrate refinery and petrochemical operations.

Converging forces contribute to falling demand for refined products

Refined products include gasoline, jet fuel, and diesel. Transportation fuels such as gasoline and diesel are at the core of most refineries' product slates and make up the largest share of refined product offtake.

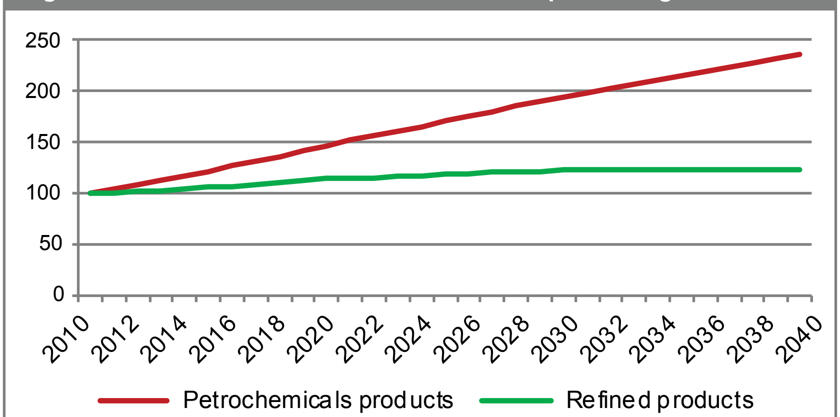
Global refined product demand has experienced an average growth rate of 1.3% annually since 2000. The outlook for the next decade is less rosy, with demand growth from 2020 to 2030 expected to average only about half the rate of the prior period. This slowdown will continue into the 2030s, with absolute demand growth peaking in the latter half of the decade before entering a gradual decline in the 2040s. In the coming years, we expect several headwinds to pressure growth in the transportation:

Reduced fuel usage: Light-duty vehicles are becoming more efficient as governments increase standards for new car sales (such as the Corporate Average Fuel Economy (CAFE) standards in the US). Additionally, increasing sales of hybrid and electric vehicles (EVs) will result in fewer internal combustion engines (ICEs), displacing demand for gasoline and diesel. Optimized commuting is accelerated by shared mobility, notably app-based ride-sharing, limiting the number of individual trips.

Substitution: In addition to increased electricity use for transportation, fuels such as compressed and liquefied natural gas (CNG and LNG), liquefied petroleum gas (LPG), hydrogen, and renewables such as biofuels are contributing to the decline of market share for traditional fuel types. As technology evolves, these fuels offer the potential for displacement even in heavier-duty market segments.

Regulation: Government policy-makers are tackling environmental concerns by introducing initiatives and, in many cases, firm targets that are designed to erode the market share of carbon-based motor fuels in both mature and emerging markets. Environmental taxation, biofuels mandates, clean fuel adoption incentives, emission-zoning and charging in areas of high pollution, and even outright bans on ICE use combine to depress traditional fuels demand, while acting as deterrents to further uptake of high-consumption vehicles.

Figure 1: Index of base chemicals and refined products growth



Source: IHS Markit. Base = 2010 ©2018 IHS Markit

Market forces accelerate petrochemical demand

In the petrochemical industry, a variety of trends are shaping market growth. Petrochemical demand encompasses derivatives of the monomers, including ethylene, propylene, butadiene, and aromatics namely benzene and paraxylene.

Population is a key driver. By 2040, we expect 9.2 billion inhabitants living and thriving on the planet, an additional 1.6 billion people compared with 2017. Even if the petrochemical per-capita consumption rate remains unchanged from 2017 levels, the overall volume of products consumed will increase significantly as a simple consequence of serving more people.

Another factor is the growing movement of people from lower to middle economic classes. Upward mobility tends to allow a shift in consumer focus from life's "bare" necessities to discretionary spending on products that make their lives safer, healthier, and easier. As more developing countries adopt these modern living standards, the use of products developed, manufactured, and distributed by the petrochemical industry will rise. This petrochemical-per-capita demand results in increased production of the enablers of modern living for both durable goods, such as refrigerators and cars, and non-durable goods such as packaging. In addition, lower energy prices are likely to free up more disposable income that can be earmarked for technology, mobile devices, televisions, and other non-essential spending.

Together, population and per-capita consumption growth are driving consistently increasing demand for petrochemicals, with growth expected to continue through at least 2040.

Key questions to inform integration decision-making

Deciding whether and where integration is appropriate for petrochemical and refinery operations requires careful consideration. In addition to understanding mid- and long-term refining and petrochemical market drivers, executives need to consider where incorporating additional flexibility and efficiency into operations could deliver maximum value. They can then compare that with the capital needed to make any required technical changes.

For refiners, links to petrochemical production can be through feedstock provision in terms of propane, butane, or naphtha feedstocks, or through increased production of propylene and aromatics. Beyond the transfer of hydrocarbons, utility stream synergies exist for power, steam, process water, and hydrogen transfers. Other possibilities include staffing for maintenance, operations and management, and other possibilities, which could offer logistics benefits (see Figure 2).

Design-to-fit new builds can offer up-front savings in design, engineering, and construction. Reductions in equipment duplication, the integration of utilities, and access or processing of low-cost crude also offer the promise of delivering additional value.

Integrating existing operations with new petrochemical production requires retrofitting of current production assets. To optimize retrofits, decision makers need to determine whether the asset has the scale or critical mass required to make connectivity profitable.

Other questions to be considered in the integration decision process include:

Proximity: How close is the asset to a refinery or petrochemicals complex? Could excessive distance mean the cost of connectivity is an economic deterrent? Can a refinery or petrochemicals plant be added if distance is too great?

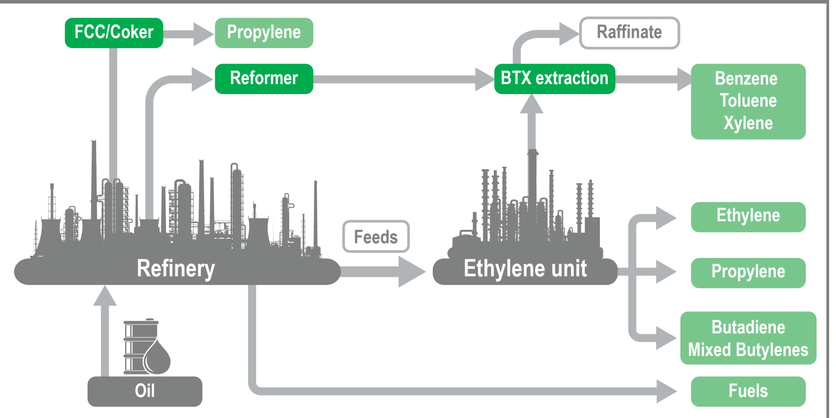
Potential for synergies: Will integration support transfer of hydrocarbons, utilities, or both? Olefins or aromatics? What are the alternatives to the site in terms of displaced streams? Does integration offer the best economic solution?

Future demand patterns: Which streams can be liberated for petrochemical use, and when does it make sense to implement that shift? Can the resulting margin cover the costs of connectivity if trade patterns change? Are volumes sufficient?

Crude slate: Should a combined operation shift to an alternative crude feed slate that supports profitability at both sites?

Customer base constraints: Is the asset in a cluster of industries that prohibits material changes to the feed/product/energy balance mix? Does it make sense to change the operation or force others to spend capital to change their business?

Figure 3. Potential Refinery-to-Petrochemical Integration Scenario



Source: IHS Markit

Strategies for navigating complexity to achieve flexibility

Uncertainty in traditional fuels markets and the promise of growth in petrochemicals markets is leading to renewed interest in the greater flexibility afforded by integration. Careful exploitation of synergies can mitigate the vulnerabilities of standalone refinery or petrochemicals operations, while catering to increased demand in the growth areas of petrochemicals; however, there are many available pathways and technologies as well as potential pitfalls.

Optimal solutions are highly specific to each company, based on asset location and technological profile and the role of those assets in terms of wider short- and long-term strategic considerations. In a changing marketplace, competitor investment decisions are also highly influential in impacting product balances at both a local and worldwide level, requiring ongoing and intensive market monitoring. With extensive strategic, technological, and geographical market expertise across all world regions, IHS Markit is ideally placed to help companies make informed and robust business decisions for durable success in complex, global, and increasingly integrated product markets.

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