

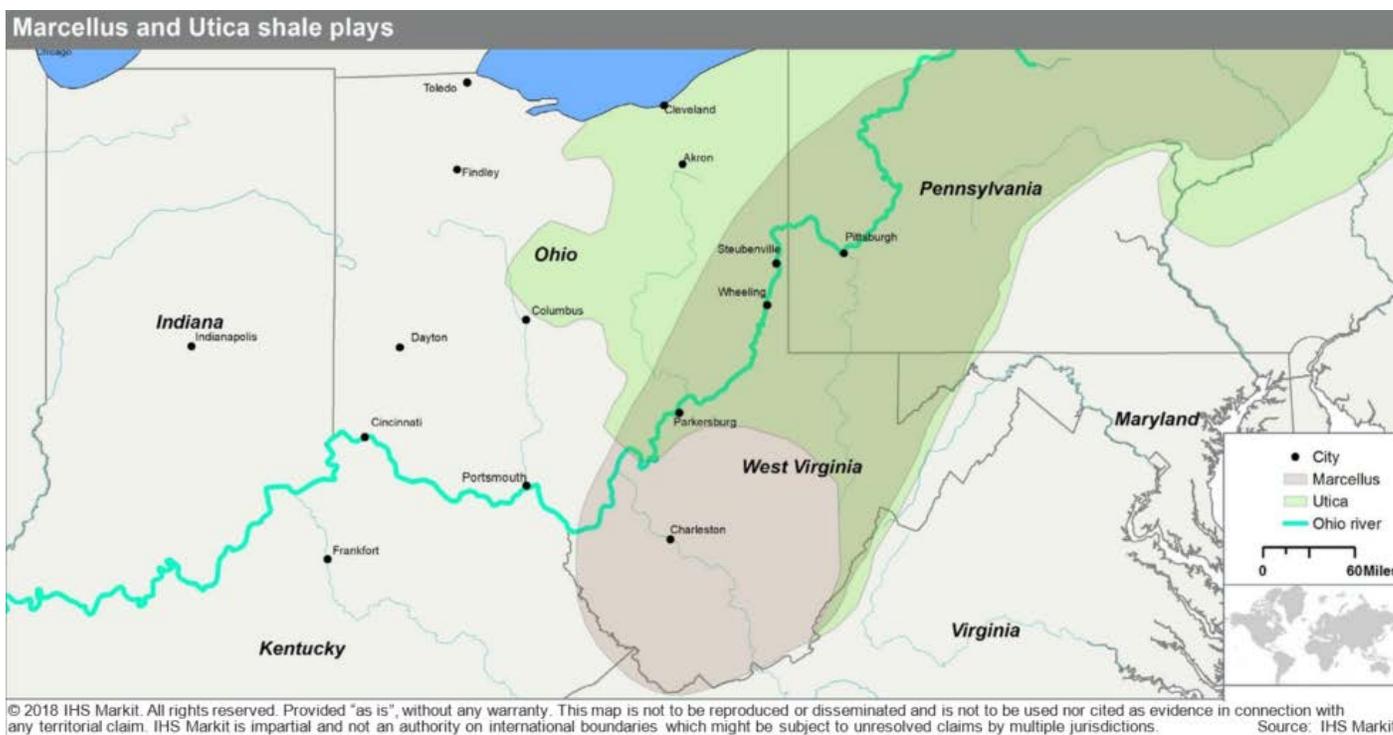
# The Shale Crescent USA Region

An emerging energy and renewed chemical industry cluster

March 2019

## Introduction

The Marcellus and Utica shale plays are some of the largest natural gas resources in the world and underlay the Shale Crescent USA region of Ohio, Pennsylvania, and West Virginia. **IHS Markit forecasts that this region will supply 45% of the nation's natural gas production by 2040**, which is even more significant from the fact that the United States is the largest producer of natural gas in the world. The natural gas produced in the Marcellus and Utica shales in many areas is rich in natural gas liquids (NGLs) which include ethane, propane, and butane. **IHS Markit forecasts NGL production from these two plays will nearly double, from 0.60 million barrels per day (b/d) in 2018 to 1.17 million b/d in 2040.** This robust outlook is attracting high value, energy-intensive, and NGL consuming petrochemical industries to the Shale Crescent USA region. While a previous study conducted by IHS Markit evaluated the prospects for a world-scale ethylene and polyethylene plant based on ethane feedstock, this current study examines the prospects for projects based on methane, propane, and normal butane (LPG). **This IHS Markit report examines the feasibility of selected chemical industry investments in the Shale Crescent USA Region and compares them with competing opportunities in other U.S. and global regions.**



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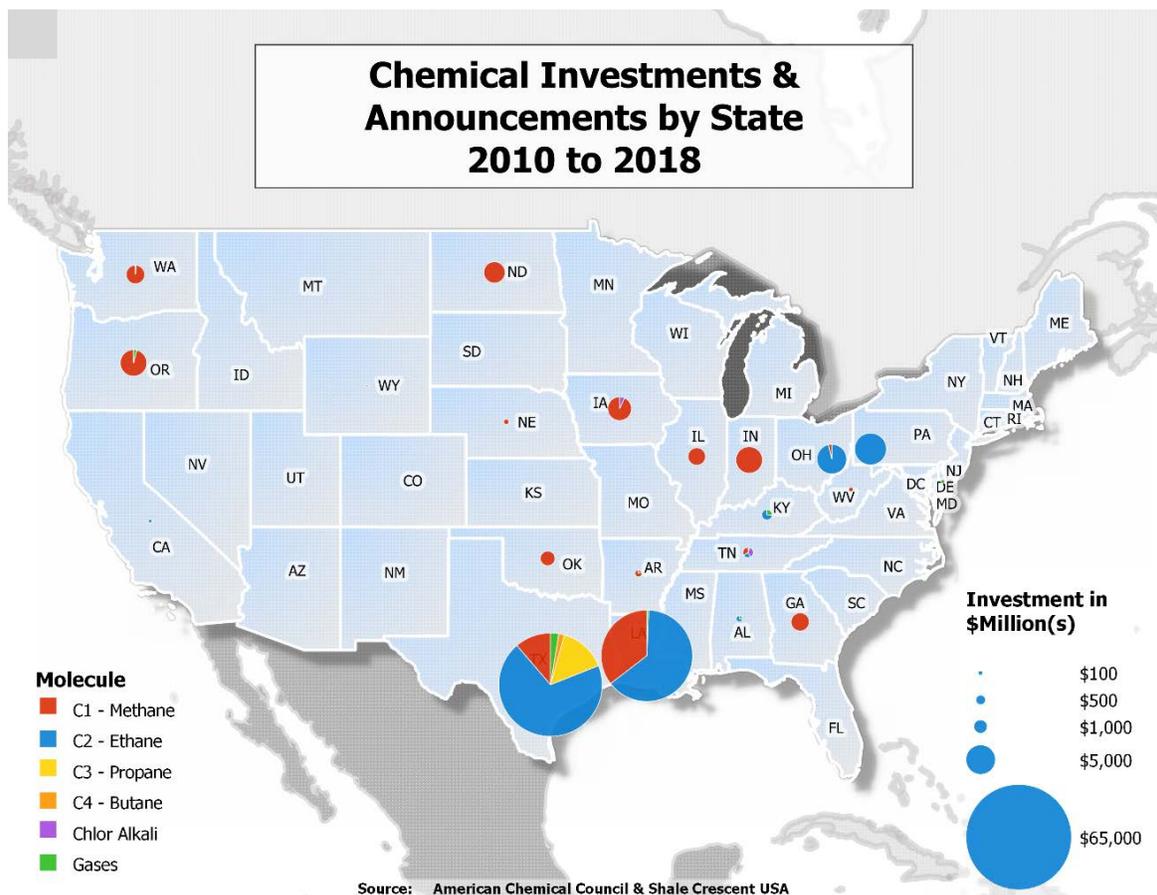
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## Historical Perspective

Historically, industrial development in the United States has centered around proximity to growing markets and advantaged feedstocks. As examples, the industrial and manufacturing heartland of the United States (e.g., automobile production) developed around the steel industry in the U.S. Midwest, and the fertilizer industry developed in close proximity to the agricultural and grain producing belts of the mid-continent and plains states. While the beginnings of the chemical industry in the U.S. can be traced back to the first major commercial ethylene plant built by Union Carbide in Clendenin, WV in 1920, the center of chemical production and commerce has since shifted to the hydrocarbon-rich U.S. Gulf Coast, as the benefits of feedstock and refinery integration considerations drove the large-scale development we see today. A byproduct of this focused development in the Gulf Coast region is significant movement of unfinished materials and fertilizers moving to the Midwest and to the farm states.

The recent availability of large and growing volumes of economically advantaged petrochemical feedstocks as a result of the shale gas development in the Shale Crescent USA Region, offers the potential for realigning chemical production with the large population market demand centers. The graphic below illustrates recent chemical industry investment by location and value chain. While natural gas in the Shale Crescent Region can support ammonia and urea production, the relatively lower cost of moving natural gas feedstock closer to the agricultural market versus moving ammonia or urea, favors locating production in the mid-continent and west coast states. However, the Shale Crescent region is gaining traction in the area of ethylene and polyethylene, as investments are moving ahead for producing this thermoplastic closer to the value-added manufacturing and population centers of the Northeast and Midwest U.S. Polypropylene, the largest volume thermoplastic used in the automobile industry, is another candidate also likely to benefit from this trend.



**Estimated Logistics Benefits of the Shale Crescent USA Region versus the U.S. Gulf Coast for Natural Gas and LPG** is an independent report by IHS Markit commissioned by Shale Crescent USA (funded in part by JobsOhio) to evaluate and compare the major chemical investments in the region with existing producers in other competitive regions.

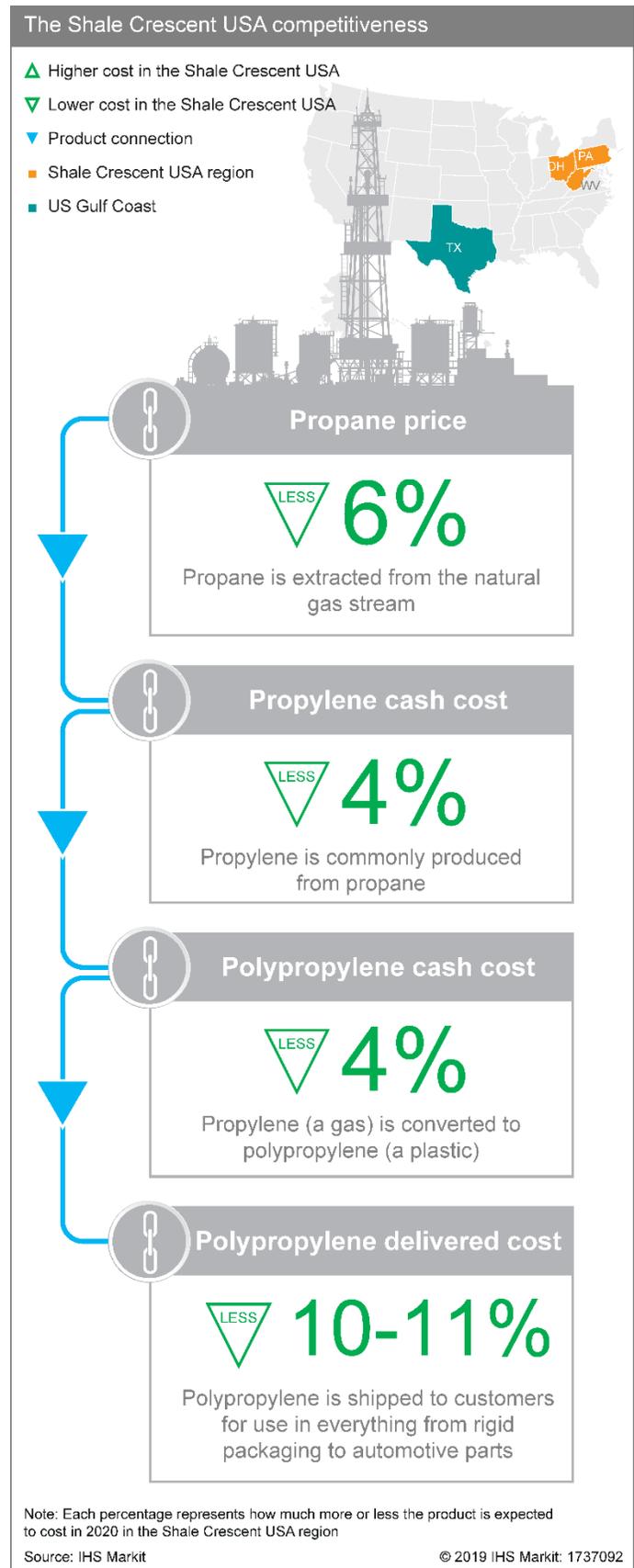
The questions addressed by this study are:

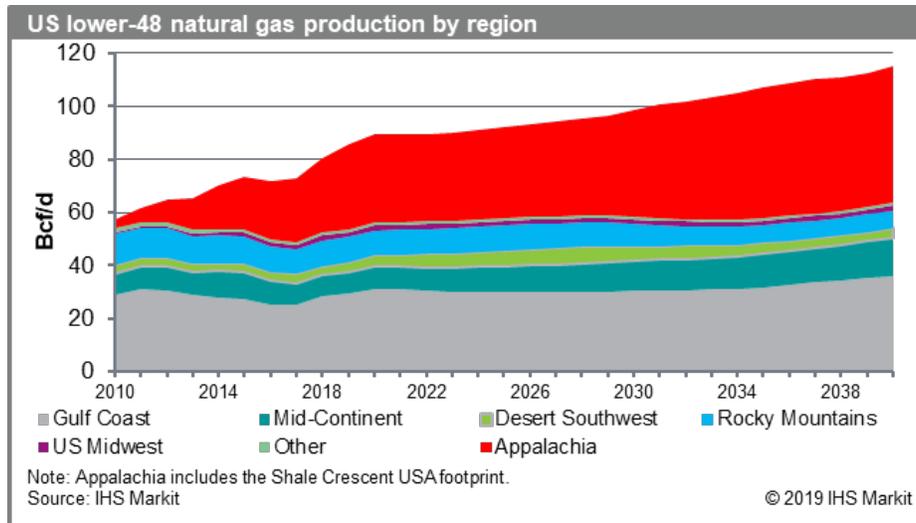
- What is the outlook for natural gas and LPG supplies in the Shale Crescent USA Region, and how significant is the region in terms of overall U.S. growth in hydrocarbons production?
- Will the forecast supply of natural gas and LPG be sufficient to support petrochemical production in the region?
- Is there an inherent logistics-related cost advantage to the local price of natural gas and LPG in the Shale Crescent USA Region?
- What petrochemical products could be produced from natural gas and LPG in the Shale Crescent USA Region? Which are the most likely products based on market, economic, and technical factors?

The analysis conducted by IHS Markit highlights the chemical industry development opportunities for the Shale Crescent USA Region based on predicted volumes and prices of natural gas and LPG production in the Marcellus and Utica shale plays, the estimated logistics-related cost advantage of feedstock supply, and the cost to distribute the chemical products to a mix of regional domestic and international customers.

## Natural Gas

The Appalachian region, including the Marcellus and Utica shale plays, has become the “breadbasket” of U.S. natural gas production, with a resource base that will play a key role in satisfying America’s increasing reliance on natural gas, as well as keeping energy costs moderate. IHS Markit expects Appalachian production to grow from approximately 29% of the U.S. total in 2018, to supply 45% of the nation’s natural gas production by 2040. Favorable production economics make the Marcellus and Utica shale plays amongst the most cost competitive in the nation.



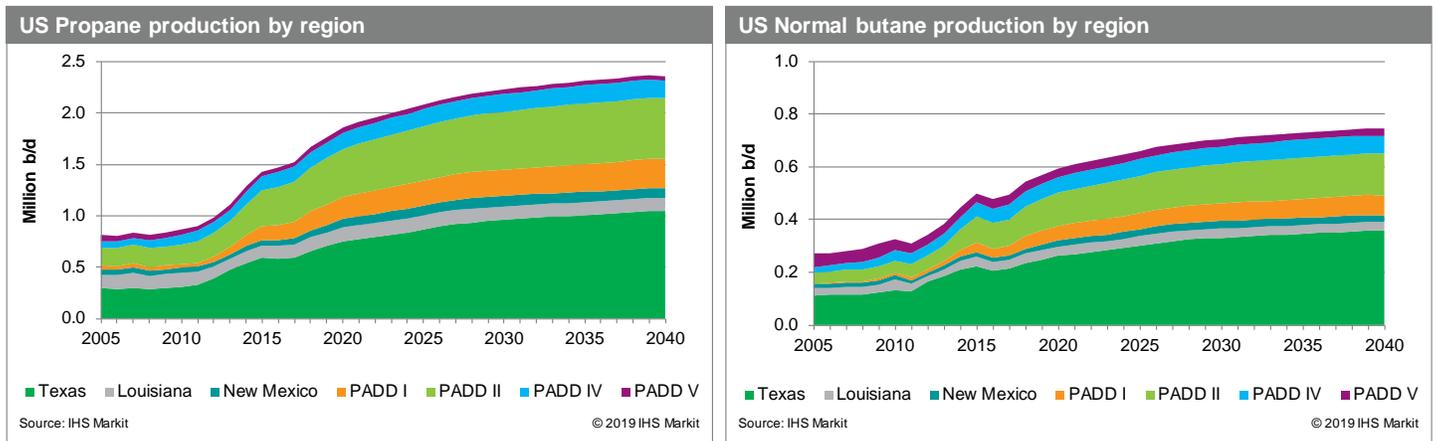


**Appalachian production is expected to grow from 28 billion cubic feet per day (Bcf/d) in 2018 to 51 Bcf/d in 2040**, almost as much as the entire U.S. produced 10 years ago. Today, the basin's influence on natural gas markets has extended further into markets outside the region, an influence enabled by 20 Bcf/d of new pipeline takeaway capacity built over the past five years. However, natural gas prices beyond Appalachia will remain largely influenced by associated gas production (gas produced as a byproduct of oil production), pipeline constraints and the increasing cost of expansions to move gas to consuming markets. Over the longer term, associated gas production will slow in other areas of the country and enable Appalachia natural gas production to increase as additional natural gas pipelines exiting Appalachia region are forecasted to be added. These additional natural gas pipelines will help propel Appalachia natural gas production rates to higher levels. **Low production costs and varying degrees of pipeline takeaway capacity constraints will lead to considerable price discounts in the region to the Henry Hub benchmark price through 2040.** The price discount at Dominion South Point is expected to expand beyond \$0.75/MMBtu by the early 2030s because of intensifying pipeline constraints, prompting another round of pipeline takeaway capacity additions. **This pricing represents an approximately 15% discount to Henry Hub pricing.**

U.S. end use demand for natural gas is expected to grow by more than 20% by 2040, to more than 100 Bcf/d and therefore, the U.S. will continue to rely on Appalachian production as a critical component of its energy supplies.

## Propane & Butane (LPG)

LPG production increases as a by-product of increasing U.S. natural gas production. U.S. propane production in 2018 was approximately 1.35 million b/d and is expected to increase to 1.76 million b/d in 2025 and will continue to expand through 2040. Onshore U.S. LPG production and supplies have outstripped U.S. onshore demand and exports via water and pipeline to international markets has been required to balance. Since early 2013, the U.S. increased its net exports of LPG and exports are expected to continue to increase over the long term. The U.S. has correspondingly emerged as the largest propane exporter in the world and the second largest butane exporter in the world behind the Middle East. The Mont Belvieu, Texas propane and butane prices, major global benchmark prices, have correspondingly moved downward in relation to the other propane and butane global prices.



U.S. propane growth has been propelled by shale gas and tight oil growth. In early 2013 the U.S. exported approximately 0.3 million b/d of propane and is expected to exceed 1.5 million b/d by 2040. **For the Shale Crescent USA Region, it is expected that by 2025 propane production from the tri-states (West Virginia, Ohio, and Pennsylvania) is expected to reach almost 0.3 million b/d, approximately 17% of total U.S. production.** Unless investment is made in the region in petrochemicals, most of this propane production will be exported to other countries. The Shale Crescent USA region is within PADD I and PADD II and accounts for a majority of the production from these PADDs.

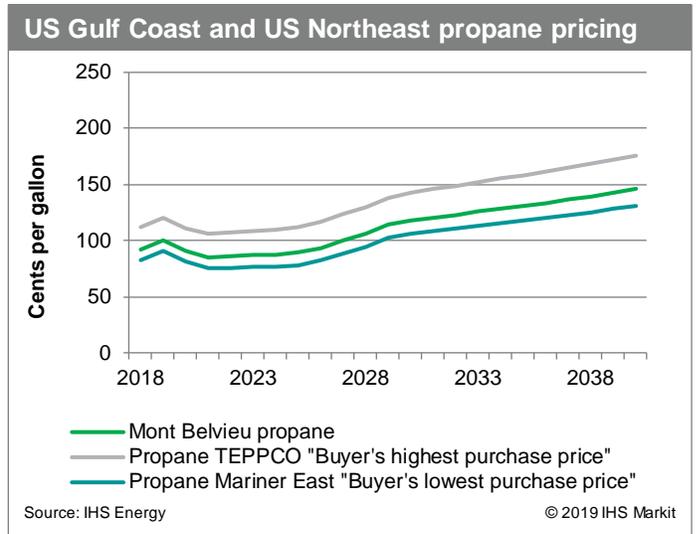
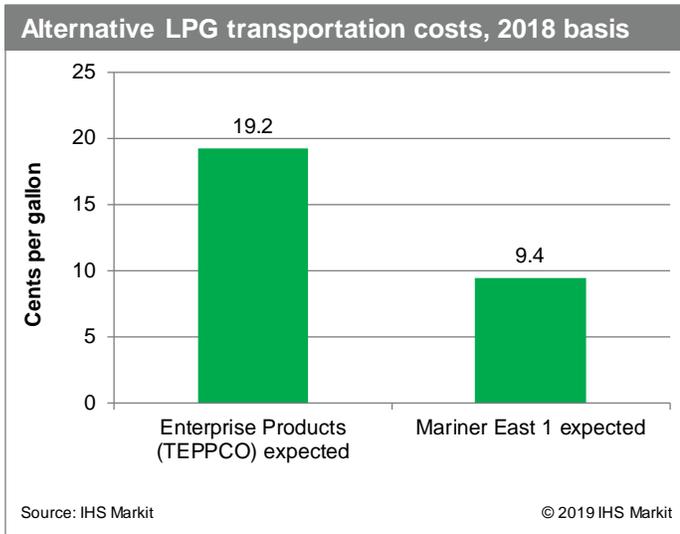
Based on our forecast and outlook for natural gas and propane, there is available supplies of propane in the Shale Crescent USA region to support the typical consumption rate of an integrated Propylene (via Propane Dehydrogenation) to Polypropylene project. A Propane Dehydrogenation to Propylene project's typical consumption rate is in the range of 22,000 to 25,000 b/d.

U.S. normal butane has also grown but the exports have not been significant as U.S. onshore end uses are quite high as compared to overall normal butane availability. Domestic consumption includes refineries, isomerization, base chemicals including cracking and others, and industrial demand. U.S. normal butane production in 2018 was approximately 0.47 million b/d and is expected to increase to 0.59 million b/d in 2025. However, growth in refineries has stagnated and as such U.S. onshore normal butane demand over the long term will only consume about 50% of available normal butane production. Therefore, unless investment is made in domestic consumption capability, approximately 0.4 million b/d will be exported by 2040. **By 2025 butane production from the tri-states (West Virginia, Ohio, and Pennsylvania) is expected to reach almost 80,000 b/d, approximately 13% of total U.S. production.** The Shale Crescent USA region is within PADD I and PADD II and accounts for a majority of the production from these PADDs.

The Shale Crescent USA Region's gas processing margin shared between upstream and midstream companies are positive and in 2018 their propane gas processing margins were in the range of 30 to 50 cents per gallon (cpg) compared to a Mont Belvieu market price of approximately 93 cpg. Butane gas processing margins are similar, and also quite positive and also creates a value uplift to upstream operators' single well economics. It is therefore valuable for upstream operators to extract and recover LPG, propane and normal butane, and correspondingly deliver to end use markets onshore U.S. and offshore.

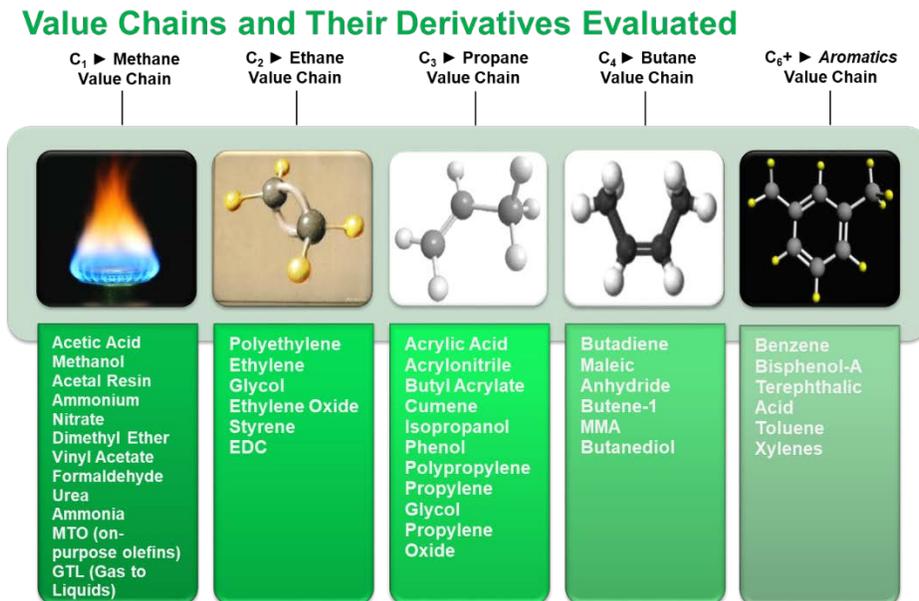
**Propane and normal butane supply in the Shale Crescent USA Region exceeds demand and available alternatives determine the price to be paid by a downstream chemical manufacturing plant operator.** Over the long term, residential, commercial, and refinery end use markets in the Shale Crescent USA Region are limited and transfers out and exports are required to balance supply and demand. Therefore, **as production swells and both propane and butane supply outstrip demand, the prices will drop and present promising economics for petrochemical assets in the region.**

To calculate these economics, some assumptions must be considered. The value or acquisition cost of incremental production of propane and normal butane in the Shale Crescent USA Region is derived by the Mont Belvieu price and purity pipeline transportation costs. The cost of transportation can be viewed as an avoided cost for the upstream operator and their netback, or an incremental cost borne by others, to effectuate a downstream sale and purchase. Our view of LPG transportation cost is therefore bounded by the Energy Transfer Partners-Sunoco Logistics Mariner East 1 posted pipeline tariff and Enterprise Products TE Products Pipeline Company (TEPPCO) posted pipeline tariff. IHS Markit estimates the Shale Crescent USA Region's propane price to lie in the range of a 11% discount or a 22% premium to the Mont Belvieu price. IHS Markit estimates the Shale Crescent USA Region's butane price to lie in the range of a 9% discount or a 17% premium to the Mont Belvieu price.

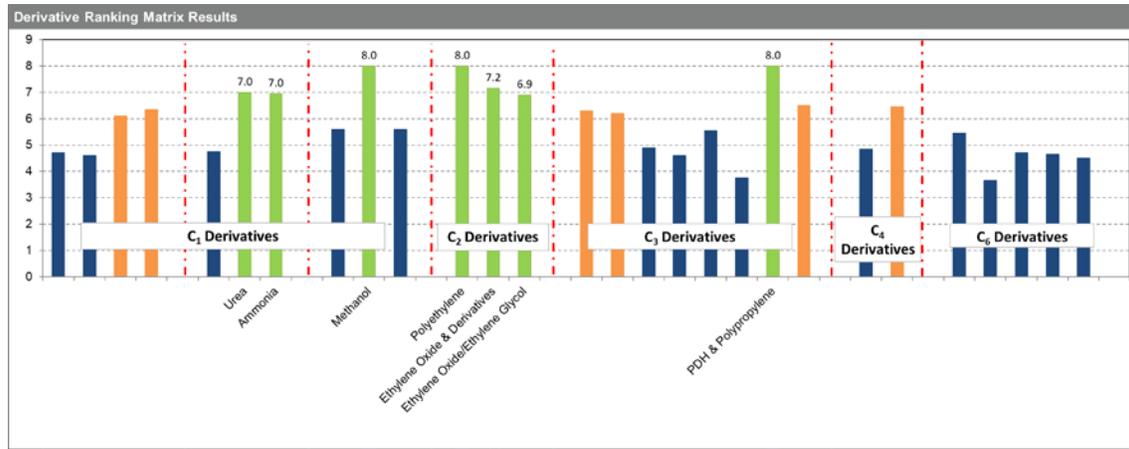


## Chemical Product Screening

There is a large and diverse group of chemical products that can be produced from the Methane (C<sub>1</sub>), and LPG (Propane C<sub>3</sub>; Butane C<sub>4</sub>) feedstocks available in the Shale Crescent USA Region. These are depicted in the exhibit below.



IHS Chemical has surveyed the chemical products in the C<sub>1</sub>, C<sub>3</sub> and C<sub>4</sub> value chains using a proprietary screening and ranking methodology that considered nearly a dozen factors comprising market, technology, and economic dimensions. These individual factors were weighted and ranked, resulting in an overall attractiveness fit being determined for each product. The results are depicted in the exhibit below:



The most highly ranked first tier targets (identified by the green bars), namely Methanol, Ammonia, Urea, Propylene (via PDH), and Polypropylene were selected for a more detailed analysis of the individual market, technology, and economic dimensions.

## Chemical Product Detailed Analyses

Upon analysis of the cost competitiveness of chemical derivatives of natural gas, IHS Markit determined that Shale Crescent USA Region-based production cost of ammonia, urea, and methanol are forecast to be comparable with existing competitive producers within the North American region. This is primarily due to a natural gas cost advantage in the Shale Crescent USA Region, as well as proximity to large demand centers in North America. **For example, the delivered cost for urea in the Shale Crescent Region based on an integrated ammonia/urea facility is 12% less when compared to obtaining urea from the US Gulf Coast.** Ammonia production is largely integrated to urea and other ammonia derivative production on-site, and therefore has limited merchant market potential. However, for urea, there are several offtake possibilities in the U.S. Northeast and Midwest, namely for fertilizer use (82% of domestic urea demand), as well as in the form of diesel exhaust fluid (12% of domestic urea demand).

Methanol production cost in the Shale Crescent USA Region is also expected to fare well in domestic markets driven by a natural gas cost advantage over the Gulf Coast. **The delivered cost for methanol to the Shale Crescent region is 26% less as compared to obtaining methanol from the Gulf Coast.** However, new North American methanol production is focused on export market opportunities, resulting in a gross export position of 1.7 million tons in 2018, growing to over three times that volume by 2025. This represents an overabundance of domestic supply, with which a Shale Crescent USA Region plant would need to compete.

Competitiveness Analysis Overview			
Chemical Product	U.S. + Canada demand within 700 miles	Considered Shale Crescent scale, kMT/year	Shale Crescent's expected target markets
Ammonia	31%	1,000	Integrated with Urea; U.S. Midwest & Plains States
Urea	39%	1,780	U.S. Midwest & Plains States
Methanol	15%	1,000	Local markets adjacent to Shale Crescent and Exports
Propylene	9%	500	Integrated with Polypropylene
Polypropylene	77%	500	Local markets adjacent to Shale Crescent and Exports

Source: IHS Markit

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Looking to propane derivatives, a propane dehydrogenation plant located in the Shale Crescent USA Region is expected to be competitive with existing competitors along the U.S. Gulf Coast on a cash cost basis due to comparative forecast propane feedstock pricing. Within the greater North American region, Canadian propane dehydrogenation plants are expected to have the lowest propylene cash costs due to lower cost propane in the Alberta area. Integrated to propylene production, Canadian polypropylene plants have the lowest cash cost basis due to advantageous feedstock cost. The upcoming Alberta projects will retain this advantage into 2040s. Both the U.S. Gulf Coast and Shale Crescent USA Region plants will be able to compete with Canadian plants on a delivered cost basis within U.S. demand centers in the U.S. Northeast and Midwest, as well as in overseas markets such as West Europe through export terminals in along the U.S. Northeast coast.

Plants based in the Shale Crescent USA Region and U.S. Gulf Coast are second to Canada concerning cash costs. By 2040, plants based in the Shale Crescent USA Region will have the second lowest cash costs, just behind Alberta-based plants.

However, **polypropylene plants in the Shale Crescent USA Region would be positioned as logistically competitive in terms of supplying domestic sub-regional markets in the Eastern and Midwestern U.S.** It is predicted the Shale Crescent USA will be the most competitive region by 2040 concerning supply of these markets, gaining the advantage from Alberta-based plants.

Shifting to a delivered basis for polypropylene, the logistical advantage for Shale Crescent USA becomes more apparent. **IHS Markit estimates that around 77% of U.S. and Canadian polypropylene demand within a 700-mile radius of the Shale Crescent USA epicenter.** As a result, a competitive cost position and inherent working capital savings for a local polypropylene buyer would bode well for an integrated Shale Crescent USA Region polypropylene producer. Additionally, the presented advantages of plants located in the Shale Crescent USA Region are expected to increase over time due to a moderately increasing propane feedstock price over the long term as compared to other competing feedstock prices.

## Conclusions

The major findings of the study are:

- The Shale Crescent USA Region will be a significant contributor to the supply of natural gas, ethane, and LPG well into the future.
- The specific supply and logistics of Natural Gas and LPG in the Shale Crescent USA region affords a cost advantage for its local use within the Region, albeit not as significant as that of ethane.
- Both Methanol and Ammonia/Urea production from natural gas are economically advantaged in the region due to the low feedstock costs.
- The most advantaged LPG derivative is an integrated Propylene (via Propane Dehydrogenation) to Polypropylene project in the Shale Crescent USA Region. Access to ample supplies of locally produced propane leads to a competitive manufacturing cost for propylene and subsequently polypropylene.
- This propane feedstock advantage is augmented by the Shale Crescent USA Region's close proximity to over three-quarters of the U.S. polypropylene end use market.

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