U.S. DEPARTMENT OF ENERGY

Ethane Storage and Distribution Hub in the United States

Report to Congress
November 2018

United States Department of Energy
Washington, DC 20585

Message from the Secretary

As called for by the House of Representatives Report 114-532 accompanying the *Energy and Water Development Appropriations Bill, 2017*, the Department of Energy is submitting a report on *Ethane Storage and Distribution Hub in the United States*.

This report is being provided to the following Members of Congress:

- **The Honorable Michael R. Pence**
  President of the Senate

- **The Honorable Paul Ryan**
  Speaker of the House of Representatives

- **The Honorable Richard Shelby**
  Chairman, Senate Committee on Appropriations

- **The Honorable Patrick Leahy**
  Vice Chairman, Senate Committee on Appropriations

- **The Honorable Rodney P. Frelinghuysen**
  Chairman, House Committee on Appropriations

- **The Honorable Nita M. Lowey**
  Ranking Member, House Committee on Appropriations

- **The Honorable Lamar Alexander**
  Chairman, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable Dianne Feinstein**
  Ranking Member, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations

- **The Honorable Mike Simpson**
  Chairman, Subcommittee on Energy and Water Development
  House Committee on Appropriations

- **The Honorable Marcy Kaptur**
  Ranking Member, Subcommittee on Energy and Water Development
  House Committee on Appropriations

- **The Honorable Greg Walden**
  Chairman, House Committee on Energy and Commerce

- **The Honorable Frank Pallone, Jr.**
  Ranking Member, House Committee on Energy and Commerce

- **The Honorable Lamar Smith**
  Chairman, House Committee on Science, Space, and Technology

- **The Honorable Eddie Bernice Johnson**
  Ranking Member, House Committee on Science, Space, and Technology

- **The Honorable Lisa Murkowski**
  Chairwoman, Senate Committee on Energy and Natural Resources

- **The Honorable Maria Cantwell**
  Ranking Member, Senate Committee on Energy and Natural Resources

If you have any questions or need additional information, please contact me or Mr. Dwayne Bolton, Principal Deputy Assistant Secretary or Mr. Shawn Affolter, Deputy Assistant Secretary for Senate Affairs, Office of Congressional and Intergovernmental Affairs, at (202) 586-5450, or Ms. Bridget Forcier, Associate Director for External Coordination, Office of the Chief Financial Officer, at (202) 586-0176.

Sincerely,

Rick Perry

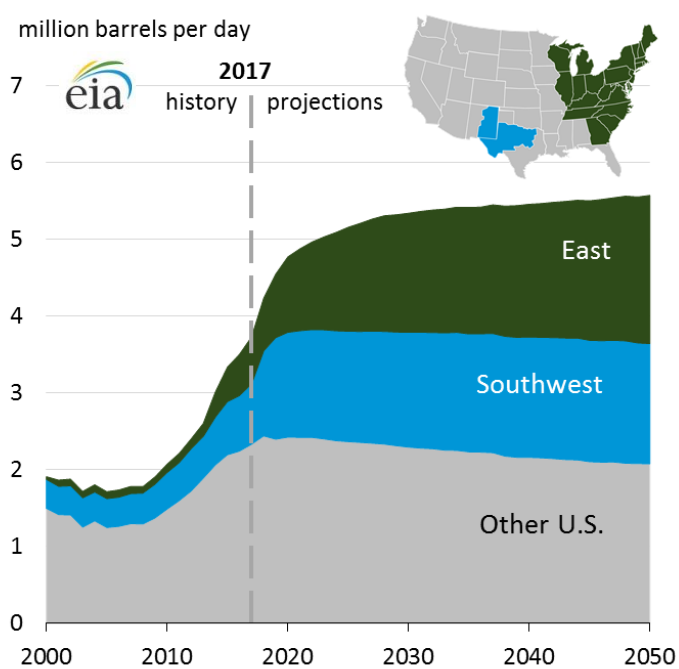
Rick Perry

Executive Summary

The U.S. Department of Energy (DOE) prepared this document at the request of Congress for a report on the feasibility of establishing an ethane storage and distribution hub in the United States.[1] Large hubs for natural gas liquids (NGL), including ethane, are established in the United States, but the boom in crude oil and natural gas production from shale formations across the U.S. has transformed global energy markets and may present opportunities for industry to establish additional hubs. This significant increase in production has made the U.S. the largest combined crude oil and natural gas producer in the world.[2] In addition to these crude oil and natural gas resources, several of the shale plays provide valuable resources in the form of NGLs, including ethane, which are separated from raw natural gas stream at natural gas processing plants. These natural gas plant liquids (NGPL), and especially ethane, are key feedstocks for the petrochemical industry, used to produce compounds for making plastics and resins.

To produce this report, DOE gathered and analyzed information regarding ethane supply and related infrastructure. This analysis considered projected trends in ethane production over the coming decades, where changes in ethane production are projected to occur, the location and capacity of established ethane storage hubs in North America, and natural gas liquids pipelines, among other things. The analysis focused on identifying where significant growth in ethane production is projected and established ethane hubs do not exist.

Figure ES-1: U.S. NGPL Production by Region[3]



In its *Annual Energy Outlook 2018 (AEO 2018)*, the Energy Information Administration (EIA) projects NGPL production to nearly double between 2017 and 2050, supported by an increase in global petrochemical industry demand. Most NGPL production growth in the reference case occurs before 2025 when increased demand spurs higher ethane recovery and producers focus on natural gas liquids-rich plays, where NGL-to-gas ratios are highest.

The large increase in NGL will come from the Marcellus and Utica plays production in the East and from the Permian basin in the Southwest over the next 10 years. This growth is explained mainly by the close association between the production of NGPL and the development of natural gas and crude oil resources in those regions. By 2050, the East and Southwest regions account for more than 60 percent of total U.S. NGL production in the *AEO 2018* reference case.[4]

North America has a long history of NGL production, storage, and use in the petrochemical industry. Several large hubs for NGLs are established, most notably in Mont Belvieu, Texas; Conway, Kansas; and Sarnia, Ontario, Canada. A NGLs hub requires a concentration of physical assets that connect to supply and demand sources via different transport, storage, and distribution options. Achieving such a critical mass generally requires some level of local fractionating or processing capacity, ample storage capacity, and multiple transport options to move commodities in and out of the hub as supply and demand change.

In addition to the assets that actively transport products from one point to another, storage plays a critical role. Storage of NGLs is necessary to balance seasonal supply and demand variations. Large volumes of NGLs are primarily stored as a pressurized liquid in underground caverns, but some areas without suitable geology may use aboveground tanks. Storage helps mitigate production volatility and in turn reduces risk for those end users that need a steady and reliable stream of feedstock. Storage is particularly important for ethane crackers that use furnaces and complex processing that are laborious to restart.[5] Having ethane feedstock available in storage helps large petrochemical plants ensure continuing operations.

Development of the Mont Belvieu hub began in the 1950's with the build out of underground storage caverns in salt formations, and today over 240 million barrels of NGLs storage capacity is available there.[6] Mont Belvieu is also a mature trading hub with a high level of liquidity and transparency that sets spot and futures prices for NGLs, attracts physical as well as financial trading, and continues to draw potential investments for related infrastructure projects.

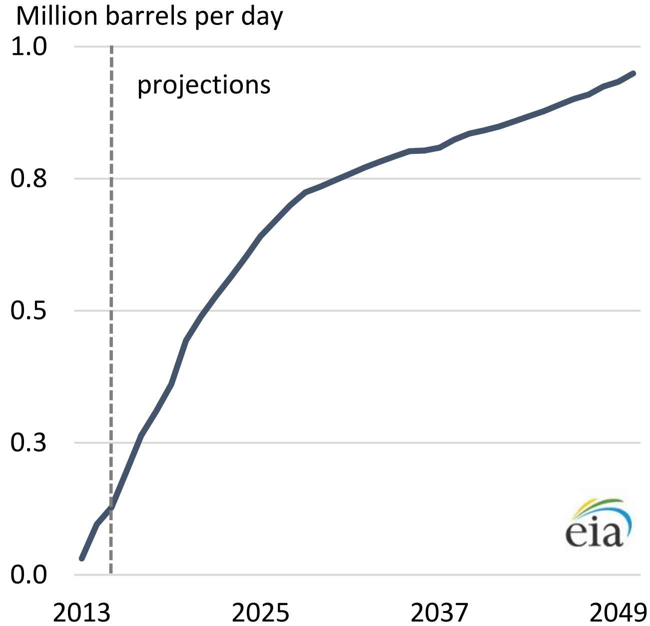
In addition to Mont Belvieu, the second-largest North American NGLs storage hub is located in Conway, Kansas, and both Mont Belvieu and Conway are in relatively close proximity to the growing NGL production projected from the Permian basin in the Southwest. The East region of the U.S. currently is without an NGL storage hub similar to Mont Belvieu, Conway, or Sarnia. The extent to which East region NGLs will be converted and consumed locally will depend on regional infrastructure additions and, more specifically, the interplay between storage and transportation.

Between early 2011 and mid-2013, industry announced capacity expansions, feedstock changes, and new plant construction because of the significant increase in the availability of ethane in the United States.[7] These investments have been focused near the Mont Belvieu hub on the Gulf Coast and near the hub in Sarnia, Ontario. Construction of three new ethylene crackers on the Texas Gulf Coast was completed at the end of 2017. Ethane exports by pipeline to Canada are expected to increase in 2018 as shipments on the Utopia pipeline begin to flow and as an ethylene plant expands capacity in Sarnia.[8] Additional pipeline and export infrastructure has been built to export ethane by tanker from terminals at Morgan's Point, Texas, and Marcus Hook, Pennsylvania; both facilities opened in 2016.[9]

Lacking storage in the East Region, several pipelines have been built to deliver NGL products from the East region to established hubs at Mont Belvieu and Sarnia; the first pipeline to enter service that moves ethane out of the Appalachia region to Canada was Sunoco Logistics' Mariner West pipeline, which was commissioned in December 2013.[10] Early in 2014, the Appalachia-Texas-Express (ATEX) pipeline began shipments of ethane from the Appalachia region into the Midwest and Gulf Coast.[11]

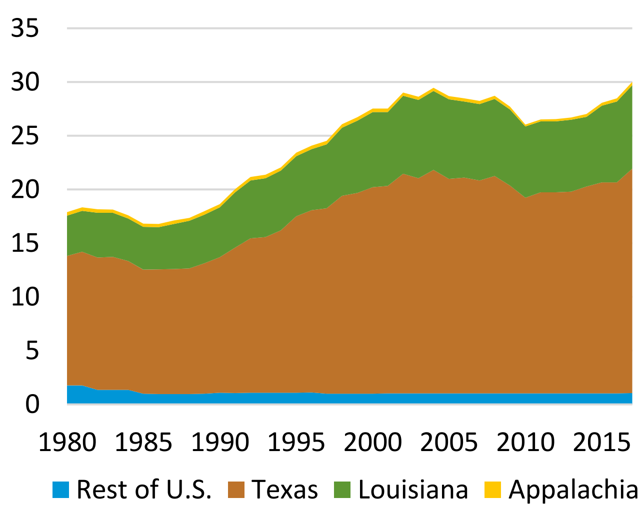
Beyond moving ethane from its production in the Appalachia basin to established North American hubs and overseas markets, the projected growth in NGPL production in the East region presents an opportunity for industry to establish an ethane storage and distribution hub in proximity to production of the resource in the Marcellus and Utica shale plays. Ethane production in the East region is projected to continue its rapid growth in the coming years. Projected production in 2025, at 640,000 barrels per day (b/d), is more than 20 times greater than regional ethane production in 2013 (Figure ES-2). By 2050, ethane production in the region is projected to reach 950,000 b/d.[13]

Figure ES-2: East Region Ethane Production[12]



When used for petrochemical production, ethane is recovered from the natural gas stream and after fractionation is piped to a steam cracker that uses the steam to thermally crack feedstocks into lighter hydrocarbons. Ethylene, the most common product derived from ethane, is used in the production of several other products. The majority of ethylene demand in the U.S. goes to the production of polyethylene, which is the most commonly produced plastic in the world.[15] Polyethylene is used to manufacture many common consumer products, including food packaging and containers, bottles, and housewares.

Figure ES-3. U.S. Ethylene Production Capacity[14]
Capacity (million metric tons)



Globally, North America has the second largest ethylene production capacity in the world behind the Asia-Pacific region. Ethylene production capacity is highly concentrated in the United States Gulf Coast; over 95 percent of U.S. ethylene production capacity is located in either Texas or Louisiana (Figure ES-3).

Significant production capacity growth is projected across the ethane value chain, which includes the production of intermediate products such as polyethylene, ethylene oxide, ethylene dichloride, and others.

Figure ES-4. Projected Ethane Value Chain Production Capacity in the U.S. [16]

Capacity (million metric tons)

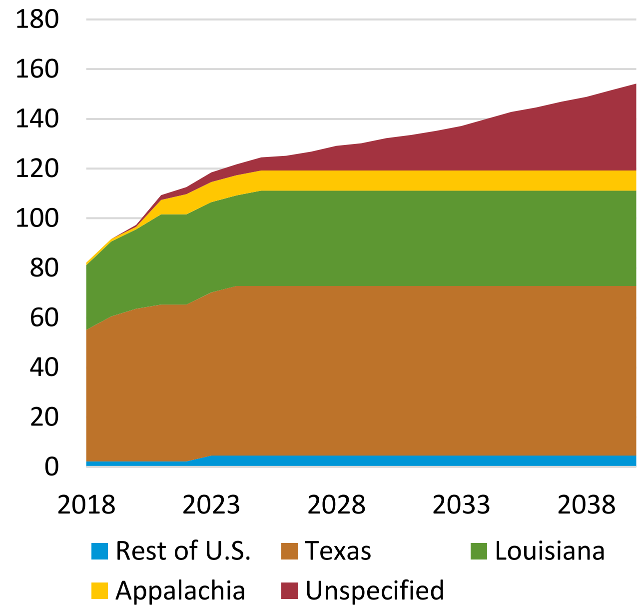


Figure ES-4 depicts the projected production capacity growth by region in the U.S.; between 2018 and 2040, production capacity of ethylene and intermediate petrochemical products is expected to increase by over 85percent. The unspecified capacity depicted in Figure ES-4 represents projected new capacity that has not been proposed for a specific location to date.

The required investments to build a petrochemical hub are significant. For example, a new 125,000 barrels per day NGL fractionator and related infrastructure (including additional storage capacity) in Mont Belvieu, Texas, announced by ONEOK, Inc., is reported to cost $575 million;[17] at Mont Belvieu, Enterprise Product Partners operates eight NGL fractionators with a total plant capacity of 670,000 barrels per day.[18] Shell Chemicals' ethane cracker project under construction in Pennsylvania is reported to cost $6 billion.[19] The new infrastructure associated with a petrochemical hub would include gathering lines, processing plants, fractionation facilities, NGLs storage facilities, ethane crackers, and then some combination of plants for polyethylene, ethylene dichloride, ethylene oxide, and other infrastructure.

The efficient production and distribution of natural gas requires sufficient natural gas processing capacity, where processors separate dry natural gas from NGLs and remove contaminants that can cause mechanical issues in pipelines and compressors.[20] Natural gas produced in the Appalachian basin tends to contain higher amounts of ethane, and regional processing plants extract most ethane separately to manage pipeline natural gas heat content.[21] Pipelines have a range of acceptable heat content for natural gas going through their systems, and removing NGLs from the stream helps to ensure the natural gas meets pipeline specifications.[22] In support of the dramatic increase in production between 2010 and 2016, natural gas processing capacity for the Marcellus and Utica plays grew nearly tenfold and fractionation capacity increased twentyfold.[23, 24] Since ethane's main use is as a petrochemical feedstock, the supply of ethane does not have substantial energy security considerations.

The establishment of an ethane storage and distribution hub near production from the Marcellus and Utica plays could provide benefits to the broader petrochemical and plastics industries along the lines of supply diversity. The present day geographic concentration along the Gulf Coast of petrochemical infrastructure and supply may pose a strategic risk, where severe weather events limit the availability of key feedstocks. Petrochemical expansion beyond the Gulf Coast would increase geographic diversity. This geographic diversity could provide manufacturers with flexibility and redundancy with regard to where they purchase their feedstock and how it is transported to them. Moreover, this flexibility and redundancy, as well as the overall increase in U.S. feedstock production, could mitigate the potential for any price spikes in petrochemical feedstocks that could be caused by a severe weather or other disruptive event in any one region of the U.S.

ETHANE STORAGE AND DISTRIBUTION HUB IN THE UNITED STATES

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I. Legislative Language

Congressional Request for a Feasibility Study

The U.S. Department of Energy produced this report in response to the following Congressional request:

> *"The Department is directed to issue a report on the feasibility of establishing an ethane storage and distribution hub in the United States, given the increased production of natural gas liquids (NGLs) from shale developments and recognizing that ethane is the largest component of those NGLs. The report should examine potential locations, economic feasibility, economic benefits, geologic storage capabilities, above ground storage capabilities, infrastructure needs, and benefits to energy security."*[25]

II. Introduction

The application of horizontal drilling and hydraulic fracturing techniques in oil and gas production has revolutionized the energy system of the United States. By unlocking the hydrocarbon resources in low permeability shale formations, the United States produces more natural gas than any other country in the world. The increased oil and natural gas production is yielding an added benefit in the form of natural gas liquids (NGL). NGLs are hydrocarbons — in the same family of molecules as natural gas and crude oil, composed exclusively of carbon and hydrogen. Ethane, propane, butane, isobutane, and natural gasoline (pentanes plus) are all NGLs. Use of NGLs spans nearly all sectors of the economy. NGLs are used as inputs for petrochemical plants, burned for space heating and cooking, and blended into vehicle fuel.

Given the projected increase in supply of ethane in the United States and in response to a request from Congress, the Department of Energy has prepared this report on the feasibility of establishing an ethane storage and distribution hub in the United States. To produce this report, DOE gathered and analyzed information regarding ethane supply and related infrastructure. This analysis considered projected trends in ethane production over the coming decades, where changes in ethane production are projected to occur, the location and capacity of established ethane storage hubs in North America, and natural gas liquids pipelines, among other things. The analysis focused on identifying where significant growth in ethane production is projected and established ethane hubs do not exist.

Report Overview and Findings

The main content of this report is divided into the following five sections. Each of the following sections provides insights and analysis in support of the following findings:

Section III: A Rapidly Evolving Energy Landscape

- The U.S. Energy Information Administration (EIA) in the *Annual Energy Outlook 2018* (*AEO 2018*) forecasts natural gas production from shale resources will more than double over the coming decades.
- The reference case in EIA's *AEO 2018* projects U.S. natural gas plant liquids production to nearly double between 2017 and 2050.
- Ethane production in the East region, where the Appalachian basin contributes most of the production volumes, is projected to continue its rapid growth in the coming years, reaching 640,000 barrels per day in 2025 – more than 20 times greater than regional ethane production in 2013.

Section IV: A Hub Defined

- A NGLs hub requires a concentration of physical assets that connect to supply and demand sources via different transport, storage, and distribution options.

- Storage of NGLs is necessary to balance seasonal supply and demand variations. Storage helps mitigate production volatility and in turn reduces risk for those end users who need a steady and reliable stream of feedstock.
- The three most prominent NGLs hubs in North America are sited in Mont Belvieu, Texas; Conway, Kansas; and Sarnia, Ontario, Canada.

Section V: The Industrial Ecosystem and Regional Activity

- Appalachia's abundant resources coupled with extensive downstream industrial activity may offer a competitive advantage that could enable it to displace marginal producers and help the U.S. gain global petrochemical market share.
- Nearly one-third of U.S. activity in the petrochemical ecosystem occurs within 300 miles of Pittsburgh, with over $300 billion of net revenue, 900,000 workers, and 7,500 establishments.

Section VI: Market Analysis for Appalachian Petrochemicals

- U.S. petrochemical manufacturing capacity and production is poised to continue expanding given the expectation of shale production, though the geographic distribution is evolving and not yet clear.
- Projected, but unspecified to a particular region, incremental capacity growth will generate nearly $227 billion in revenue between 2018 and 2040.
- Development of an Appalachian cluster is not necessarily in conflict with Gulf Coast expansion, since Appalachian capacity may serve regional demand for NGLs derivatives, freeing up Gulf Coast production for other markets, including exports overseas.

Section VII: Benefits of Geographic Diversity

- Since ethane's main use is as a petrochemical feedstock, the supply of ethane does not have substantial energy security considerations.
- Over 95 percent of the country's ethylene production capacity is located in Texas and Louisiana. Previous severe weather events along the U.S. Gulf Coast have disrupted the petrochemical supply chain's ability to meet downstream manufacturing demand.
- Expanding the petrochemical asset base beyond the Gulf Coast would enhance geographic diversity of this vital industrial sector and support reliability.

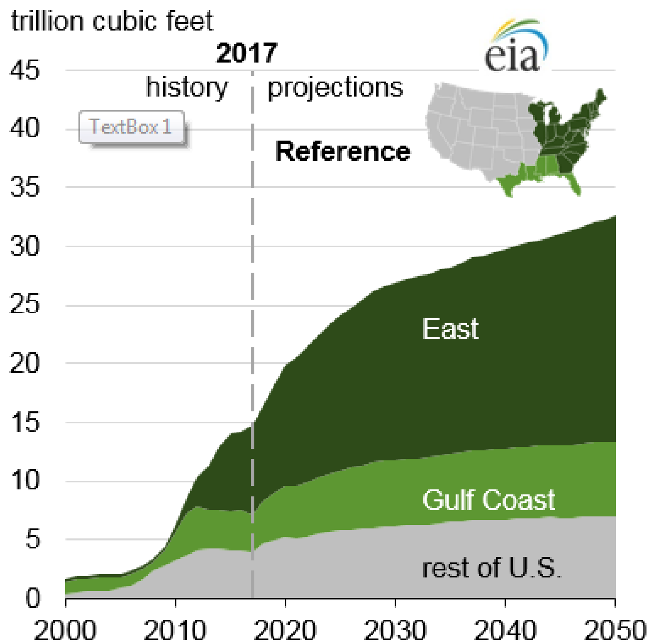
In June 2018, DOE released an updated *Natural Gas Liquids Primer* which provided an overview of ethane, propane, butanes, and natural gasoline, an outlook for the ethane and propane markets, an assessment of the natural gas and natural gas liquid resources in Appalachia, and a description and quantification of NGL infrastructure in Appalachia. Where relevant, findings from the *Natural Gas Liquids Primer* are integrated or cited in this report.

III. A Rapidly Evolving Energy Landscape

The U.S. energy landscape has undergone a dramatic transformation over the past decade as new exploration and production technologies and approaches – from advances in seismic detection to horizontal drilling and hydraulic fracturing – have unleashed the energy and economic potential of resources residing within America's shale formations.

A. *Natural Gas and Natural Gas Liquids Production*

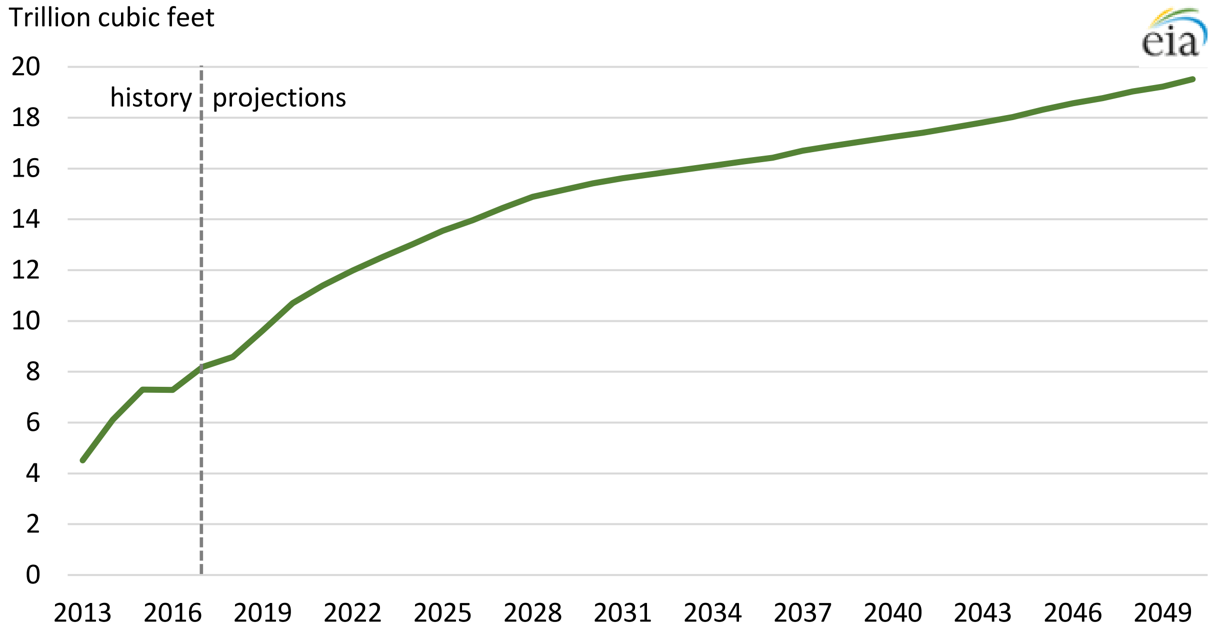
Figure 1. Shale Gas Production by Region[26]



The U.S. Energy Information Administration (EIA) in the *Annual Energy Outlook 2018* (*AEO 2018*) projects natural gas production from shale resources will more than double over the coming decades.[27] Continued development of the Marcellus and Utica plays in the East is the main driver of growth in total U.S. natural gas production across most cases and the main source of total U.S. dry natural gas production. EIA forecasts production from the Eagle Ford and Haynesville plays in the Gulf Coast region to be a secondary source of domestic dry natural gas, with production largely leveling off after 2028. Associated natural gas production from tight oil production in the Permian basin grows strongly through the *AEO 2018* projection period. Continued technological advancements and improvements in industry practices are expected to lower costs and to increase the volume of oil and natural gas recovery per well. These advancements have a significant cumulative effect in plays that extend over wide areas and that have large undeveloped resources (such as in the Marcellus, Utica, and Haynesville).[28]

The Appalachian region – consisting of Ohio, Pennsylvania, West Virginia, and Kentucky – has seen a significant increase in production of natural gas and NGLs. The region is home to the aforementioned Marcellus and Utica shale formations, as well as the undeveloped Rogersville shale. The Appalachian Basin's shale resource endowment is so bountiful that, were it an independent country, the region would be the world's third largest producer of natural gas today.[29]

Figure 2. East Region Natural Gas Production[30]



Natural gas production in the Appalachian region is projected to continue to experience very steady growth in the short and long-term. Natural gas output, estimated at 8.19 trillion cubic feet (Tcf) in 2017, is projected to increase by 65% to 13.55 Tcf in 2025. Output in 2050 is projected at 19.5 Tcf.[31] A recent "Today in Energy" article from EIA provides additional context:

> *Significant growth in natural gas production over the past decade—primarily from the Marcellus and Utica shales in the Appalachian Basin—have increased gross natural gas output in Ohio, Pennsylvania, and West Virginia. Production in these three states increased from a combined 1.4 billion cubic feet per day (Bcf/d) in 2008 to nearly 24 Bcf/d in 2017, with their combined share of total U.S. natural gas production reaching 27%, up from just 2% in 2008, based on data through October 2017....*
>
> *Prior to 2011, natural gas production in these states was lower than demand, and interstate pipelines moved natural gas into the area primarily from production areas in the Gulf Coast. In recent years, however, increased supply has been able to meet demand within these states and in neighboring states. Existing pipelines have been modified to transport natural gas out of, instead of into, Appalachia, and new pipelines have been announced to link Appalachian supply to downstream markets.*[32]

Natural gas, particularly natural gas produced from shale resources, is composed of a mixture of several hydrocarbons, the composition of which varies significantly across plays and even within the same play. In addition to natural gas (i.e., methane), NGLs (ethane, propane, butane, isobutane, pentane, pentanes plus) can account for a significant portion of the raw gas stream. Although methane is largely used for electric power generation and heating, NGLs have properties conducive to fuel and chemical production. When producing a "basket" of products, the challenge facing the producer is to efficiently and effectively match supply and demand for each of the constituent products with its own market dynamics in ways that lead to the best return overall. This challenge is often made more difficult by infrastructure limitations that impede the economical transportation, storage, and distribution of these constituents – from when they enter the market place to their conversion and eventual end use.

Table 1. Natural gas liquids, uses, products, and consumers[33]

NGL	Chemical formula	Uses	End-use products	End-use sectors
Ethane	C_2H_6	Petrochemical feedstock for ethylene production; power generation	Plastics; anti-freeze; detergents	Industrial
Propane	C_3H_8	Fuel for space heating, water heating, cooking, drying, and transportation; petrochemical feedstock	Fuel for heating, cooking, and drying; plastics	Industrial (includes manufacturing and agriculture), residential, commercial, and transportation
Butanes: normal butane and isobutane	C_4H_{10}	Petrochemical and petroleum refinery feedstock; motor gasoline blending	Motor gasoline; plastics; synthetic rubber; lighter fuel	Industrial and transportation
Natural gasoline (pentanes plus)	Mix of C_5H_{12} and heavier	Petrochemical feedstock; additive to motor gasoline; diluent for heavy crude oil	Motor gasoline; ethanol denaturant; solvents	Industrial and transportation

The reference case in EIA's *AEO 2018* projects NGPL production to nearly double between 2017 and 2050. Most NGPL production growth in the reference case occurs before 2025, when producers focus on NGLs-rich plays, where NGLs-to-gas ratios are highest, and increased demand spurs higher ethane recovery.[35] After 2025, production migrates to areas where this ratio is lower.

The large increase in NGPL production in the East and Southwest over the next 10 years is explained mainly by its close association with the development of natural gas and crude oil resources in those regions. By 2050, the East and Southwest regions account for more than 60% of total U.S. NGPL production.[36]

Figure 3. U.S. NGPL Production by Region[34]

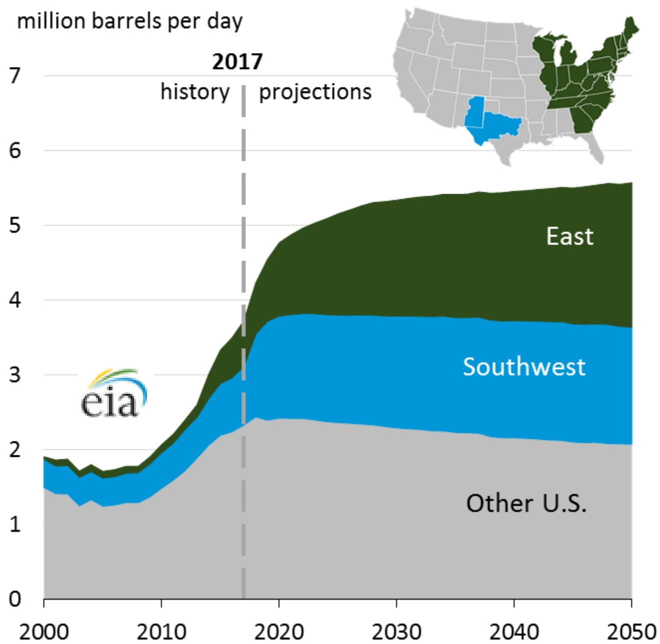
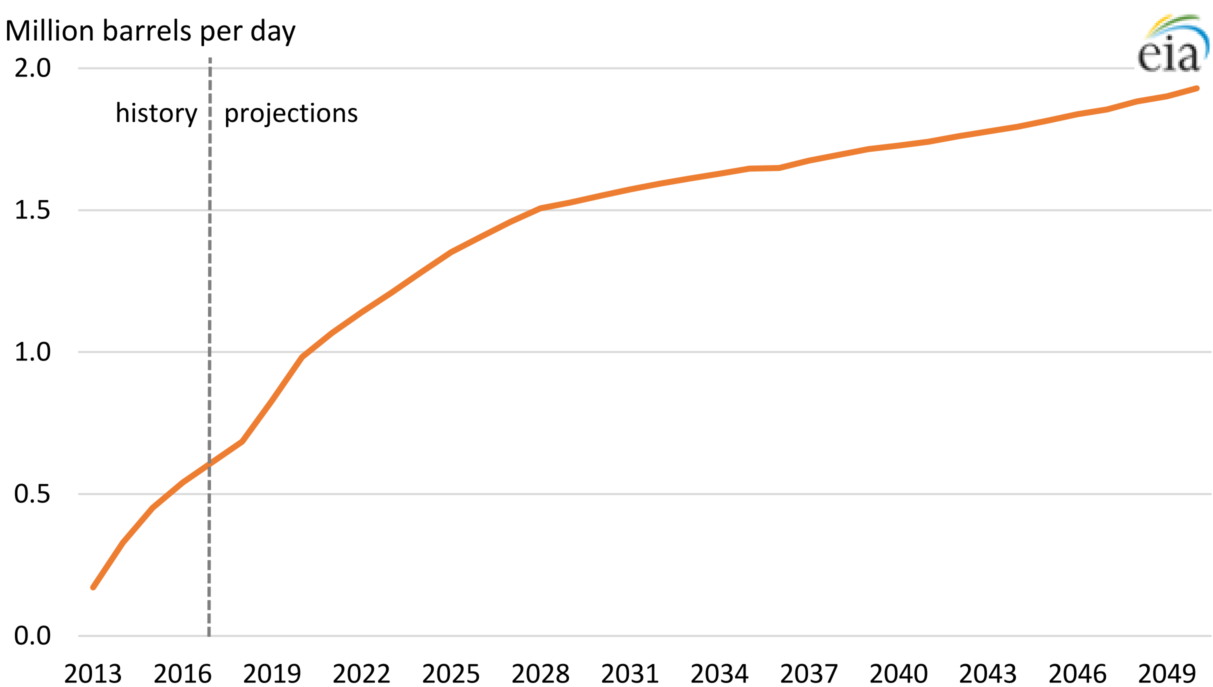
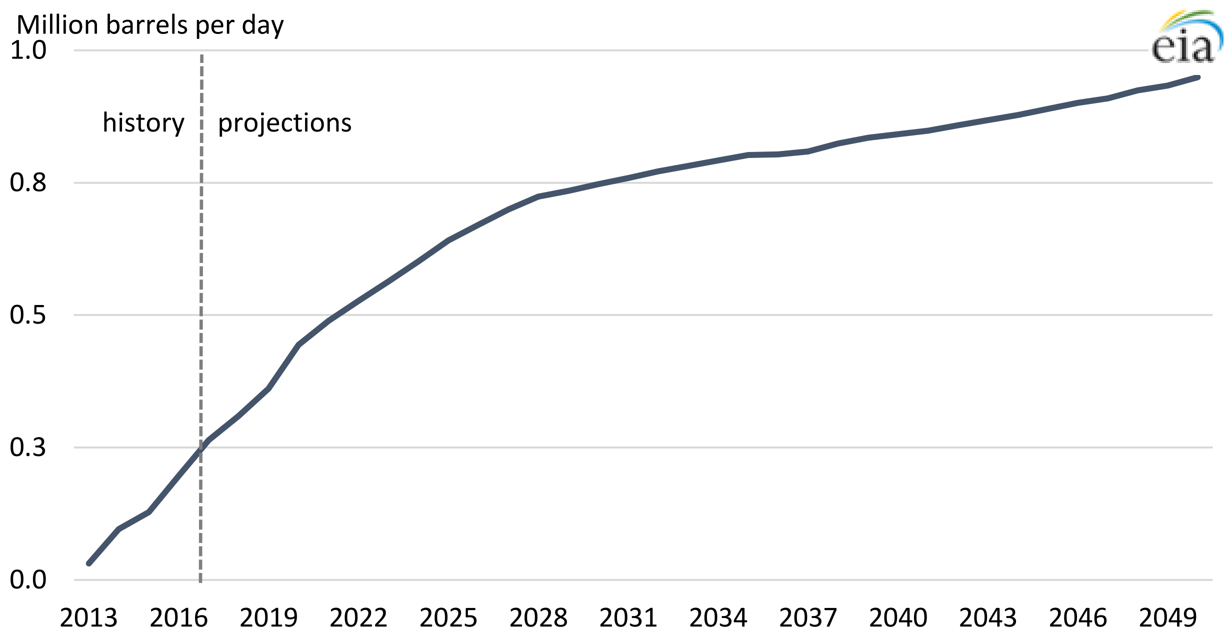


Figure 4. East Region NGPL Production[37]



NGPL output in the East region, and by proxy in the Appalachian basin, will continue to grow throughout the forecast period. As natural gas production gradually migrates away from liquids-rich gas areas, which are expected to slowly deplete, to dryer areas, the rate of growth in NGPL production will slow relative to the rate of natural gas production growth. NGPL output from 2017 to 2025 will more than double from 610,000 b/d in 2017 to 1.35 million b/d in 2025. NGPL output is projected to reach 1.93 million b/d in 2050.[38]

Figure 5. East Region Ethane Production[39]



Ethane production in the region is projected to continue its rapid growth in the coming years. Projected production in 2025, at 640,000 b/d, is more than 20 times greater than regional ethane production in 2013. By 2050, ethane production in the region is projected to reach 950,000 b/d, on the back of both higher natural gas liquids production in general, and higher recovery of ethane as gas plants improve their capacity to extract a higher proportion of ethane out of raw natural gas in order to satisfy growing demand. As will be described later in the report, a world-scale ethane cracker typically consumes around 90,000 b/d of ethane for ethylene production.[40]

B. *A Focus on the Appalachian Basin*

As described above, EIA projects significant growth in domestic NGPL supply over the coming decades in both the East region dominated by Appalachian basin production and the Southwest region where the Permian basin contributes the bulk of production. Section IV of this report provides details on the existing NGL storage and distribution hubs in North America. Notably, the largest existing North American NGL storage hub is located in the Southwest at Mont

Belvieu, Texas, and the second largest is located in close proximity at Conway, Kansas. The eastern region of the United States currently is without a similar NGLs storage hub.

Between early 2011 and mid-2013, industry announced capacity expansions, feedstock changes, and new plant construction because of the significant increase in the availability of ethane in the United States.[41] These investments have been focused near the Mont Belvieu hub on the Gulf Coast and near the hub in Sarnia, Ontario. Construction of three new ethylene crackers on the Texas Gulf Coast was completed at the end of 2017. Ethane exports by pipeline to Canada are expected to increase in 2018 as shipments on the Utopia pipeline begin to flow and as an ethylene plant expands capacity in Sarnia.[42] Additional pipeline and export infrastructure has been built to export ethane by tanker from terminals at Morgan's Point, Texas, and Marcus Hook, Pennsylvania; both facilities opened in 2016.[43]

Lacking storage in the East Region, several pipelines have been built to deliver NGL products from the East region to established hubs at Mont Belvieu and Sarnia; the first pipeline to enter service that moves ethane out of the Appalachia region to Canada was Sunoco Logistics' Mariner West pipeline, which was commissioned in December 2013.[44] Early in 2014, the Appalachia-Texas-Express (ATEX) pipeline began shipments of ethane from the Appalachia region into the Midwest and Gulf Coast.[45]

Beyond moving ethane from its production in the Appalachia basin to established North American hubs and export markets, the projected growth in NGPL production in the East region presents an opportunity for industry to establish an ethane storage and distribution hub in proximity to production of the resource in the Marcellus and Utica shale plays. This report focuses on considerations related to the establishment of an ethane storage and distribution hub in proximity to production of the resource in the Marcellus and Utica shale plays.

A wave of infrastructure investments – including the Marcus Hook NGL export facility near Philadelphia, Pennsylvania – is enabling NGLs production from the Marcellus and Utica plays to reach global markets. The extent to which Appalachian NGLs will be converted and consumed locally will depend on regional infrastructure additions and, more specifically, the interplay between storage and transportation. As it relates to local utilization, NGL storage solutions within the Appalachian region are beginning to expand and will be discussed in greater detail later in Section IV of this report. As storage capacity in the region increases, so too does the potential to use locally produced NGLs as petrochemical feedstocks in manufacturing operations expanding and coming online within Appalachia.

Existing North American NGLs Hubs – including Mont Belvieu, Texas; Conway, Kansas; and Sarnia, Ontario, Canada (described in further detail later in this report) – provide models and insights for the establishment of any new NGLs hub.

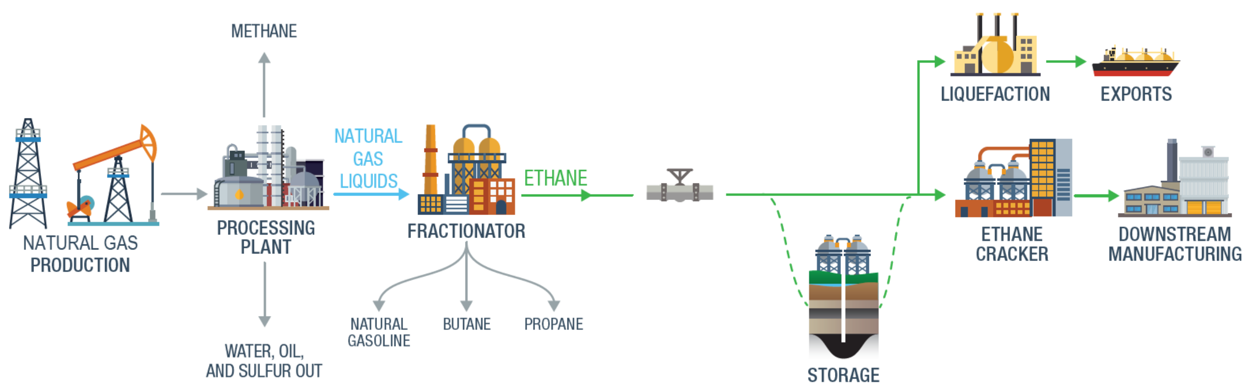
IV. A Hub Defined

A. *Overview*

A NGLs hub requires a concentration of physical assets that connect to supply and demand sources via different transport, storage, and distribution options. Achieving such critical mass generally requires some level of local fractionating or processing capacity, ample storage capacity, and multiple transport options (e.g., pipelines, rail and marine facilities, trucks, etc.) or the flexibility to move commodities in and out of the hub as supply and demand change.

A NGLs "storage" hub is one with sufficient storage capacity that can be for company- and/or site-specific use; open access through third-party ownership; or both. When available storage capacity is predominantly company specific yet sizable, a locale can become a pricing point, though the price will be indexed to commodities bought and sold at the Mont Belvieu hub in Texas.[46] When sizable third-party access storage is in place, high volumes of both physical and financial trades can occur. This is when a NGLs storage hub becomes a "trading" hub, as is the case with the Mont Belvieu hub and, to a lesser extent, the Conway hub in Kansas. Financial trading of NGLs and other oil and natural gas commodities, where products are bought and sold (like gold or other valued commodities in a given asset class) but not physically exchanged, helps producers, consumers, and investors efficiently maneuver in a marketplace with greater liquidity. Such conditions allow for more effective risk management for market participants and enable interested parties to take advantage of or mitigate risks associated with price volatility through trading opportunities.

Figure 6. Ethane Value Chain



The following discussion examines the kinds of physical assets typically present in a NGLs hub. When pertinent, Appalachia-specific examples for physical NGLs infrastructure development are cited. This section then discusses what a trading hub is, how trading happens, and various ancillary benefits generated by these activities. This section also provides a look at existing NGLs trading in Appalachia and ends with a description of three existing North American NGLs hubs – Mont Belvieu, Texas; Conway, Kansas; and Sarnia, Ontario, Canada – highlighting key similarities and differences.

B. *Physical Assets Typically Present in an NGLs Hub*

The NGLs production and end-use supply chain involves several distinct midstream activities and several interrelated infrastructure components that underpin these operations (see Figure 6 above). The following discussion provides an overview of the key physical infrastructure elements typically present in a NGLs hub.

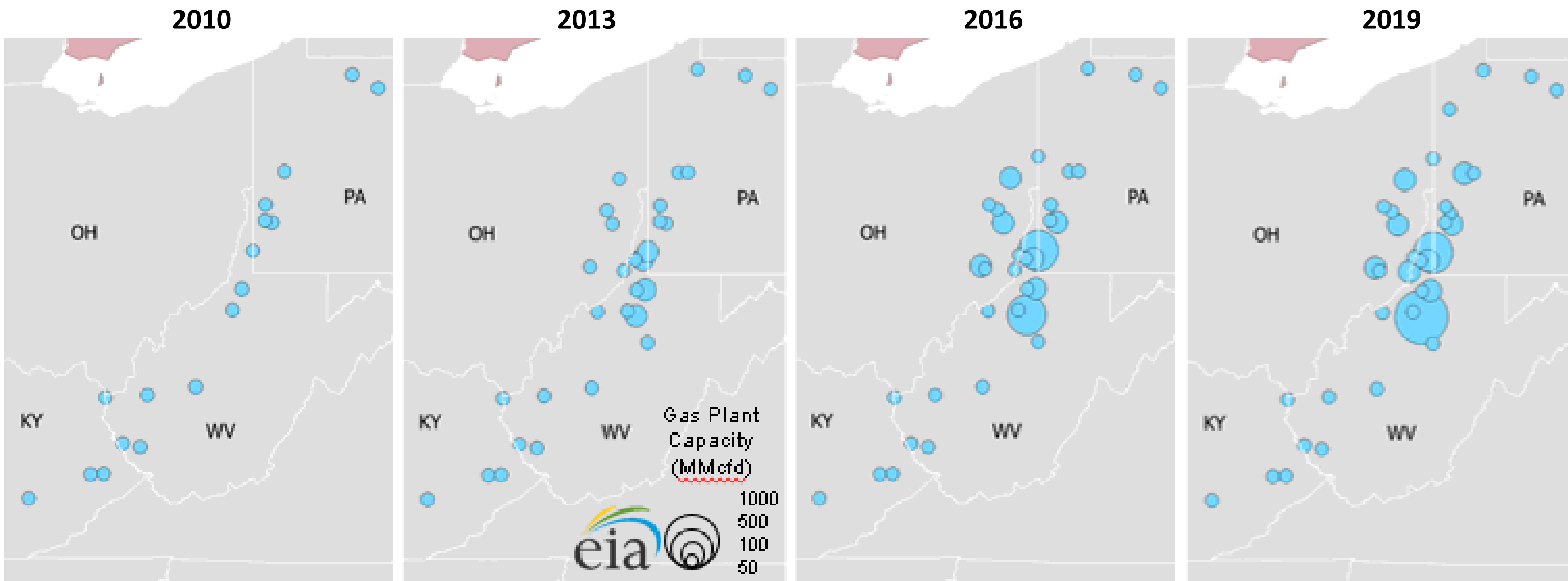
1. Natural Gas Processing Plants

When raw natural gas flows from the wellhead, depending on the quality of gas produced, processing may be required to remove water, hydrogen sulfide, carbon dioxide, and heavier, non-methane hydrocarbons. Natural gas processing plants are the midstream facilities that treat, or clean, raw natural gas, producing what is known as "pipeline quality" dry natural gas (primarily methane) and "Y-grade" NGLs (mixture of NGLs comprised of ethane, propane, normal butane, isobutane, and natural gasoline). Large portions of the Marcellus and Utica shales yield "wet" natural gas, meaning the produced natural gas contains a relatively high percentage of NGLs. The process of removing, or separating, liquids from dry natural gas (mostly methane) is called NGL recovery. In most instances, NGLs have higher values as separate products, and after recovery, make their way to value-added markets.

Modern natural gas processing plants use powerful compressors and chillers that cool natural gas to cryogenic temperatures (approximately -120^{o}F) to separate methane, the main constituent of "dry" gas, from the liquids. While processing plants can use other technologies to separate the gas and liquids streams, cryogenics allows for the highest percentage of liquids recovery.[47] Plants with cryogenic units recover more propane and can vary the recovery of ethane from the natural gas stream as the commodity price dictates. When the price of ethane is low – near or below the price of natural gas on a heating-value-equivalent basis – processors may choose to leave ethane in the natural gas stream (referred to as ethane rejection) and sell it as natural gas.

Unique to the region, gas processing plants in Appalachia extract most ethane separately from the remaining NGLs stream and have been increasing their capacity to do so faster than national fractionation capacity overall. The capacity to extract ethane separately from other NGLs is crucial for gas processors looking to balance gas quality requirements on natural gas pipelines, and is key to satisfying local and out-of-region demand for ethane as a petrochemical feedstock.[48] Figure 7 below shows the rapid build-out of gas processing plants in the Appalachian region since 2010. Between 2010 and 2016, natural gas processing capacity in Kentucky, Ohio, Pennsylvania, and West Virginia grew nearly tenfold, from 1.1 Bcf/d to 10.0 Bcf/d.[49]

Figure 7. Gas processing plants in Ohio, Pennsylvania, West Virginia, and Kentucky[50]

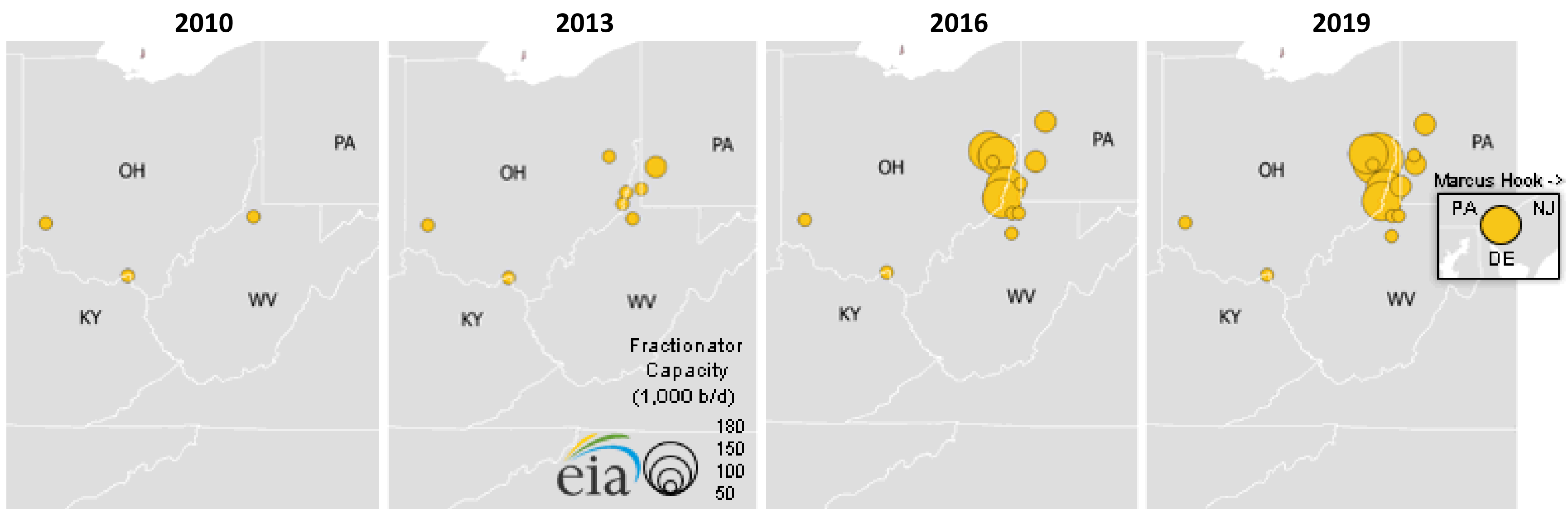


2. Fractionators

After raw natural gas is processed, NGLs leave the gas processing plant as a mix called "Y-grade" to be further refined or "fractionated" into the distinct, often referred to as "pure" products of: ethane (C_2H_6), propane (C_3H_8), normal butane (C_4H_{10}), and isobutane (C_4H_{10}), and natural gasoline (pentanes plus, a mix of C_5H_{12} and heavier). Fractionation, the separation process, can take place at a co-located fractionation plant used to separate the components of NGLs or at a stand-alone fractionator connected to gas processing plants by pipelines.[51]

While across many producing regions in the country fractionation may take place far from where the liquids are processed, in the Appalachian basin all liquids extracted are fractionated locally. Thus, the gas processing capacity buildout has been accompanied by incremental additions to regional fractionation capacity. Fractionation capacity in the Appalachian region has increased from just 41,000 b/d in 2010 to nearly 850,000 b/d in 2016, and may grow as high as 1.1 million b/d in 2019.[52] Figure 8 depicts the locations of gas processing plants and fractionators, both operating and planned, in the region. In addition to fractionating plants that break apart more than one NGLs, Appalachia has seen an increase in de-ethanization capacity to strip out ethane alone from the NGL stream. According to EIA, de-ethanization capacity has grown from zero in 2010 to over 200,000 b/d in 2016, and may reach 350,000 b/d by 2019.[53]

Figure 8. NGL Fractionation Plants in Ohio, Pennsylvania, and West Virginia[54]



3. Transportation Infrastructure

After fractionation, the component purity products must move to a suitable outlet – storage for later usage, delivery to a chemical plant or other facility, or via pipeline to market. Since NGLs are in gaseous form under normal atmospheric pressure, storage must be pressurized or refrigerated. The primary form of NGL storage, for both Y-grade and purity products, occurs in underground salt caverns. Pipelines carry product from the fractionators to underground storage locations. From there, the NGLs are further distributed to market.[55]

NGLs by Pipeline, Rail, and Barge. The most abundant NGLs (ethane, propane, and normal butane) are only liquids when they are under pressure. Since the volume of NGLs in their gaseous state is several hundred times their volume as liquids, they are nearly always moved as liquids, either under pressure or refrigerated, by pipelines (for mixed NGLs, ethane, propane and normal butane) or in tanker trucks, railcars, and special barges or tankers (for propane, butanes and natural gasoline).

Pressurized pipelines are the most cost effective way to transport ethane and form the backbone of the transportation system enabling the flow and consumption of NGLs. In addition to NGLs pipelines, rail has proven to be both flexible and responsive to the recent rapid changes in the NGLs market (other than ethane, which is not moved by rail), as new producing regions have emerged (e.g., the Appalachian Basin), and new markets are developing. Trucking is a vital element of any logistical network, serving as the "last-mile" conduit. And, to some extent, barges on inland waterways play an important role, primarily along the Gulf Coast.

Since 2010, growth in NGLs supply has had a profound impact on NGLs logistics across the country. Initially, because the expansion in supply has been relatively rapid, as with crude oil, volumes of NGLs shipped by rail grew most rapidly. Between 2010 and 2014, rail shipments of NGL grew on average by 12 percent on an annual basis, while pipeline shipments were relatively flat.[56] Since 2014, as pipelines moved from the planning and construction phases to completion, pipeline capacity began to expand rapidly, with flows growing on average 21 percent per annum between 2015 and 2017.[57]

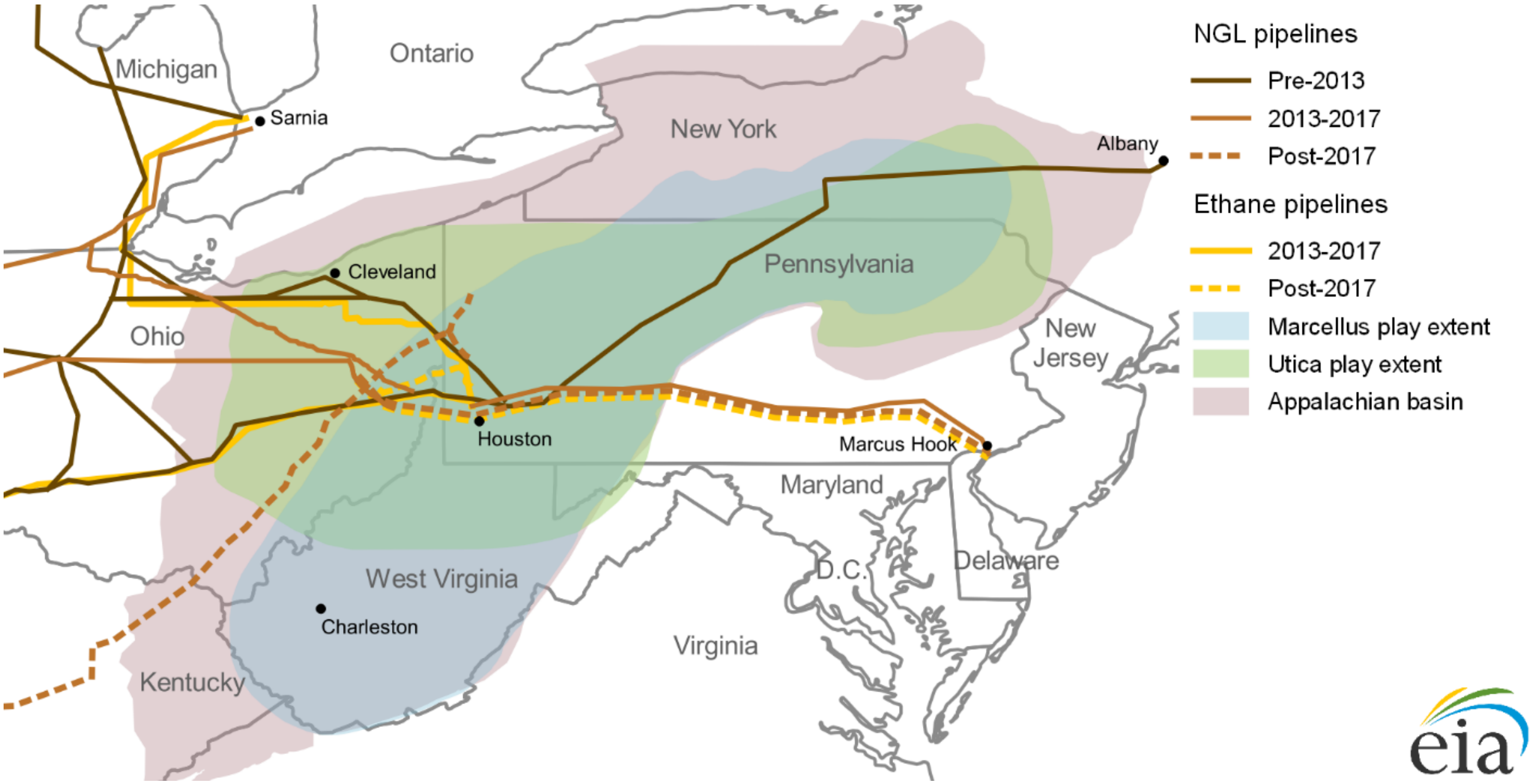
NGLs Transport in Appalachia. The first pipeline to enter service that moves ethane out of the Appalachia region to Canada was Sunoco Logistics' Mariner West pipeline, which was commissioned in December 2013.[58] Early in 2014, the Appalachia-Texas-Express (ATEX) pipeline began shipments of ethane from the Appalachia region into the Midwest and Gulf Coast.[59]

Mariner East, a pipeline also developed by Sunoco Logistics, links the Houston, Pennsylvania, production area with the Marcus Hook, Pennsylvania, storage and export terminal. Mariner East began shipping propane at the end of 2014, and ethane in early 2016.[60] The Cornerstone pipeline, built by Marathon Logistics, began service in September 2016, shipping condensate out of a number of processing plants in southeastern Ohio.[61] The pipeline connects with a number of Marathon assets, including the Canton refinery, and, through interconnecting pipelines, allows for the shipment of condensate as far west as Chicago, the take-off point for the Cochin and Southern Lights diluent pipelines to Canada. In January 2018, Kinder Morgan place UTOPIA (Utica to Ontario Pipeline) into service, an ethane pipeline that carries feedstock from southeastern Ohio to Windsor, Ontario.[62]

Sunoco Logistics, part of the Energy Transfer Partners family, is in the process of completing construction on the Mariner East 2 and Mariner East 2X pipelines. Following generally the path of the original Mariner East pipeline, but originating in southeastern Ohio, the twin pipelines are designed to vastly increase the takeaway capacity for liquids out of the Marcellus/Utica producing region. The pipelines, designed to work as an integrated system with the original Mariner East pipeline, will be capable of transporting the full spectrum of liquids produced in the region, from ethane to condensate.[63, 64]

Kinder Morgan also has a second project planned for the region, the Utica-Marcellus-Texas-Pipeline (UMTP). Unlike other pipelines discussed above, UMTP has not yet reached a final investment decision. While Kinder Morgan has secured Federal Energy Regulatory Commission approval to abandon one of its Tennessee Gas Transmission Pipeline lines and to repurpose the line for UMTP, engineering or construction work on the repurposing has yet to start.[65]

Figure 9. NGL Pipelines, Existing and Announced, in and around the Appalachian Basin[66]



While other NGLs are shipped by rail (including propane, normal butane, and isobutane), ethane is seldom transported by rail. Ethane requires either cryogenic temperatures or very high pressures to remain in liquid state.[67] Shipments of ethane by rail would require specifically-designed tanks, as opposed to the pressurized vessels generally seen transporting what is commonly referred to as LPG – propane, propylene, and butanes.

NGLs are also transported on the water. Pressurized tanks are carried on barges and can generally hold a maximum of 40,000-50,000 barrels of product. For waterborne NGLs exported to Europe or Asia, different types of vessels are used depending on the NGL.[68] For ethane, medium size vessel have a capacity of 262,000 barrels of ethane at cavern pressure, and very large ethane carriers have a capacity of over 800,000 barrels of ethane at cavern pressure.[69] Medium size vessels can load at Marcus Hook, while the largest ones usually load on the Gulf Coast in the Houston Ship Channel.[70]

4. Storage

In addition to the midstream assets that actively transport products from one point to another, storage plays a critical role. Storage provides flexibility in terms of when the product is delivered. Storage helps mitigate production volatility and in turn reduces risk for those end users that need a steady and reliable stream of feedstock – as is the case for ethane crackers. In other cases, having temporal optionality enabled by storage capacity allows entities to seize seasonal arbitrage opportunities in cases where a product is more desirable during certain times of the year.

Storage of NGLs is necessary since produced volumes typically exceed the pipeline takeaway capacity and processing capacity. Large volumes of NGLs are primarily stored as a pressurized liquid in underground caverns, but some areas without suitable geology may use aboveground tanks. Most underground caverns are in salt formations, but some propane storage caverns are mined out of shale, granite, and limestone rock. After NGLs are transported to consumers, they are stored in pressurized tanks above or below ground.[71]

Today the vast majority of NGLs storage is in underground salt caverns, and in the U.S., they extend from Kansas to southern Texas and New Mexico. The storage locations in Mont Belvieu, Conway, and Sarnia all benefit from access to underground salt formations for NGLs storage. Mont Belvieu is the largest NGLs hub in North America with over 240 million barrels of NGLs storage capacity is available there.[72] Conway has salt cavern NGLs storage capable of holding 21 million barrels.[73] And Sarnia, Ontario, the largest city on Lake Huron and situated directly across from Port Huron, Michigan, has over 20 million barrels NGL storage capacity.[74]

Storage is particularly important for ethane crackers that use furnaces and complex processing that are laborious to restart, particularly after a cold shutdown. Having ethane feedstock in storage helps ensure continuing operations, which is particularly critical for ethane crackers during supply interruptions. On the production side, when ethane demand is lower, storage allows producers to store more ethane rather than rejecting ethane into pipeline gas or curtailing production.

The ability to store ethane also allows processors to more appropriately size their ethane recovery units, knowing their off-take agreements can be satisfied from storage at times when their ethane could garner higher revenue in the natural gas stream than as purity product.[75]

The Appalachian region, and a greater area around it, has generally been dependent on storage outside the region to satisfy peak-season NGL demand. Only a few facilities satisfy the criteria of being significant to the market; nearly all of which store propane and are connected to the TEPPCO pipeline.[76]

Enterprise Products Partners LP (EPP) has invested in expanded access and deliverability of propane at its Harford Mills, New York site, which is connected to the TEPPCO pipeline.[77] In addition to aboveground surge tanks, Enterprise currently reports 680,000 barrels of underground propane storage capacity – an increase over the 500,000 barrels of capacity reported in 2014. In 2014 alone, Enterprise invested $6 million to improve rail and truck loading and unloading capability at the terminal. [78]

Crestwood's proposed Finger Lakes NGL Storage Facility at Watkins Glen, New York, has been held in regulatory stasis for over seven years, first filing a request to convert the depleted salt caverns to hydrocarbon storage in 2009, and satisfying all of the New York State Department of Environmental Conservation's (DEC) requirements by mid-2013.[79] The project involved the use of two existing caverns on the shore of Lake Seneca at Watkins Glen, New York, near the EPP Watkins Glen terminal and with a connection to the TEPPCO pipeline.[80] As originally proposed, the facility would have been capable of holding a combined 2.1 million barrels of propane and butane. Crestwood, seeking support from the adjacent communities, has revised the project numerous times, most recently by reducing scope to storing just propane, and in only the larger, 1.5 million barrel cavern.[81] It has also shifted away from building the terminal with rail and truck access, with pipeline access now the only option. In September 2017, one of the last challenges to Crestwood's DEC application was struck down, allowing the project to possibly proceed.[82]

Sunoco's site at Marcus Hook, Pennsylvania, sits 300 feet above five granite caverns capable of storing a combined 2 million barrels of NGL and olefins.[83, a] These caverns were mined in the 1950s, 60s, and 70s, and were an integral part of operations at the shuttered Marcus Hook refinery.[84] The smallest cavern, at approximately 200,000 barrels capacity, now belongs to Braskem and is integrated into their polypropylene plant operations. The remaining capacity,

[a] Olefins are unsaturated hydrocarbon compounds with the general formula CnH2n containing at least one carbon-to-carbon double-bond. Olefins are produced at crude oil refineries and petrochemical plants and are not naturally occurring constituents of oil and natural gas. (U.S. Energy Information Administration)

at around 1.8 million barrels, belongs to Sunoco with the largest cavern capable of holding approximately 1 million barrels. Some of the capacity is set aside to serve the Paulsboro, New Jersey refinery located across the Delaware River, while the rest facilitates Sunoco's operations at the Marcus Hook terminal, including exports.

As part of the Mariner East project, storage at the site was expanded. The initial phase of the project, which accompanied the Mariner East pipeline reversal and repurposing for NGLs service, included a 300,000 barrel ethane tank and a 500,000 barrel propane tank.[85] Expansion plans include adding additional storage capacity of a 900,000 barrel propane tank, a 589,000 propane storage tank, a 575,000 butane tank, and a new 300,000 barrel ethane tank (estimated).[86] Completion of work on site was originally scheduled to coincide with the commissioning of the Mariner East 2 (ME2) and Mariner East 2X (ME2x) pipelines in late 2017 but the pipeline project has experienced delays.

Energy Storage Ventures LLC, a joint venture between Mountaineer NGL Storage and Powhatan Salt Company, is developing a NGL storage facility in Monroe County, Ohio. As part of its Phase I offering, the subterranean storage facility will operate multiple caverns with a total of 2 million barrels of NGL storage solution-mined in the Salina bedded salt formation roughly 6,500 feet below the Ohio River Valley.[87] The storage facility will serve as a centrally-located storage point for NGLs in the Appalachian region with rail and truck loading capacity as well as two 10-inch, bi-directional pipelines to Blue Racer's nearby Natrium fractionator.[88,89] Initial storage is scheduled to begin at the end of 2018 and ramp up to full operable capacity by mid-2020. With sufficient interest, project sponsors may develop Phase II and expand the facility up to its permitted 3.25 million barrels capacity.

Appalachia Development Group LLC (ADG) is developing the Appalachia Storage and Trading Hub, a proposed underground storage facility for natural gas liquids. The proposed project is intended to be a catalyst for further mid- and downstream development associated with the Marcellus, Utica, and Rogersville shales. To determine its basic eligibility for a federal loan guarantee, ADG submitted a Part I application in September 2017 to the U.S. DOE Loan Program Office (LPO). In January 2018, the LPO invited ADG to submit a Part II application for a loan guarantee under the DOE Title XVII Loan Program, which entails submitting a comprehensive application for the proposed project. ADG is seeking a $1.9 billion loan guarantee that will first require securing an additional $1.4 billion in equity. The site of the proposed hub has yet to be determined. [90]

Appalachian Geologic Study on Potential for NGLs Storage

In August 2017, the Appalachian Oil and Natural Gas Consortium (AONGRC) released a geologic study that looked at and mapped the potential underground storage options for NGLs produced in the Marcellus and Utica shale plays.[91] The AONGRC is housed at the West Virginia University (WVU) Energy Institute and is a partnership among two WVU departments and the state geological surveys of West Virginia, Ohio, Pennsylvania, and Kentucky.

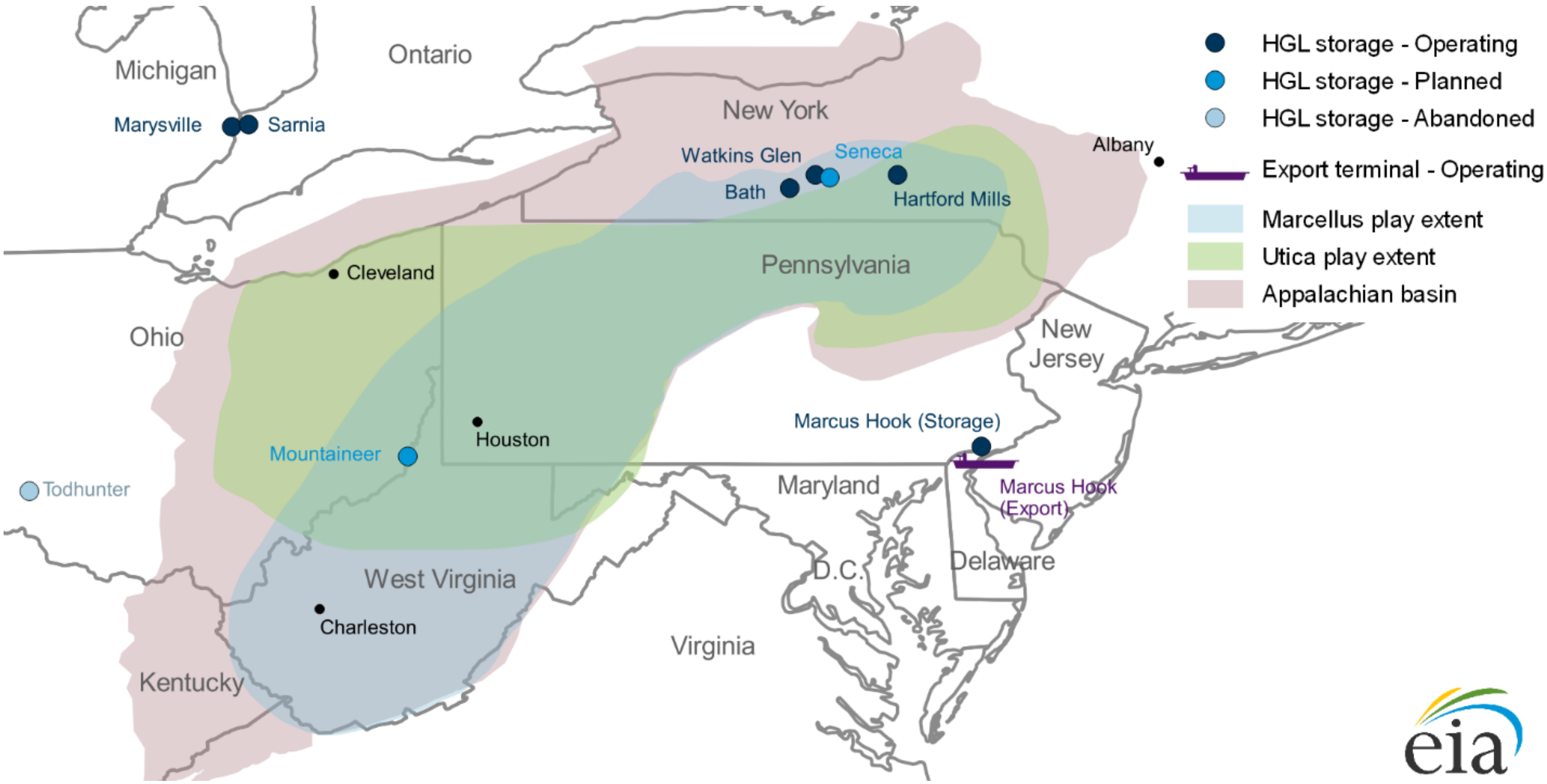
This scientific study evaluated prospective geologic formations in West Virginia, Ohio, and Pennsylvania that offered subsurface locations and conditions eligible for hosting underground NGLs storage, prerequisites for an ethane storage and distribution hub and potential growth of the petrochemical industry within the region. Specifically, the following three subsurface storage prospects were investigated and found to be suitable for prospective underground storage facilities:

- "The Northern Prospect encompasses the northern panhandle of West Virginia and adjacent portions of eastern Ohio and western Pennsylvania, presenting storage opportunities in the Clinton/Medina sandstones of Ohio's Ravenna-Best Consolidated Field and two Salina F4 Salt cavern opportunities straddling the Ohio River. In addition, the Oriskany Sandstone occurs throughout this portion of the Appalachian basin, overlying both intervals, and offers a potential stacked opportunity based on available subsurface data.

- "The Central Prospect includes portions of southeastern Ohio, southwestern Pennsylvania and north-central West Virginia and contains five storage opportunities: Greenbrier Limestone mined-rock cavern options; depleted gas reservoirs in the Keener to Berea interval in and between the Maple-Wadestown and Condit-Ragtown fields; a depleted gas reservoir in the Upper Devonian Venango Group in the Racket-Newberne (Sinking Creek) gas storage field; depleted gas reservoirs in in Upper Devonian sandstones in the Weston-Jane Lew field; and a Salina F4 Salt opportunity near Ben's Run in West Virginia.

- "The Southern Prospect is situated in the Kanawha River Valley of West Virginia and comprises the most storage opportunities of any prospect evaluated for this Study, including mined-rock caverns in the Greenbrier interval; an Oriskany Sandstone natural gas storage field; and various depleted gas fields in the Keener to Berea, Oriskany Sandstone and Newburg sandstone intervals. What's more, many stacked and adjacent opportunities are available within a relatively small geographic area. The number, variety and stacking of storage opportunities in the Southern Prospect shows its potential to support a thriving petrochemical industry."[92]

Figure 10. NGL Storage and Export Facilities[93, b]



[b] On this graphic, "HGL" is a nomenclature used by EIA to refer to Hydrocarbon Gas Liquids, which are both the natural gas liquids (paraffins or alkanes) and olefins (alkenes) produced by natural gas processing plants, fractionators, crude oil refineries, and condensate splitters but excludes liquefied natural gas and aromatics.

5. Ethane Crackers

After NGLs are processed in gas processing plants and separated into individual products at the fractionator, ethane is transported to and fed into a cracker that, under high temperature and pressure, and in combination with steam, "cracks" or transforms the ethane (C_2H_6) molecule into ethylene (C_2H_4) and minor quantities of co-products such as hydrogen, carbon monoxide, and other byproducts of pyrolysis. Ethylene is integral to the production of plastics and other petrochemical intermediate products. Use of locally-produced ethane as the feedstock allows crackers to reduce their feedstock costs and supply risk, improving plant economics.

Table 2. Proposed Major Appalachian Ethane Crackers[94]

Company	Location	Announced Capacity (tpa)	Ethane Feed (1,000 b/d)	Possible Completion
Shell Chemicals	Monaca, PA	1.6 mil.	96	2020-21
Odebrecht/Braskem	Washington Bottom, WV	1 mil.	60	2022+
PTT Global / Daelim Industrial Co.	Shadyside, OH	1.5 mil.	90	2022+

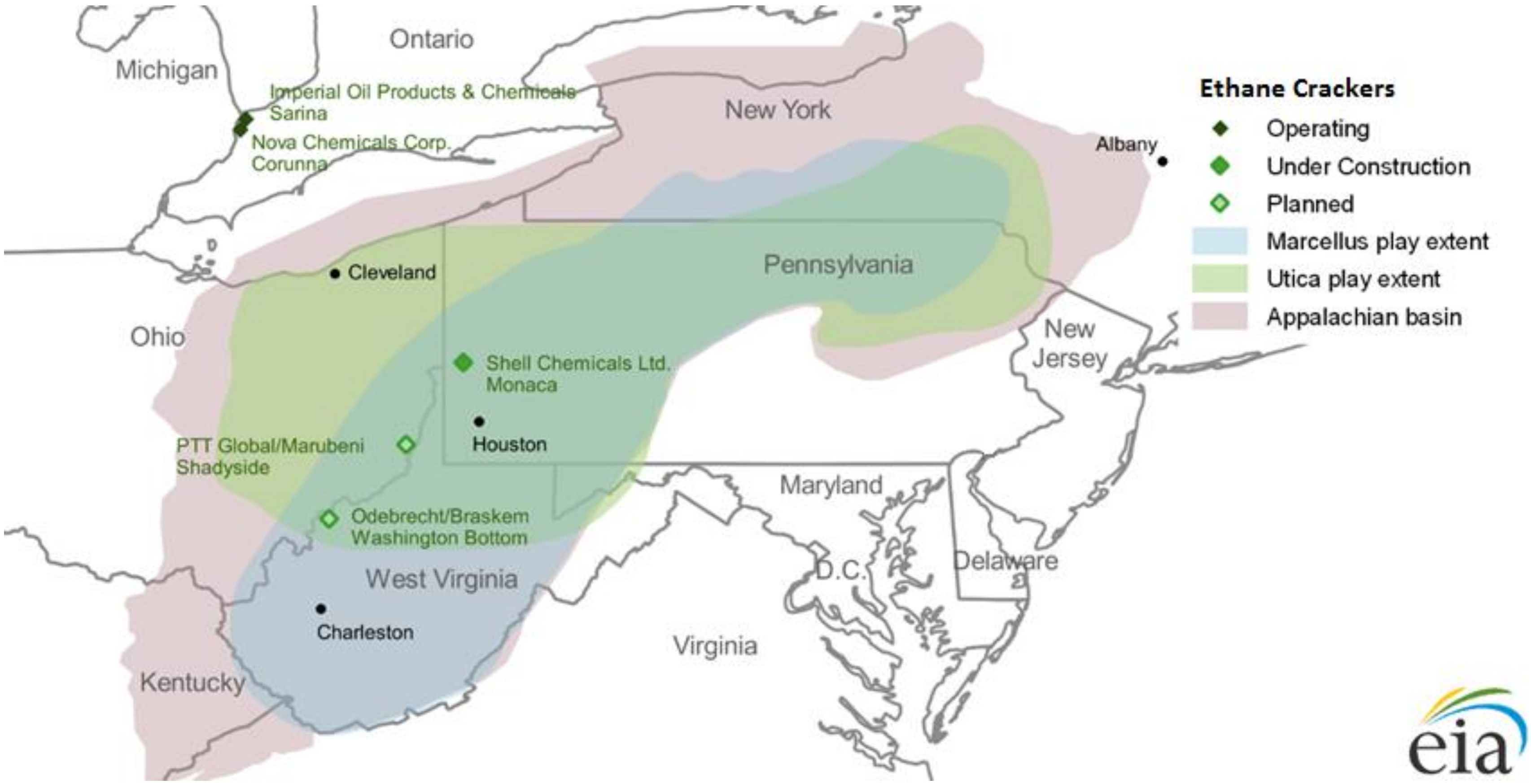
First proposed in 2012, Shell Chemicals' project is the first ethane cracker project in the Appalachian region to move to the final investment decision stage (FID); it is also the biggest.[95] Shell's project will have the potential to consume up to 96,000 b/d of ethane for the production of 1.6 million metric tons per year of ethylene, and will feature on-site capacity to then convert this ethylene into derivative products: low- and high-density polyethylene (LDPE and HDPE).[96] The facility, once built, will increase ethane demand in the region on the scale of a medium-size pipeline. It will also significantly increase the supply of plastics feedstock in a region that is currently a net importer of these materials. With two other cracker projects proposed for the region, local demand for NGLs feedstock, primarily ethane, could be as high as 275,000 b/d – nearly as much as current capacity for moving all liquids out of the region.

In addition to Shell, PTT Global Chemical of Thailand has proposed building a petrochemical cracker at Shadyside in Belmont County, Ohio. PTT has delayed making FID, and recently partnered with Daelim Industrial Co. of South Korea, a major construction and petrochemicals company. Both PTT Global and Daelim, through its Yeochun subsidiary, are leading petrochemical producers in their respective countries. The companies will jointly conduct a feasibility study, and expect making a final investment decision at the end of 2018.[97] PTT Global has set capacity for the planned cracker at 1.5 million metric tons per annum, translating into 90,000 b/d of ethane feedstock demand.[98] Like Shell's ethane cracker under construction in Monaca, Pennsylvania, the PTT/Daelim project would include derivatives production – with polyethylene most likely, but monoethylene glycol also a possibility. The joint experience in petrochemicals of both PTT Global and Daelim provides a general sense of optimism that this project will eventually move forward.

The Ascent Project, Odebrecht/Braskem's cracker proposed for Washington Bottom in Wood County, West Virginia, was an early candidate for success.[99] Challenges at parent company Odebrecht have delayed this potential major investment. Braskem developed a new petrochemical project in Mexico in a joint venture with IDESA in mid-2016;[100] the 1.05 million mt/y cracker is paired with high-density polyethylene (HDPE) and low-density polyethylene (LDPE) lines that generate polyethylene pellets for Mexican and overseas markets. Feedstock for the cracker is supplied by Pemex from three of its gas plants, which is intended to provide built-in redundancy for sufficient ethane supply.[101] The proposed cracker in West Virginia would be built very much along the lines of the Braskem/IDESA project, including sourcing ethane from multiple gas plants to avoid the need for storage facilities.

The sole existing petrochemical cracker in the region is Westlake Chemical's Calvert City, Kentucky plant. Initially, the cracker used propane as a feedstock, receiving its supply via the TEPPCO pipeline as well as by rail and truck from in-region producers. In early 2014, the feedstock slate at the 204,000 mt/y cracker changed to 100% ethane, as the ATEX pipeline came online carrying Appalachia-produced ethane south and via the existing TEPPCO lateral line connecting to the plant.[102] Moving away from propane has resulted in the elimination of propylene from the cracker's product output slate, which has impacted in-region polypropylene producers. Nonetheless, adoption of locally-produced ethane as the feedstock allowed the cracker to reduce its feedstock costs and supply risk, improving plant economics and facilitating another capacity expansion and further investment in the plant, reported by Westlake as being in excess of $300 million.[103] The plant's current 330,000 mt/y capacity translates to approximately 20,000 b/d of ethane feedstock demand, all sourced from the Appalachian basin via the ATEX pipeline.

Figure 11. Ethane Crackers[104]



C. *Market Perspective*

In addition to infrastructure enabling commodity flows and demand response, energy hubs feature an array of financial activities and relationships involving multiple parties. Such parties include commodity producers and consumers, transportation and logistics service providers, hub operators, legal service providers, financial institutions, traders, and regulators. This confluence of activities and actors shapes the market dimensions of a hub and the relationships between and among the parties involved become more complex when physical and financial commodity transactions occur. An energy hub engenders economies of scale in resource utilizations, information sharing, and innovations, which, in aggregate, enhance the hub's value over time. Energy hubs and the activities shaping them are also highly visible, allowing them to attract potential participants and investments in infrastructure and the commodities traded there.

1. A Market Hub Defined

A market hub is a center of activity that facilitates various kinds of transactions involving one or more commodities. Market hubs can be categorized into three main categories: transit hubs, trading hubs, and transition hubs.[105,106] The unique characteristics of an individual hub and how it functions depend on several factors including its geographic location, infrastructure asset base (including access to storage), development history, and state of maturity. Not all hubs will grow to become benchmark trading hubs, i.e., ones that set the reference price. In general, benchmark hubs attract significant trading volumes because they are used for both physical balancing of supply and demand and portfolio risk management; conversely, non-benchmark hubs engage in physical balancing of supply and demand and are used by shippers to adjust and balance their respective physical portfolios.

Transit Hubs. Transit hubs are key transit or trans-shipment points whose chief role is to facilitate the transport of NGLs. They are important in the physical context of NGLs deliveries to various demand centers. Additionally, transit hubs entail a network of physical infrastructure for storing and moving NGL commodities in and out of the hub. NGLs transit hubs are found in Conway, Kansas; Hattiesburg, Mississippi; and Napoleonville, Louisiana.

A transit hub may reach a high level of interconnectedness with other hubs or demand/supply centers through pipeline, rail, marine, and/or other transportation modes. The Conway, Kansas, NGLs hub is a case in point. It holds sizable salt cavern storage capacity, offers third-party access, and has a highly interconnected system of pipelines with other regions yet serves mainly as a transit point for NGLs commerce. From Conway, propane is sent north to meet highly seasonal demand ranging from crop drying (Midwest) to home heating (Midwest and Northeast), or south to satisfy Gulf Coast petrochemical and export demand; butanes move to Conway from producing regions and Midwest refineries, and are either stored to satisfy seasonal demand for gasoline blending in the region or shipped to the Gulf Coast for export or in-region consumption; ethane also either passes through Conway on its way to the Gulf Coast, where it is consumed as a petrochemical feedstock or exporter, or to Midwestern petrochemical plants as a feedstock. There is not much local demand for NGL processing and/or end use in the immediate vicinity of Conway, but the hub's interconnectedness with Midwestern demand centers, Midcontinent and Rockies production, and the Gulf Coast NGL complex make Conway central in the logistics of NGL.

Financial trading beyond physical trading can occur at transit hubs such as Conway. However, transit hubs tend not to attract non-physical trades due to relatively limited, transit-focused NGLs infrastructure, activities, and transactions.

Transitioning Hubs. Transitioning hubs are those that have achieved a certain level of trading hub development (trading hubs are addressed next). They attract some, yet limited, financial trades due to a number of possible reasons. Transitioning hubs may not have access to ample cheap storage and/or storage that allows third-party access. They may not have as much takeaway capacity by way of pipelines, rail, barge, etc., to become a fully evolved trading hub. Additionally, they may not have the same openness and transparency due to a market structure that is in a relatively early stage of development. With greater openness and transparency, a transitioning hub will attract a higher number of traders, buyers, and sellers, boosting liquidity which attracts financial traders and augments risk management options.

Over time, a transitioning hub has the potential to develop further as additional investments are made to enhance its interconnectedness with other participants, markets, and hubs. If the hub is geographically well positioned to meet rising demand, the likelihood of continuous development is enhanced.

Trading Hubs. Trading hubs are those that can be used for both physical balancing (of supply and demand) and financial risk management purposes (for market participants looking to optimize their portfolios and investment returns). For example, NGLs producers can trade deliveries to the hub for sales while hedging against potential price declines by buying a "put option" at the trading hub. At the same time, an ethane buyer can trade timely deliveries of the commodity and simultaneously hedge against potential price increases through a "call option" for ethane available at a trading hub.

There are multiple stages of development for trading hubs. To reach maturity, they must have liquidity for both short-term (spot) and longer-term (or forward) trading, be transparent, fully open, and accessible to a wide range of participants. As stated previously, the maturation of a physical hub into a benchmark trading hub can take a decade based on the experience of natural gas trading hub developments in North America and Europe, which began with deregulation of natural gas pricing.[107] The key stages are illustrated in Table 3 below. In North America, Mont Belvieu is the only trading hub that has reached maturity (stage 10 of hub development listed below) and trades all purity NGLs.

Table 3: Stages of Development of Market Hubs[108]

Stages		Explanation
1	Gas prices deregulated and gas sales unbundled from gas transmission	Governments deregulate the price of natural gas and regulators reform the market to separate the commodity sales function from transportation and other logistics services. Number of buyers and sellers increases.
2	Third party access to transport facilities, terminals	Regulators mandate that all potential infrastructure users have access on nondiscriminatory commercial terms, known as third-party access (TPA). This opens the hub network to the new buyers and sellers.
3	Bilateral trading predominates	Multiple parties begin to contract with each other on their own terms and over the TPA facilities. Producers can trade directly with distributors and large end users. The number of parties and transactions expands.
4	Transparency in pricing and volumes traded	Price reporting entities (PRE) begin publishing pricing information where prices and volumes are reported and published daily, weekly, or monthly, under rules to ensure accuracy. Reliable price information supports bilateral trading and reduces transaction costs.
5	Standardization of trading rules and contracts	Instituted by regulators or an industry organization, such as the North American Energy Standards Board (NAESB), ensures common use of terms and standardized trading and transfer practices. This facilitates trading by reducing transaction costs and making trading more efficient.
6	Over-the-counter (OTC) brokered trading	In addition to producers, distributors, and end users, traders such as merchants, financial institutions, and brokers enter the market to trade gas and provide additional market liquidity.
7	Price indexation	Liquidity at the hub increases to the point that PRE-reported prices at the hub become a reliable indicator of market balance. The reported prices become a reliable index that parties will cite for future pricing in long-term contracts.
8	Non-physical traders enter	Non-physical traders offering pure financial hedging instruments based on the hub index enter the market to take price risk and offer customized OTC hedging services linked to the index.
9	Futures exchange	A commodity exchange such as the New York Mercantile Exchange (NYMEX) creates a standardized tradeable futures contract and offers a trading platform under exchange rules.
10	Liquid forward price curve	Parties trade large numbers of futures contracts for deliveries many months out, providing future price discovery and a means of managing price risk on future commitments.

2. The Relationship Between Storage and Trading

It is common, in both the spot and futures markets, when physical barrels of NGLs are traded, that they do not physically move from location-to-location. Instead they are traded 'in place' within storage facilities or pipelines. This is one reason why storage capacity at a trading hub is so critical.

Storage is an integral part of the NGLs supply chain, and different kinds of storage exist, from distributed to bulk terminal with third-party access. Bulk terminal with third party access type of storage is essential for a hub to generate high-volume physical and financial trading opportunities. At the same time, such storage is still privately owned and access is driven by market forces; thus, a vertically integrated company owning part of the storage capacity is likely to have greater access than a firm lacking those attributes.

Reliable and transparent price signals can enhance the potential for the hub to provide further flexibility and attract additional market participants.[109] For example, volatility in the price of an NGL might signal the opportunity for storage developers to build additional storage capacity. Volatility on the spot market could also provide an incentive to develop more short-term storage. Further, spreads between summer and winter pricing based on over-the-counter deals or on the exchange for the futures market could signal an expected shortage in seasonal storage. Such a signal in turn can incentivize investment for extra seasonal storage. Similarly, such price signals can indicate a lack of connectivity of the hub to demand or supply centers and induce investment for mid-stream infrastructure buildout. These changes can come from commercial investment by system operators, shippers, and financial traders.

D. *Existing Hubs*

1. Mont Belvieu

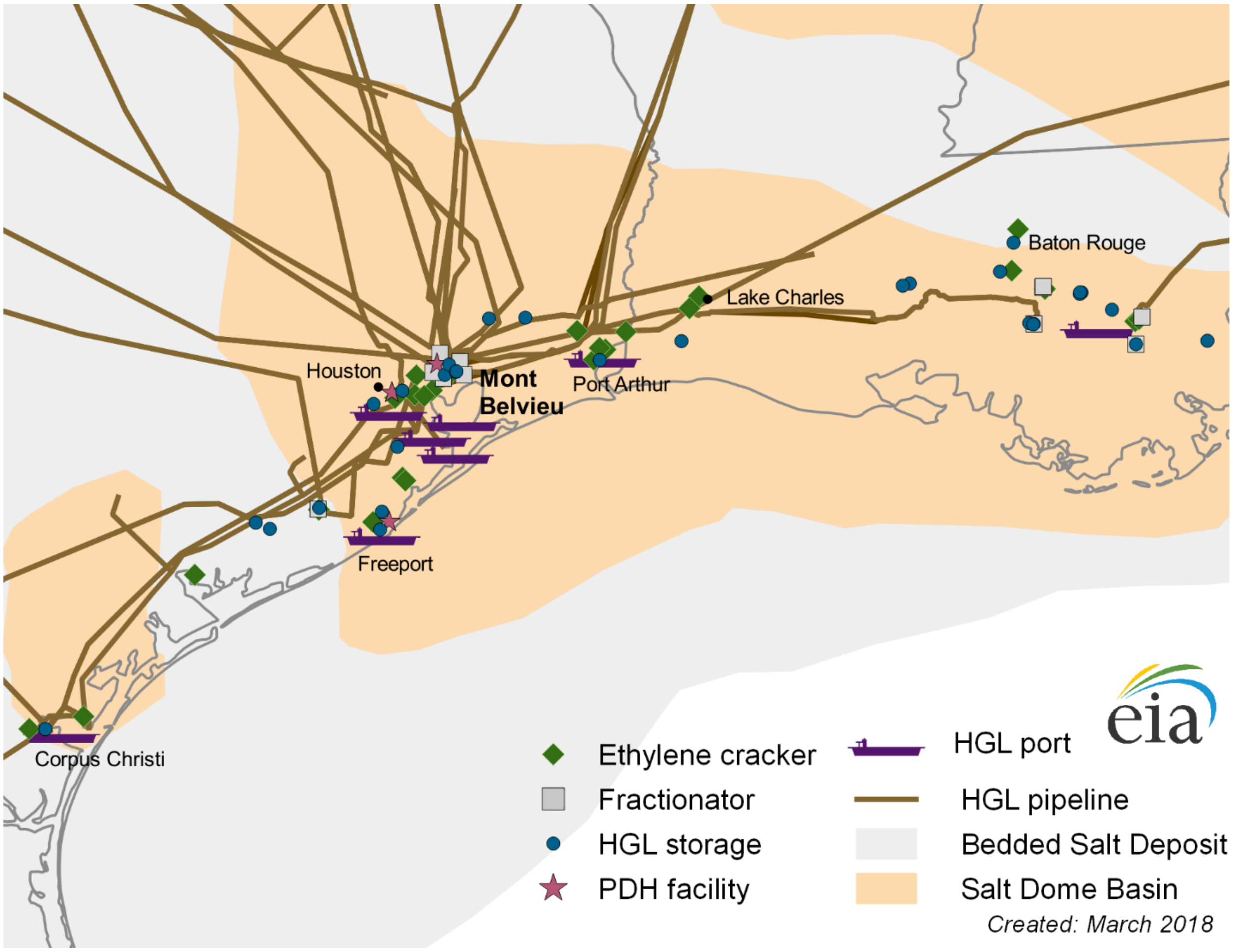
Mont Belvieu is the biggest NGLs hub in North America. Geographically, it is a small town in Texas with a population of about 5,600 people, covering approximately 14 square miles, and sits about 30 miles east of downtown Houston. Mont Belvieu features:

- extensive salt dome storage facilities;
- termination points for a network of pipelines gathering Y-grade from the major production areas in Texas, Oklahoma, the Rockies and connecting to the Conway trading hub;
- a large number of fractionation facilities that separate NGLs into purity products;
- origin points for a pipeline distribution network delivering NGLs products to end user markets in the Northeast (TEPPCO pipeline), the Southeast (Dixie Pipeline), and along the Gulf Coast from Corpus Christi, Texas to the Mississippi delta; and
- proximity to petrochemical plants and oil refineries that consume NGLs as feedstock.

Mont Belvieu consists of underground caverns leached out of pure salt. Since the 1950's, oil companies have been building out enormous storage caverns in the salt dome that resides thousands of feet beneath the surface. Currently, over 240 million barrels of NGLs storage capacity is available there, making it the largest underground NGLs storage in North America and the world.[110] Above ground, a multitude of fractionators separate Y-grade into purity NGLs before injecting large volumes of these products into underground caverns.

Over the years, the hub has also developed a diverse set of transport options for onshore (pipeline, rail, and to a lesser extent trucking) and offshore (cargo vessels) shipments to domestic as well as export markets. Mont Belvieu is also in close proximity to major end-use consumption, including petrochemical plants, oil refineries, and other industrial complexes. Based on these attributes and after decades of development, Mont Belvieu has become a mature trading hub with a high level of liquidity and transparency that attract physical as well as financial trading and continue to draw potential investments for related infrastructure projects.

Figure 12. Mont Belvieu and Other Gulf Coast NGLs Infrastructure[c]



[c] See footnote 'a' on page 27 regarding the "HGL" nomenclature on this graphic. "PDH" refers to propane dehydrogenation plants.

2. Conway

Located in the heart of the Midwest is another key NGLs production and storage hub at Conway, Kansas. Although not as large as the Mont Belvieu complex, Conway is the second-largest NGLs hub and primarily serves Midwest demand, feeding fuel supplies for much of the region's industrial and consumer NGL markets. More than 21 million barrels of NGLs storage capacity is in service at Conway. Mid-continent fractionation and storage operations occur at Conway East and Conway West, Conway Fractionator, Mitchell, and the Hutchinson rail facilities. 40 miles west is Bushton, Kansas, which while geographically distinct is an integral element of the Conway hub. Each is further described below.[111, 112]

Conway East is equipped with rail docks capable of spotting as many as 30 rail cars at a time and maintains an automated truck docking station that can service up to 6 trucks concurrently (4 loading and 2 unloading). The Conway East location connects to 8 different pipelines and has approximately 70 active caverns.

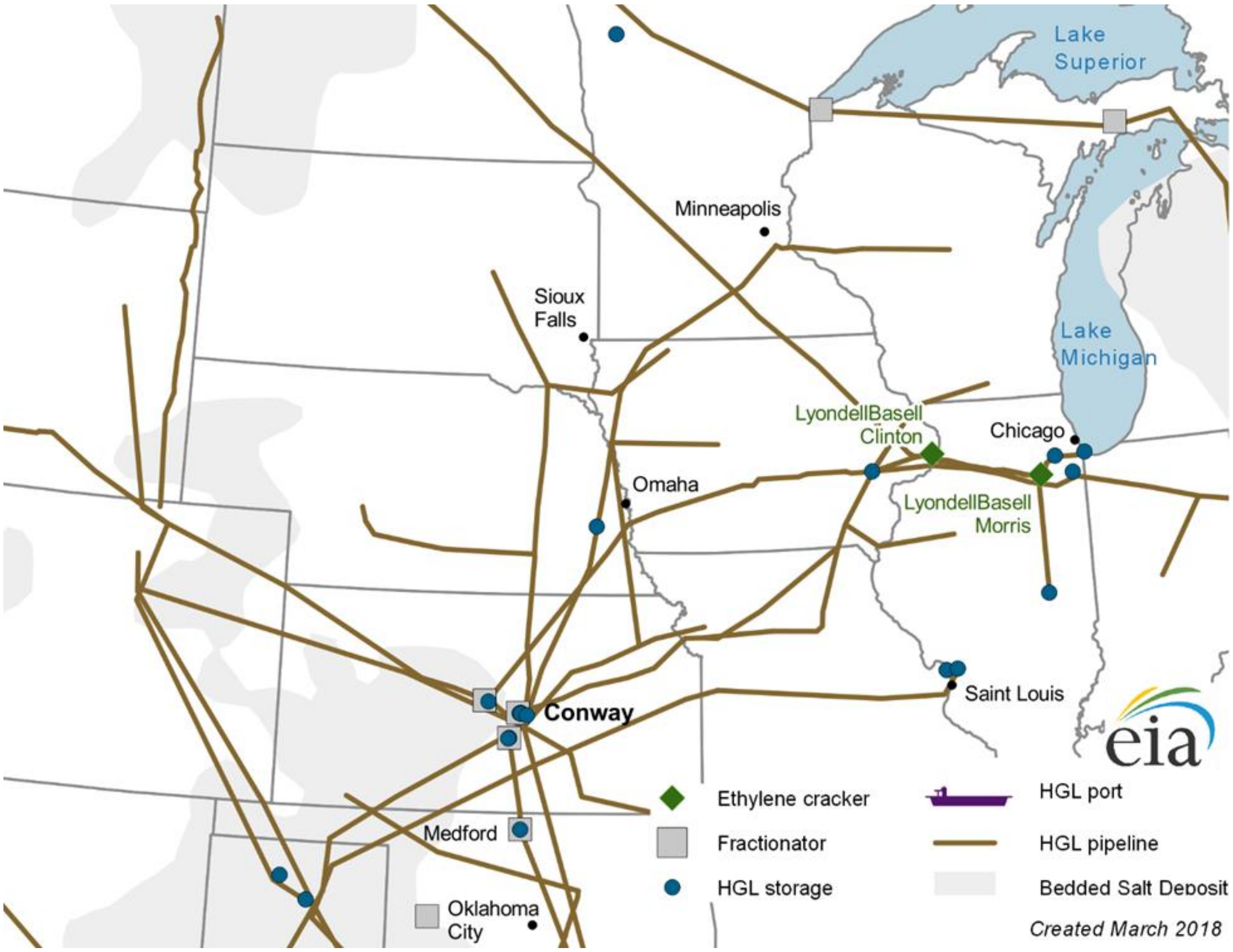
The Conway West location consists of 52 active caverns, including several with 20-inch thick casing which are designed to handle the high flow rates common to the commercial activities that transit through the Conway Hub. The Mitchell location consists of 30 active caverns and is connected to Conway West with propane, ethane/propane, and brine lines.

The Conway Fractionator is located beside the Conway West facilities and jointly owned by Williams Partners, L.P., Conoco Phillips, and ONEOK. Using thermal distillation, the fractionator facility separates the liquids mix into five products – ethane/propane mix (commonly 80% ethane, 20% propane), propane, isobutane, normal butane and natural gasoline – that are stored underground or transported via pipeline to industrial or consumer markets.

The Hutchinson rail facility is located beside BNSF railroad facilities and capable of moving normal and refinery grade butane, isobutene, propane, propane/propylene mix, and natural gasoline. Hutchinson is a versatile link in the Conway Hub infrastructure chain featuring 5 rail tracks used for staging up to 150 rail cars, an 8 spot rail loading rack, and 22 storage vessels. The rail terminal can both send out and receive NGL.

Highly integrated with the Conway complex, Bushton, 40 miles to the west, is home to NGL-related infrastructure owned and/or operated by OneOK, a major midstream operator. The site is the terminus for the Overland Pass pipeline, which brings unfractionated Y-grade from gas plants in the Rockies, and via the Bakken NGL pipeline from the Williston Basin. Bushton is also the origin point for OneOK's North System, which delivers purity NGL products to the Midwest. OneOK Midstream holds 19 million barrels of NGL storage in the Midcontinent, with much of this capacity at Bushton, where the company also owns 210,000 b/d of fractionation capacity.[113]

Figure 13. Conway and Midwest NGLs Infrastructure[d]



3. Sarnia

Sarnia, Ontario, is located near the southern tip of Lake Huron, on the Ontario-Michigan border. It is one of Canada's leading refinery and petrochemical centers, dating as far back as World War II, and has the following attributes:

- three oil refineries with a combined capacity of about 227,000 barrels per day;

[d] See footnote 'a' on page 27 regarding the "HGL" nomenclature on this graphic.

- two major fractionators, the Plains All America/Pembina fractionator and NOVA Chemicals' Corunna petrochemical complex which also includes a large steam cracker for ethylene production;
- three key underground, salt dome NGLs storage facilities, with a combined capacity of about 15 million barrels (though for different HGL – both natural gas liquids and olefins produced at the refineries and petrochemical plants); and
- pipeline and rail infrastructure that move crude and NGLs into and across the various facilities located within, and in near proximity to, the hub.

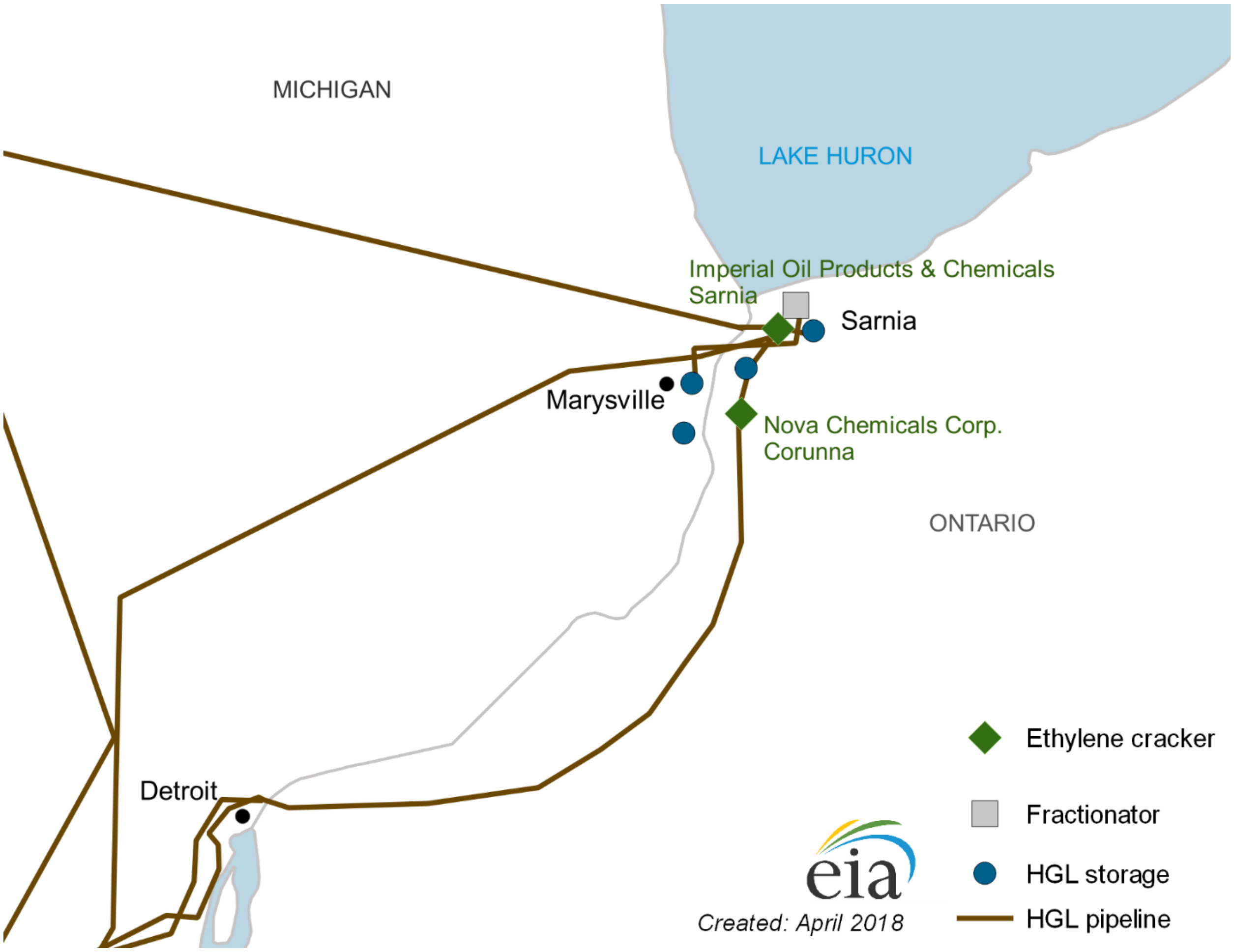
Regarding storage at Sarnia, the existing underground salt domes at Pembina's Corunna facility can hold up to 5 million barrels of ethane, propane, and butanes.[114] The DCP Midstream Partners' Marysville NGLs storage across the St. Clair River can hold up to 8 million barrels.[115] Marysville is used primarily to store propane but was expanded in 2014 to store up to 1 million barrels of ethane.[116] The Plains All American has an aggregate storage capacity of 10 million barrels in the Sarnia area at its Sarnia facility, Windsor storage terminal, and St. Clair terminal.[117]

NGL fractionation at Sarnia sources the Y-grade from natural gas processing in Alberta.[118] The resulting propane and butane is either sent to storage facilities for later use at petrochemical plants in Sarnia, or for loading onto rail cars, trucks and to local pipelines for shipment elsewhere. Ethane is piped in from Marcellus/Utica through Sunoco Logistics' Mariner West pipeline or Kinder Morgan's UTOPIA pipeline for NOVA Chemical's 1.8 billion pound/year Corunna cracker, with some ethane also used as feedstock in Imperial Oil's cracker.[119] Ethane can be stored at DCP Midstream Partners' Marysville, Michigan, NGLs Storage facility across the St. Clair River from Sarnia. NOVA Chemicals also can store ethane at the Pembina Corunna facility, which is located next to the NOVA cracker.

A substantial portion of NOVA Chemicals' propane and butane supplies are delivered by rail, mostly from the Marcellus/Utica region. DCP's Marysville NGLs Storage operation can receive railed shipments of propane and butane, as can Pembina Corunna and NOVA Chemicals. The balance of NOVA Chemicals' current propane and butane needs is piped in mix from Alberta on Enbridge's Line 5, and fractionated at the Plains/Pembina Sarnia Fractionator.

Through various transportation modes (land, rail and waterborne shipping), Sarnia provides immediate access to key North American and world markets. Specifically, Highway 402 links Sarnia to Ontario's 400-series highway system (to the east) as well as Michigan's Interstate 94/69/75 road system to the West. In terms of rail, Sarnia is serviced by CN North America and CSX Transportation, hosting the second largest international railyard in Canada while also providing access to the St. Clair rail tunnel that links Ontario and Michigan. In terms of waterborne transit, the Sarnia Hub is bordered by water, has access to the Port of Sarnia, and can link into the St. Lawrence Seaway. There are also ship fueling and repair operations as well as multiple deep water docking spots nearby.

Figure 14. Sarnia NGLs Infrastructure[e]



[e] See footnote 'a' on page 27 regarding the "HGL" nomenclature on this graphic.

V. The Industrial Ecosystem and Regional Activity

As with any commodity market, supply and demand are the basic factors that influence the movement of petrochemical products. Section II of the report highlighted NGLs supply projections; demand, and the composition thereof, is the focus of this section which aims to explore the industries that will convert and use petrochemical products and derivatives. Understanding the ecosystem of industries and products that are associated with petrochemicals requires analyzing the landscape from multiple vantage points. The petrochemical value chain, for example, contains products that progress along a variety of paths from production to consumption. The industrial ecosystem consists of companies that create and capture value by using conversion techniques that create value-added products. The following sections explore both the petrochemical value chain and the industrial ecosystem, with a concerted look at the extent to which downstream industries reside in the Appalachian region.

A. *Ethane Value Chain*

A value chain involves a sequence of events that advance a product through phases of production to the final customer. The range of products in the petrochemical value chain can be categorized by the stages of processing. The American Fuel and Petrochemical Manufacturers trade association classifies petrochemicals as base or derivative.[120] Base petrochemicals include the olefins ethylene, propylene, and butadiene, and aromatics benzene, toluene, and xylene (commonly referred to together as BTX). All petrochemicals produced using base petrochemicals as feedstocks are considered derivatives.

The petrochemical value chain is complex and includes multiple feedstocks. This report focuses on the ethane value chain, as ethane is the primary NGL being produced in the Appalachian region. The following discussion focuses on the ways ethane is used in the downstream petrochemical and plastics value chains. This report does not address the petrochemical value chains derived from propane or heavier feedstocks.

Over 99% of U.S. ethane is produced from natural gas processing facilities, with only small amounts produced at crude oil refineries.[121] When used for petrochemical production, ethane is piped to an ethylene cracker that uses steam to thermally crack feedstocks into lighter hydrocarbons. These steam crackers can crack either gaseous feedstocks (ethane, propane, or butane) or liquid feedstocks (naphtha or gasoil). Cracking each of these different feedstocks will yield different products.

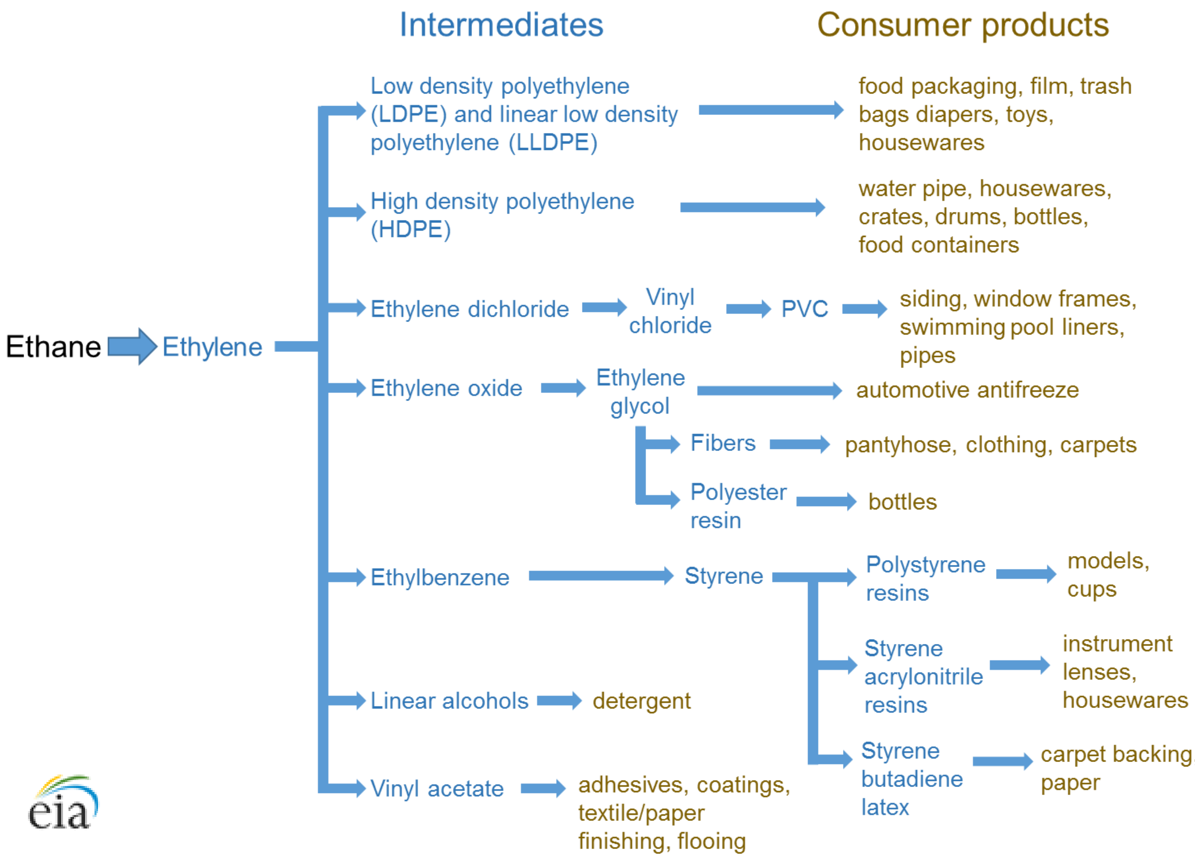
Ethylene, the most common product derived from ethane, is used in the production of several other products. About 60% of ethylene is used to produce polyethylene, 15% for ethylene oxide, 10% for ethylene dichloride, 6% for ethylbenzene, and 9% for other products.[122]

Globally, North America has the second largest ethylene production capacity in the world behind the Asia-Pacific region. The countries with the largest ethylene production capacity include the U.S., China, and Saudi Arabia. Japan, South Korea, Canada, and Germany also maintain ethylene production capacity.[123]

Polyethylene (PE) is the most commonly produced plastic in the world, and accounts for about 60% of ethylene feedstock demand in the U.S.[124] Ethylene enters the plant as a gas or slurry and is subsequently converted into hard, plastic pellets that are easier to store and ship. Depending on the amount of pressure used, the density of the PE produced will vary. Low-pressure results in high-density PE, and high-pressure results in low-density PE. The three common types of PE resins each have different characteristics and uses. They include high-density polyethylene (HDPE), low-density polyethylene (LDPE), and linear low-density polyethylene (LLDPE).

Once PE pellets are produced in the polyethylene plant, the pellets are transported via truck, rail, or barge to plants downstream for further processing. Over longer distances, PE pellets can also be bagged and shipped in intermodal containers.

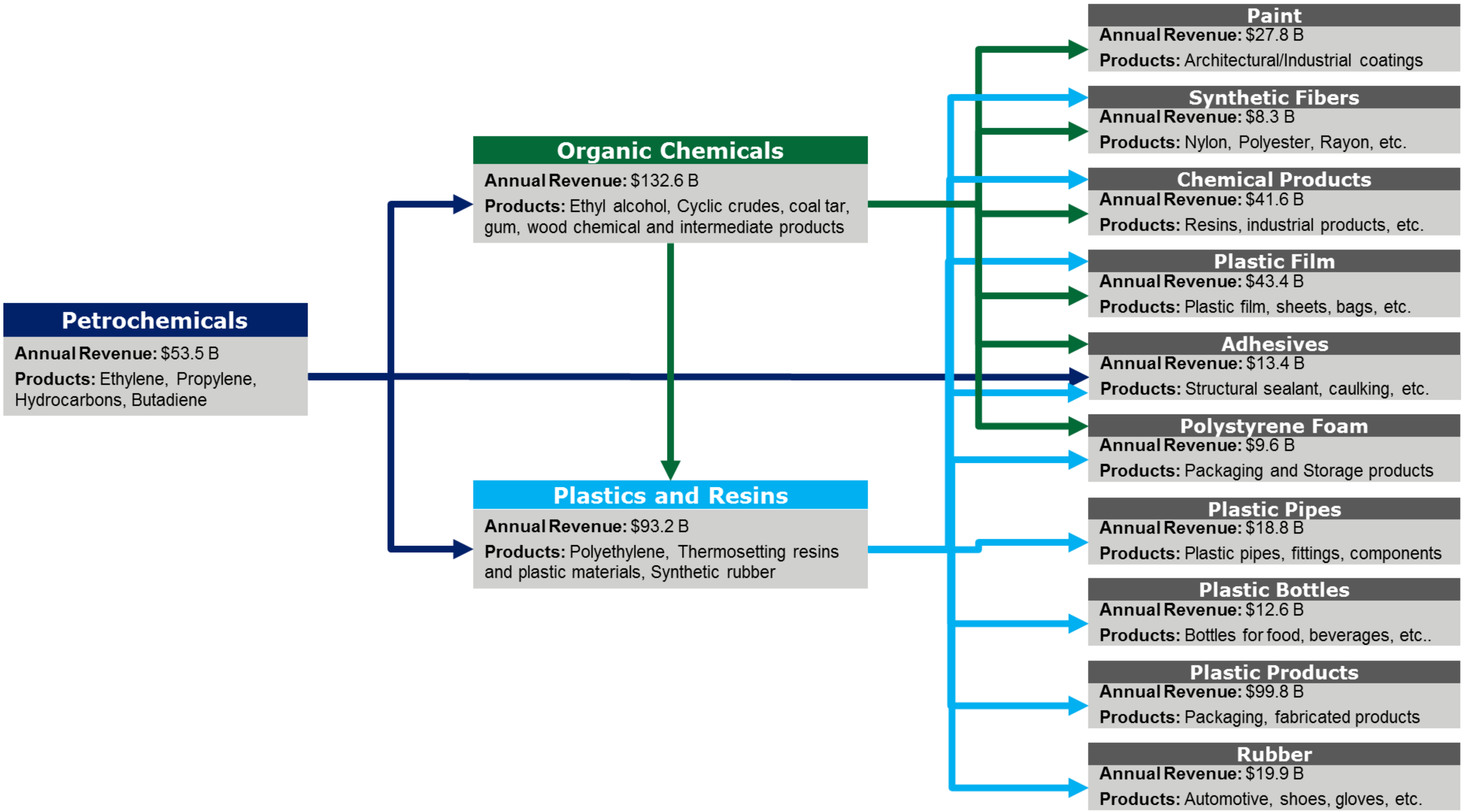
Figure 15. Ethane Value Chain – Intermediate and Consumer Products[125]



B. *Industry Ecosystem*

The ecosystem of industries that advance products along the aforementioned value chain are shown in Figure 16. The industrial ecosystem is an alternative representation of the value chain where each industry represents the connectivity between nodes of the value chain and the corresponding conversion event. Focusing on the industries — as defined by the North American Industry Classification System (NAICS) — facilitates analysis of the corresponding statistical data, which spans a range of economic topics. [126] The figure below identifies the 13 industries that were included as part of this analysis. Each box in the figure represents similar companies that are grouped based on the processes used and goods produced.

Figure 16. Petrochemical Ecosystem of Industries[127]



Each industry above creates and captures value through specific conversion processes. For example, the petrochemical manufacturing industry uses a variety of methods to convert natural resources into products that serve as feedstocks to the rest of the ecosystem. The olefins and polyolefins produced by petrochemical manufacturers are used by companies downstream to manufacture organic chemicals, plastics, and resins. Organic chemical manufacturers convert base chemicals into a variety of intermediates to be used by downstream manufacturing industries. Plastic and resin manufacturers further refine olefins into a form that can be easily converted into a final product. Finally, wide ranges of companies make use of the chemicals, plastics, and resins, which have unique properties that are conducive to select applications.

The industries identified in the preceding figure represent a subset of the broader chemical sector, which contributes significantly to the U.S. economy. The American Chemistry Council estimates that "over 96 percent of all manufactured goods are directly touched by chemistry, either as a material or processing," and the entire value chain of chemical products is "responsible for over six million American jobs and more than 25 percent of America's GDP [gross domestic product]." [128, 129]

C. *Petrochemical Clusters*

Clusters, defined as "geographically proximate group(s) of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities," are critical engines of national and regional economies.[130] As Michael Porter from Harvard Business School has described:

> *Clusters are concentrations of highly specialized skills and knowledge, institutions, rivals, related businesses, and sophisticated customers in a particular nation or region. Proximity in geographic, cultural, and institutional terms allows special access, special relationships, better information, powerful incentives, and other advantages in productivity and productivity growth that are difficult to tap from a distance. As a result, in a cluster, the whole is greater than the sum of the parts.*[131]

Understanding clusters and their composition can help gauge the growth potential and productivity within a region, such as in the case of Appalachian petrochemicals.

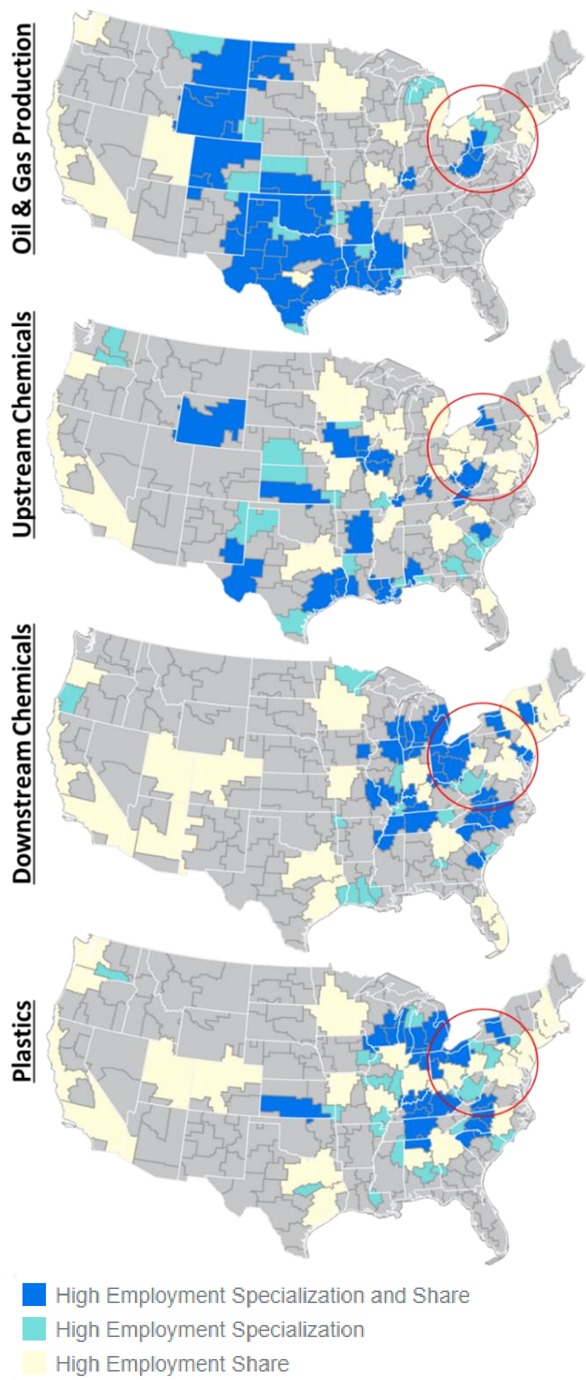
U.S. Cluster Mapping, an online tool developed by Harvard Business School's Institute for Strategy and Competitiveness in partnership with the U.S. Department of Commerce and U.S. Economic Development Administration, synthesizes over 50 million open data records on industry clusters and regional business environments in the U.S. to highlight competitive regional clusters. The maps in Figure 17 showcase national clusters using employment specialization and employment share, which collectively gauge the degree to which there exists a critical mass of economic activity.[f, g] Looking at the maps associated with portions of the oil and gas value chain, one can see the regions with apparent clusters of activity. With respect to oil and gas production, the Gulf Coast dominates the landscape while there is notable activity across the Marcellus and Utica shale formations.

While the Gulf Coast has dominated upstream chemical production over the past 50 years, port cities with access to raw materials also exhibit high employment shares. New Jersey and New York are among the top 10 states for upstream chemical production employment share. There is strong activity in Ohio, West Virginia, and Pennsylvania as well.

Appalachia and its surrounding regions have significant activity in the downstream chemical sector, with a strong base of independent manufacturers as well as multi-national corporations such as PPG Industries, Dow Chemical Inc., Sherwin-Williams, and BASF.

Finally, the plastics industry demonstrates a high level of employment share and specialization within the Appalachian region. Many of Appalachia's plastic products are destined for the automotive, construction, and consumer products sectors, which are prevalent if not in Appalachia then in peripheral geographies such as the Midwest, Mid-Atlantic, or New England.

Figure 17. Petrochemical Clusters



[f] In the maps, high employment specialization is defined as: location quotient of a cluster employment area must be greater than the 75th percentile when measured across all economic areas, and location quotient of cluster employment area must be greater than 1.0, share of national cluster employment greater than the 25th percentile, and share of national cluster establishments greater than the 25th percentile

[g] High employment share on the other hand is defined by meeting the following criteria: share of national cluster employment must be greater than the 90th percentile when measured across all economic areas.

D. *An Appalachian Petrochemical Cluster*

Appalachia has a legacy of petrochemical manufacturing with the world's first facility beginning operations in 1920 in Clendenin, West Virginia.[132] Today, the petrochemical value chain in Appalachia has activity at each end of the chain with little activity in the middle (*i.e.,* converting fossil fuels into base chemicals and intermediates). Upstream from petrochemical manufacturing, natural gas production within the region is experiencing rapid growth. At the other end of the value chain, there are numerous converters and plastic manufacturers in the region.

The up- and downstream activity within Appalachia translates to competitive advantages that are inciting investment in the petrochemical space. A unit of Royal Dutch Shell, for example, identified three primary reasons for their decision to proceed with the construction of an ethane cracker in western Pennsylvania:

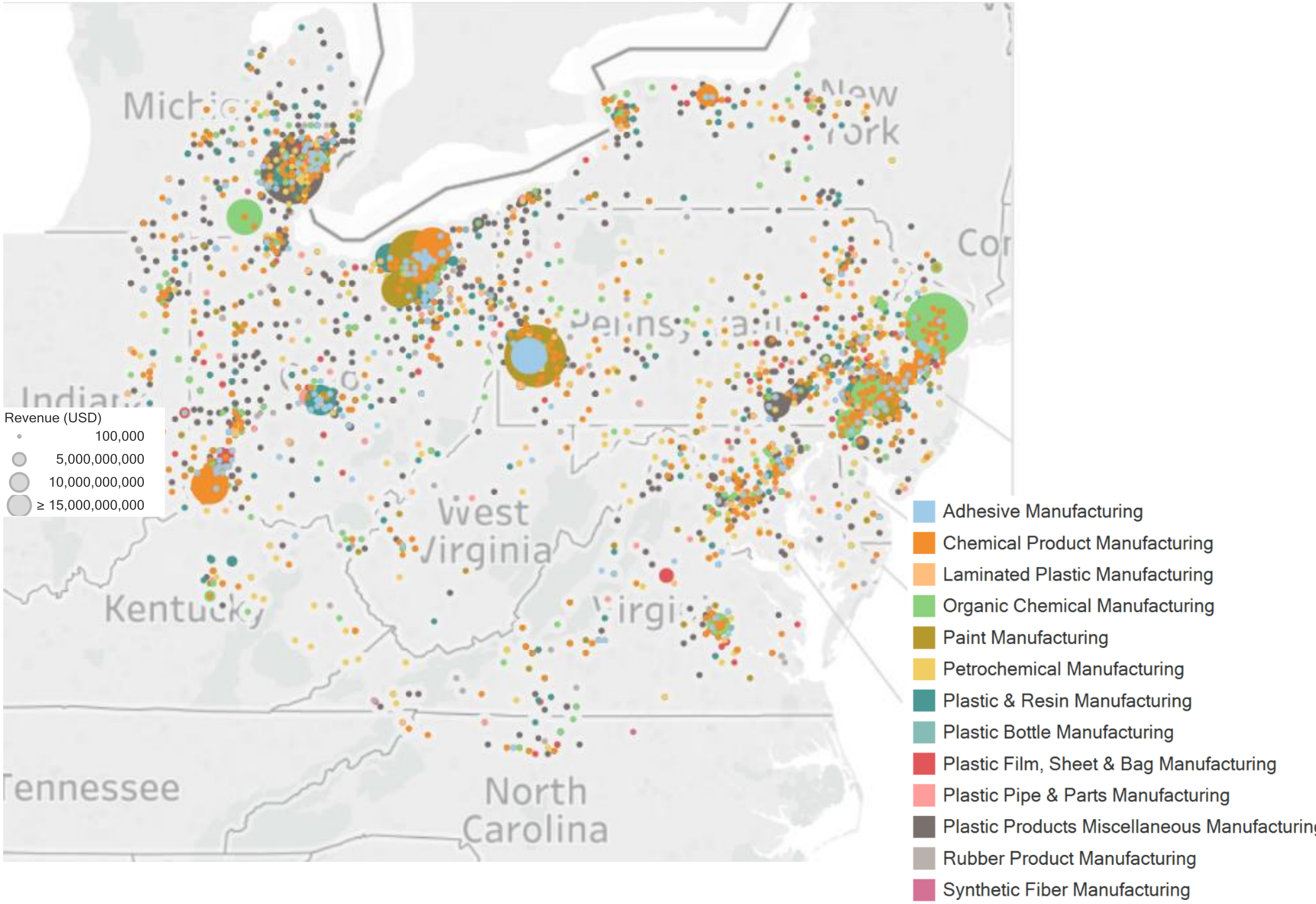
- a cost-advantaged feedstock (upstream),
- market proximity (downstream), and
- strong local support (incentives).[133]

Proximity to downstream markets offers several advantages, including a shorter, more secure, and less costly supply chain. In addition, the ability to quickly access markets not only improves transportation efficiencies, but also offers inventory advantages in that producers can more quickly respond to fluctuations within demand centers. Not to mention that as products achieve their final form, it is often to the advantage of the manufacturer to be located near the point of consumption since there is a higher cost of transportation per ton-mile for bottles, pipes, and other hollow products compared to fluids and even pellets.

This section looks at a region that is within a 300 mile radius of Pittsburgh to explore activity within the industries that comprise the petrochemical sector.[h] Plastic manufacturers and converters within 300 miles of the region are major consumers of petrochemical products generated within and outside the region. The following image depicts the location of the companies and the industry with which they align within the radius in question. The industries depicted represent the 13 that were identified as part of the broader ecosystem (Figure 16) and are important to understanding the petrochemical opportunity in Appalachia.

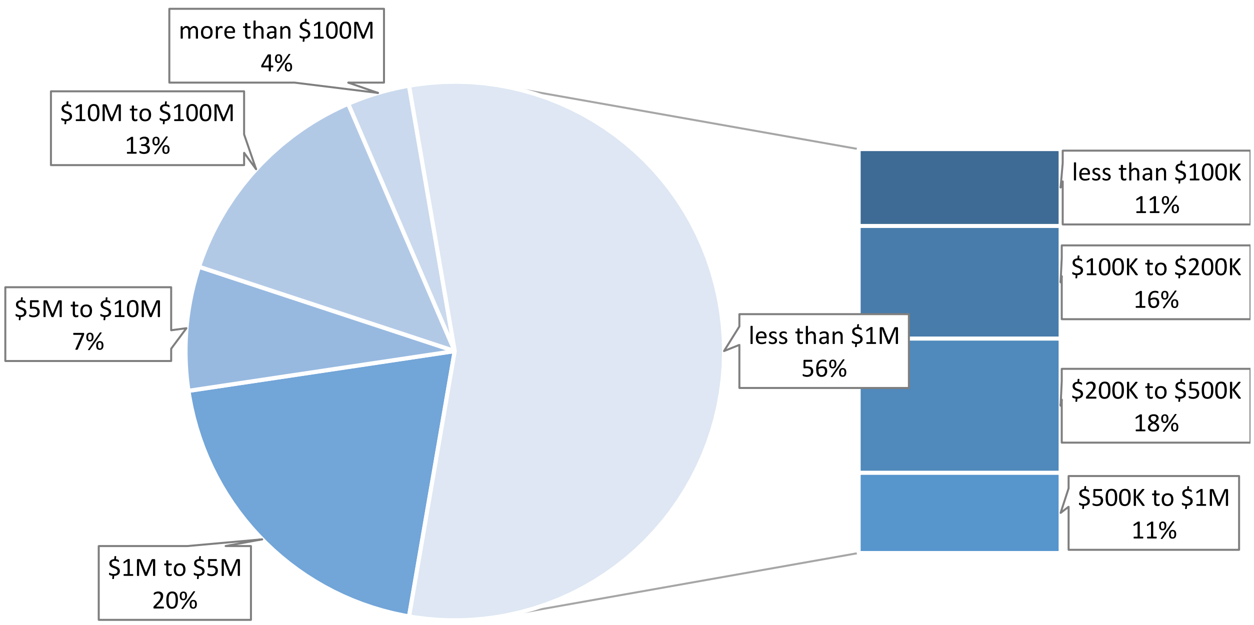
[h] Area includes: Indiana, Kentucky, Maryland, Michigan, New Jersey, New York, Ohio, Pennsylvania, Virginia, West Virginia; 300 miles generally represents the range of same-day / one-day delivery by truck.

Figure 18. Industry Revenue by NAICS code within 300 miles of Pittsburgh, PA[134]



As one might expect, economic activity is largely dominated by the metropolitan areas of Pittsburgh, Cleveland, Detroit, and Philadelphia. Notable companies include PPG Industries, Covestro, Nova Chemicals, Lubrizol, Sherwin-Williams Company, Ashland, Airgas, and BASF. Detroit's $6 billion International Automotive Components Group leads the plastic products manufacturing industry. PPG Industries and Sherwin-Williams Company lead the paint manufacturing industry in Pittsburgh and Cleveland with total revenues topping $25 billion. Lastly, BASF's U.S. headquarters in Florham, New Jersey, leads the organic chemical manufacturing industry with more than $16 billion in revenues. While there are roughly 40 major players with revenues greater than $1 billion within the region, thousands of other establishments span the size spectrum as illustrated below in Figure 19.

Figure 19. Appalachia's Current Cluster Composition by Company Size



Looking at the 13 industries in question, a more detailed analysis of economic activity in the region is tabulated below with specific information related to the portion of economic activity that resides within 300 miles of Pittsburgh, along with a comparison of the region to the Gulf Coast (i.e., Texas and Louisiana). Table 4 lists the revenue, employment, number of establishments of the petrochemical industries in the Appalachian region, and the percentage of each metric compared to the national total.

Table 4. Chemistry Economic Activity in 300-Mile Radius of Pittsburgh [135]

Industry	Region[i] Revenue	% of U.S. Total	Region Employment	% of U.S. Total	Region Establishments	% of U.S. Total
Plastic Products Misc. Manufacturing	$68,274,150,326	34%	250,974	25%	2,092	57%
Organic Chemical Manufacturing	$60,137,686,253	48%	100,310	34%	380	19%
Paint Manufacturing	$44,959,663,610	74%	153,648	74%	382	22%
Plastics And Resin Manufacturing	$38,612,594,411	13%	101,839	22%	501	25%
Chemical Product Manufacturing	$24,779,769,177	45%	77,562	36%	721	19%
Rubber Product Manufacturing	$10,331,054,528	38%	53,269	39%	499	24%
Adhesive Manufacturing	$8,792,104,362	34%	48,093	47%	218	20%
Plastic Film Manufacturing	$8,562,376,647	24%	33,110	25%	341	29%
Plastic Pipe & Parts Manufacturing	$2,753,563,402	30%	11,791	31%	94	24%
Petrochemical Manufacturing	$1,754,859,708	15%	5,522	21%	465	19%
Synthetic Fiber Manufacturing	$1,378,270,210	13%	3,020	18%	45	20%
Laminated Plastics Manufacturing	$1,033,708,202	24%	4,324	24%	112	24%
Plastic Bottle Manufacturing	$984,878,716	21%	23,383	57%	40	17%
Region Total	**$308,814,899,431**	**30%**	**942,737**	**32%**	**7,690**	**31%**
Gulf Coast Total	**$171,097,780,000**	**17%**	**333,220**	**11%**	**2,543**	**10%**

[i] "Region" here refers to the area within a 300-mile radius of Pittsburgh, Pennsylvania.

The numbers above demonstrate Appalachian strength in downstream petrochemical industries. With over $300 billion of net revenue, 900,000 workers, and 7,500 establishments, Appalachia accounts for nearly a third of U.S. activity in 13 petrochemical industries. The organic chemical manufacturing industry provides the highest revenue to the region, with a large portion of the industry sited in Ohio and Pennsylvania. Paint manufacturing, with over 75% of total revenue and employment in the region, is the leading industry, with PPG Industries and Sherwin-Williams located in Pittsburgh, Pennsylvania, and Cleveland, Ohio, respectively.

To better visualize the regional dispersion of revenue and employment the following maps (Figures 20 and 21) look at economic activity in the petrochemical industry by Appalachian ZIP Code™. Darker shades of green represent larger petrochemical revenues for a particular locality in the first figure below; darker shades of green represent more petrochemical employment on the second figure.

Figure 20: Petrochemical Revenue in Region

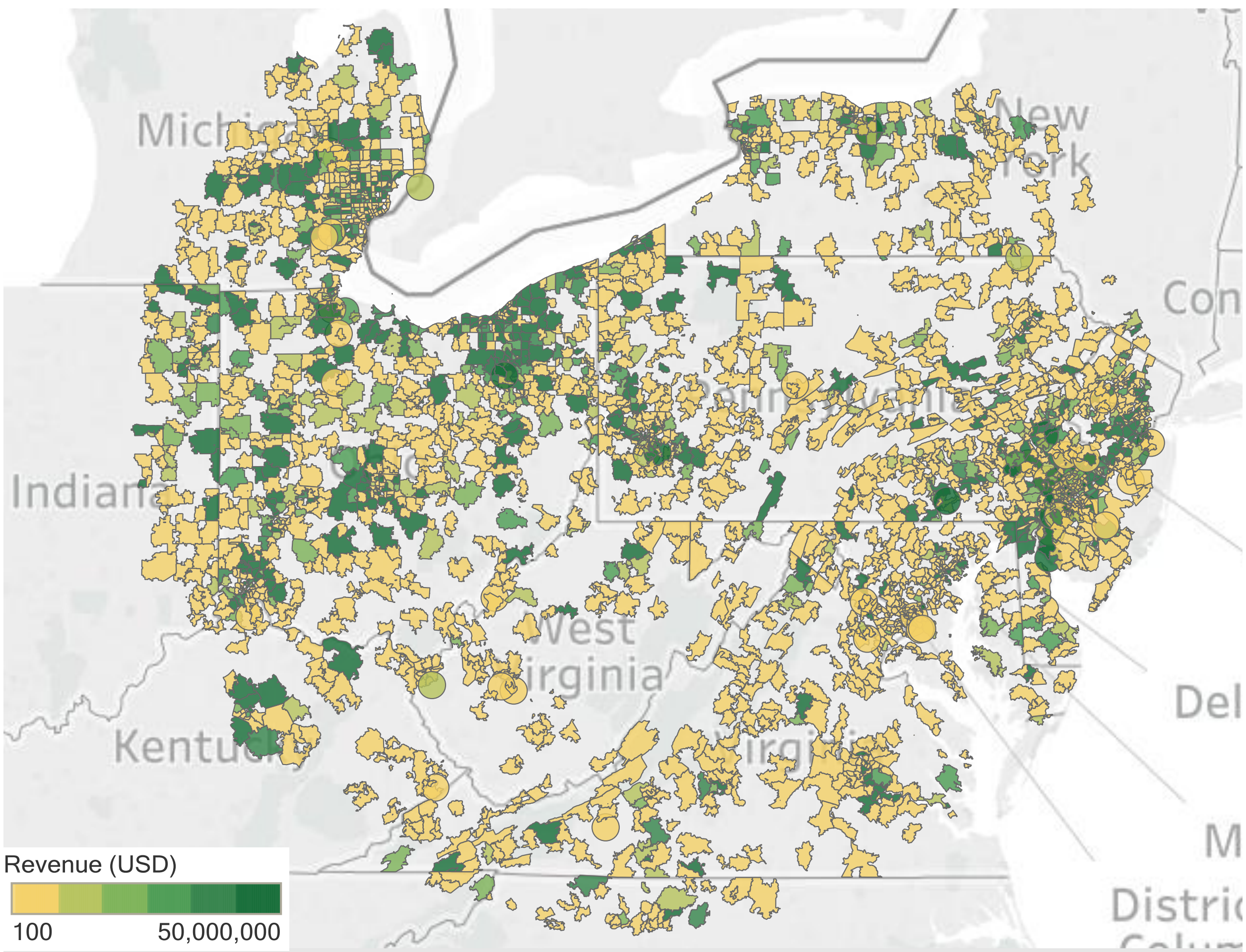
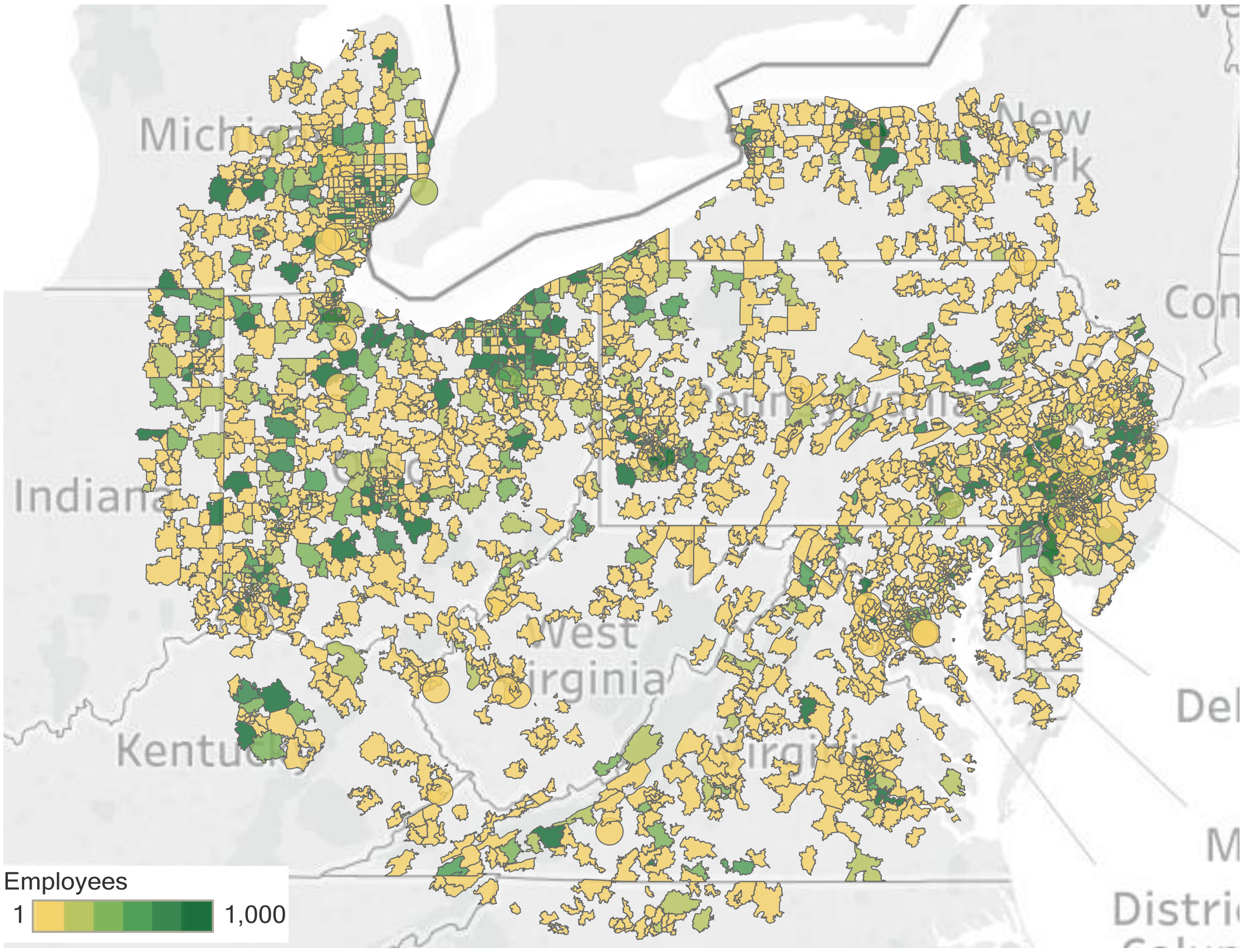


Figure 21: Petrochemical Employment in Region



E. *Economic Drivers*

A buildout of the petrochemical industry near production from the Appalachian basin could create significant economic benefits to the region. Ethane production from the Marcellus and Utica plays may be significant enough to support about four world-scale petrochemical crackers with capacities over 1 million metric tons per year of ethylene production. These facilities could then spur further investments and economic activity downstream, by manufacturers that benefit from the availability of low-cost inputs nearby. Macroeconomic drivers will influence the region's evolution, as the opportunity at hand is a regional one with global implications. In addition, microeconomic factors will determine the success of individual entities within the competitive landscape as discussed below.

1. Macroeconomic Drivers

Trade-weighted Index. The strength of the U.S. dollar relative to other currencies will impact trade decisions around the world. A strong U.S. dollar makes American products more expensive to international markets. Commodity customers are particularly price sensitive and in the case of chemicals and plastics, a small change in price can have a large impact on demand. With little product differentiation, plastic and chemical consumers are motivated to source their material from the lowest-price market, which is not only a function of production costs, but also the trade-weighted index, which is trending down over the past year but has climbed approximately 20 percent over the past 5 years.[136]

Industrial Activity. Global consumption of natural resources is largely a function of the degree of industrial activity around the world. As it relates to natural gas and petrochemicals, the consumption that stems from industrial activity includes heat, power, and products. To measure domestic industrial activity, the industrial production index (IPI) is used to forecast demand across core industrial sectors so that upstream counterparts are prepared to respond accordingly. The current IPI suggests an upward trend, which would indicate that industrial production activity is increasing, which may intensify competition for resources that can serve as either fuels or feedstocks.[137]

Construction Activity. The construction sector is a major consumer of petrochemical products including plastic materials and paint. Consequently, an increase in construction activity will cause demand for petrochemical products to rise. The degree to which construction activity increases is largely dependent on factors such as population growth, government expenditures on infrastructure projects, and interest rates. As it relates to Appalachia, an increase in industrial activity would require new construction projects that would serve as a source of demand for Appalachian derived chemicals and plastics: a virtuous cycle. Both industrial activity and construction activity are likely to be impacted by the recent tax bill and specifically lower corporate tax rates. The extent to which companies choose to reinvest funds in the form of physical assets could have a material impact on U.S. industrial and construction activity.

World Price of Crude Oil. Raw hydrocarbon materials are the basis of the petrochemical industry cost-structure. Petroleum naphtha (a crude oil derivative) serves as a major input to the petrochemical process, and as such, downstream products are price sensitive to changes in the price of oil. The surge of low-cost natural gas has positioned ethane as an economical alternative to naphtha in many markets. The spread between oil and natural gas prices will have an impact on the feedstock of choice for the petrochemical sector.

Price of Inputs. Across the 13 petrochemical industries discussed in this section, raw materials are the largest cost incurred and amount to roughly half of the revenue generated by each industry. In 2012 feedstock costs were over 60 percent of revenue as natural gas and oil demand outpaced supply resulting in higher prices.[138] When the price of inputs changes, manufacturers may attempt to pass the cost increase to downstream consumers. In a competitive market, however, manufacturers may be unable to pass through costs without pricing their product out of the market. In these cases, access to a predictable low-cost feedstock is imperative to long-term competitive success.

2. Key Success Factors

The aforementioned drivers and factors listed below that are more likely to affect the evolution of the Appalachian ecosystem were determined by reviewing detailed IBISWorld reports for each of the industries in question.[139] The drivers and factors identified in each report were aggregated across all industries in an effort to identify those that were the most prevalent with the top five macroeconomic drivers and microeconomic factors being selected for presentation. The sections that follow represent a distillation of the insight presented across those reports that elevated the following items as being important to the industry.

Economies of Scale and Vertical Integration. Capital-intensive industries often aim to achieve economies of scale to reduce variable costs and improve operational efficiency, which in turn offsets the high fixed costs of the facility. Beyond operational advantages, companies that buy inputs at bulk prices minimize procurement costs. In addition, buying in bulk also helps companies mitigate market fluctuations related to its chemical inputs. Some companies scale across the value chain in the form of vertical integration, which allows them to cut costs by sourcing their own specialty products internally. Through vertical integration, companies can gain up- and downstream profit margins, widening the gap between them and competitors.

Innovation. New technology can enable manufacturers to achieve a competitive advantage by achieving higher outputs at a lower cost. In a highly competitive industry, having the ability and agility to adopt new technology can give manufacturers an edge to reduce costs and gain higher margins. To differentiate oneself in either product or process requires targeted research to develop new, cost-effective methods of processing and converting petrochemicals into their end use. While much of the research performed by the petrochemical sector is performed in-house, Appalachia is home to a variety of institutions that are positioned at the leading edge of natural gas conversion research.

Effective Cost & Quality Control. Effective cost controls can also help companies maintain a competitive advantage over other firms in the industry. Maintaining consistent production and inventory levels allows companies to maintain steady selling costs. In addition to effective cost controls, producing high-quality products is essential in industries with price-conscious consumers. Any deviation in quality may cause a producer to lose sales, particularly in industries with high concentrations of similar products (i.e., commodities).

Contracts for Key Inputs and Outputs. The petrochemical industry is highly reliant on a consistent supply and fair price of upstream inputs, such as chemicals, plastics, and resins. Contracts with key suppliers help maintain cost consistency, which is essential to maintain predictable profits. Like supply contracts, output contracts are important to maintaining sustainable returns in a dynamic market. Contracts that lock in favorable spreads between inputs and outputs enable companies to make confident investment decisions in an evolving market.

Competitive Differentiators. Since there is little differentiation among petrochemical products, companies seek ways to differentiate themselves. The provision of exceptional after-sales service is one such way a company can deliver additional value to its customers and maintain market share in a highly competitive landscape. Optimal capacity utilization is another differentiator that impacts competitive positioning within the petrochemical space. Operators must run their facilities as close to design capacity as possible while maintaining flexibility to respond to unforeseen fluctuations in the market.

VI. Market Analysis for Appalachian Petrochemicals

A. *Methodology*

Section VI utilizes the ICIS Supply and Demand Data Service (Data Service) for estimated historical and projected future capacity, production, consumption, and trade volumes for the ethane value chain including ethylene, ethylene dichloride, ethylbenzene, ethylene glycols, ethylene oxide, high density polyethylene, low density polyethylene, linear olefins, and linear low density polyethylene.[140] Two types of facilities are included by the Data Service:

- Specific facilities, which are those that are existing/known or expected based on developer announcements and Data Service analysis, or
- Unspecified facilities, which are projected and thought to be economic but without connection to an identified or announced facility or project.

Capacity data for specific projects may have geographic granularity below the country level (e.g., state or province), and unspecified capacity additions are included on a country basis. The scenarios discussed later in this section consider the influences on the possible future locations of the unspecified capacity (e.g., Appalachia, U.S. Gulf Coast, or elsewhere), though the Data Service does not project below country level for these projects. Production, consumption, and trade data are estimated by country or global regions that combine nearby countries.

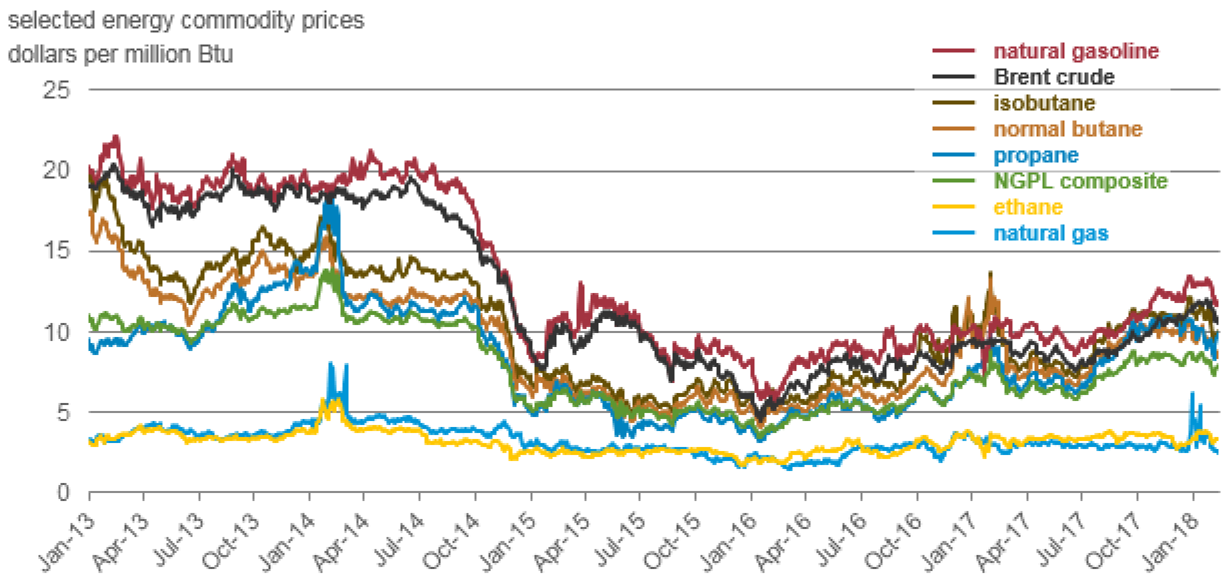
Demand for end-user products drives petrochemical consumption. As projected consumption rises over time driven by global population growth and economic development, production will first come from higher utilization of existing and expected capacity. Eventually, capacity additions beyond those expected will also be economic, resulting in unspecified capacity.

B. *Current State and Potential Future*

1. Domestic Market

Petrochemicals derived from NGLs have gained market share relative to oil-based petrochemicals as natural gas and associated NGLs prices have trended lower than crude oil derived feedstock. As shown in Figure 22, natural gas and ethane prices are relatively lower than prices for other NGLs. Even though the global oil price decline in 2014 also brought down the prices of the heavier NGLs, ethane retained its price advantage. Furthermore, this advantage is expected to remain in place into the future.

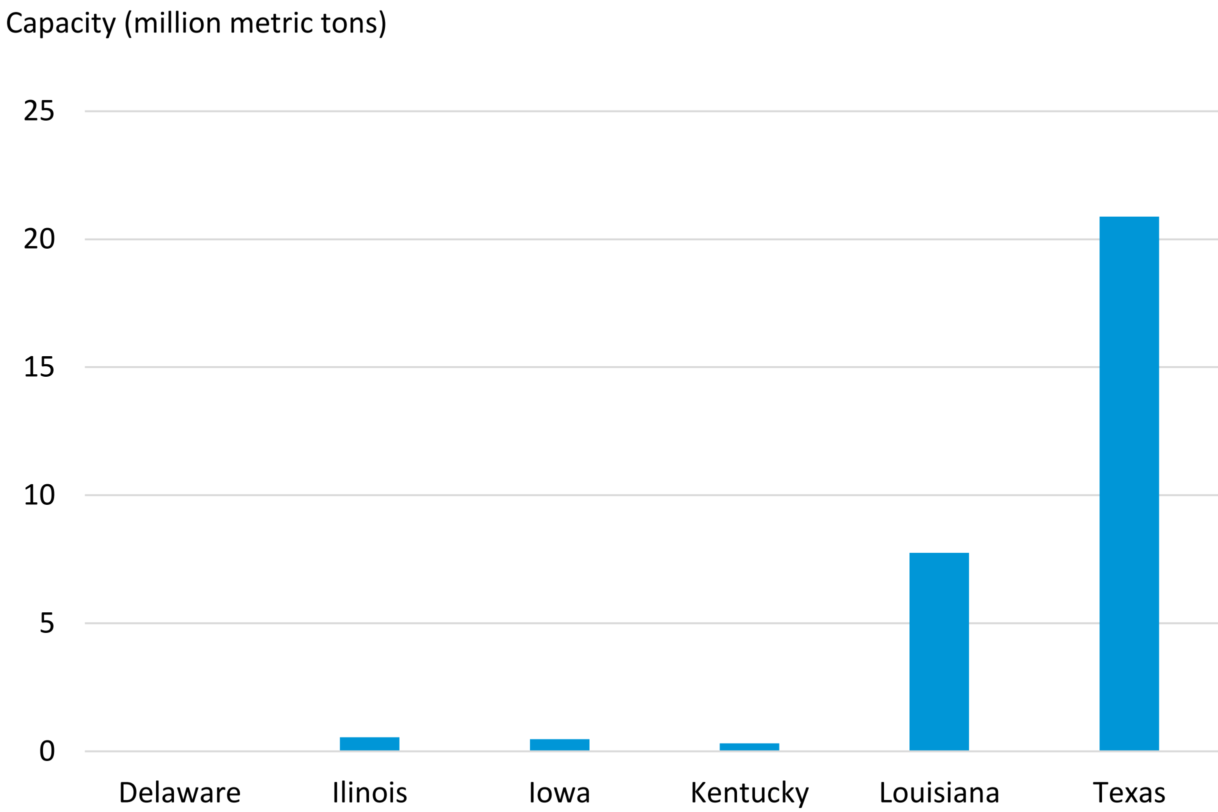
Figure 22. NGL Prices Compared to Crude Oil and Natural Gas[141, j]



Given its long history of production of both crude oil and natural gas, the U.S. Gulf Coast has built over time an extensive cluster of processing facilities and transport infrastructure. Among the Gulf Coast processing facilities, there are not just oil refineries but also petrochemical plants. Figure 23 illustrates the dominance the region has in U.S. ethylene production capacity. Of the 30 million metric tons (MMmt) of capacity, 70 percent is in Texas alone, and 95 percent is in Texas or Louisiana.[142]

[j] All prices are daily end-of-day spot prices; natural gas is Henry Hub, and NGL components are Mt. Belvieu. Natural Gas Plant Liquid (NGPL) Composite calculated based on calorific contribution of each purity to total NGPL barrel heat value.

Figure 23. Ethylene Production Capacity by State in 2017[143]

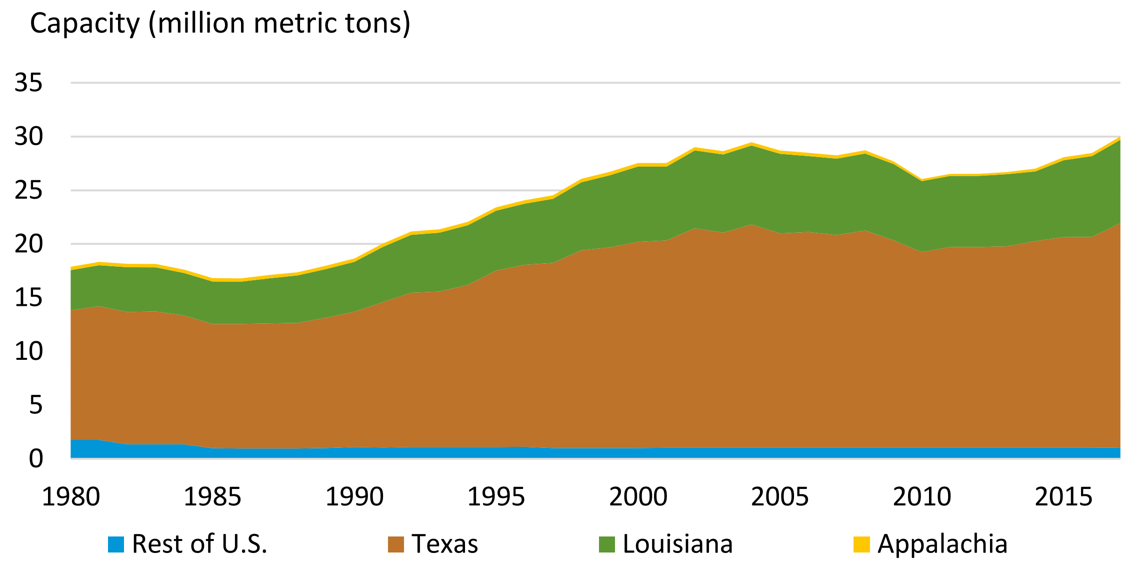


Including capacity for other facilities along the ethane value chain changes the distribution picture only slightly. Of the 76 MMmt of capacity for processing the ethane value chain in 2017, 63% are in Texas alone, and 96% are in Texas or Louisiana.[144, k]

Capacity for the production of the ethane value chain has also generally increased over time, particularly for ethylene production. Capacity declines occurred only during the oil downturn of the mid-1980s and the global recession leading into the 2010s. Figure 24 shows the capacity over time through 2017. The figure also shows the significant presence of Texas and Louisiana in the overall capacity mix over time.

[k] Ethane chain refers to the base and derivative petrochemicals ethylene, ethylene dichloride, ethylbenzene, ethylene glycols, ethylene oxide, HDPE, LDPE, linear olefins, and linear low-density polyethylene (LLDPE).

Figure 24. Historical Ethylene Production Capacity in the U.S.[145]



As the economics for petrochemicals have shifted to NGL feedstock from oil-based feedstock, the configuration and investment in the Gulf Coast have also shifted. With the synergies and benefits of the existing cluster, much of the incremental capacity for petrochemicals production is appearing in the Gulf Coast. For example, between 2004 and 2016, every new steam cracker in the U.S. was built in either Texas or Louisiana.[146] When including petrochemical facilities that produce derivatives of ethylene, the dominant locations continue to be in Texas and Louisiana.

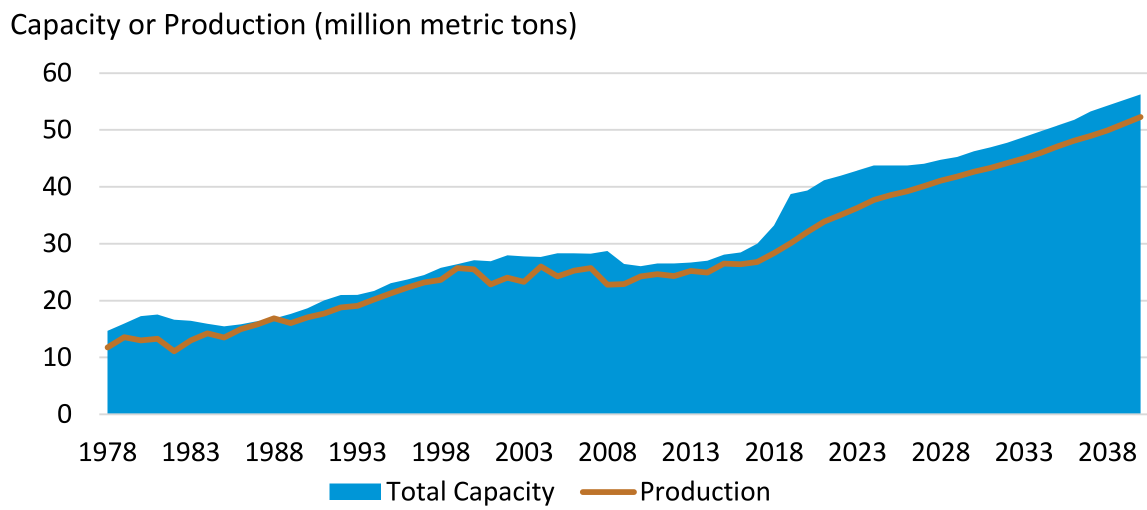
The expansion in the Gulf Coast does not mean there was no development elsewhere. In Appalachia, substantial gas processing and fractionation capacity has been added along with pipelines for both natural gas and NGLs, as described in Section IV of this report. The new infrastructure is concentrated on facilitating natural gas and NGLs production rather than on petrochemicals. Without an existing petrochemical base in the region and until confidence in a stable supply of feedstock such as ethane was established, investments in a steam cracker would have been premature.

In a step toward a petrochemical cluster in Appalachia, the Shell Chemicals ethane cracker and polyethylene plants began construction in 2017 in Potter Township, Pennsylvania. That plant could bring 1.6 MMmt per year of polyethylene production to the area.[147]

The future geographic distribution of ethylene production capacity remains to be seen, but the general expectation is for an increase in capacity and production of ethylene and associated petrochemicals. Besides the regional price and availability of feedstock, a variety of other factors can also influence the buildout. For example, financial incentives such as tax abatements or tax credits can play a role. The availability of a skilled workforce, access to the supply chain, the local market and access to other markets, funding costs, and many other considerations and risks (real or perceived) can influence any individual project decision.

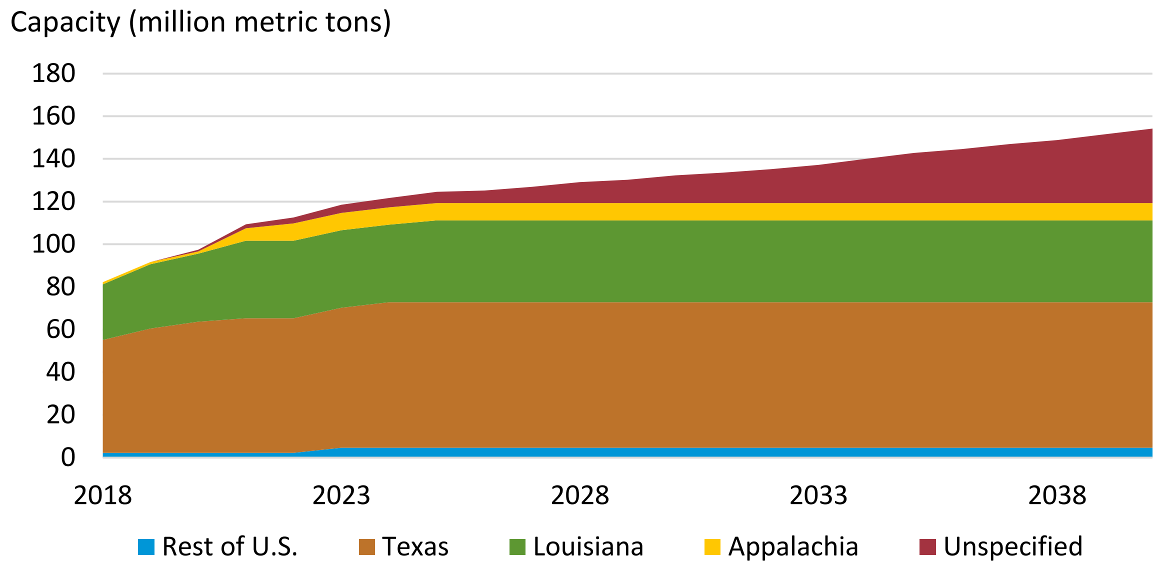
Figure 25 below illustrates the historical and projected U.S. production of ethylene along with historical and projected capacity.[148] Production is expected to nearly double by 2040 from 2017 levels. Over the same period, capacity is expected to increase nearly 90 percent, pushing average utilization up to the low 90 percent range from as low as just under 80 percent in 2019 when new capacity currently in development is expected to come online.

Figure 25. Historical and Projected Ethylene Production and Capacity in the U.S.[149]



A portion of projected additional capacity and production is based on projects proposed or already under construction. Contributions from these projects are concentrated in the near-term. These projections also include expected capacity increases from future projects not yet identified. From 2018 to 2025, total U.S. ethane value chain production capacity is estimated to increase more than 42 MMmt (51 percent increase).[150] Of that additional capacity, 65 percent is expected in Texas or Louisiana and 17 percent in Appalachia.[151] From 2026 to 2040, ethane value chain production capacity is projected to increase almost 30 MMmt (23 percent increase), with all of the incremental capacity from yet unspecified facilities.[152] Figure 26 illustrates the projected capacity growth.

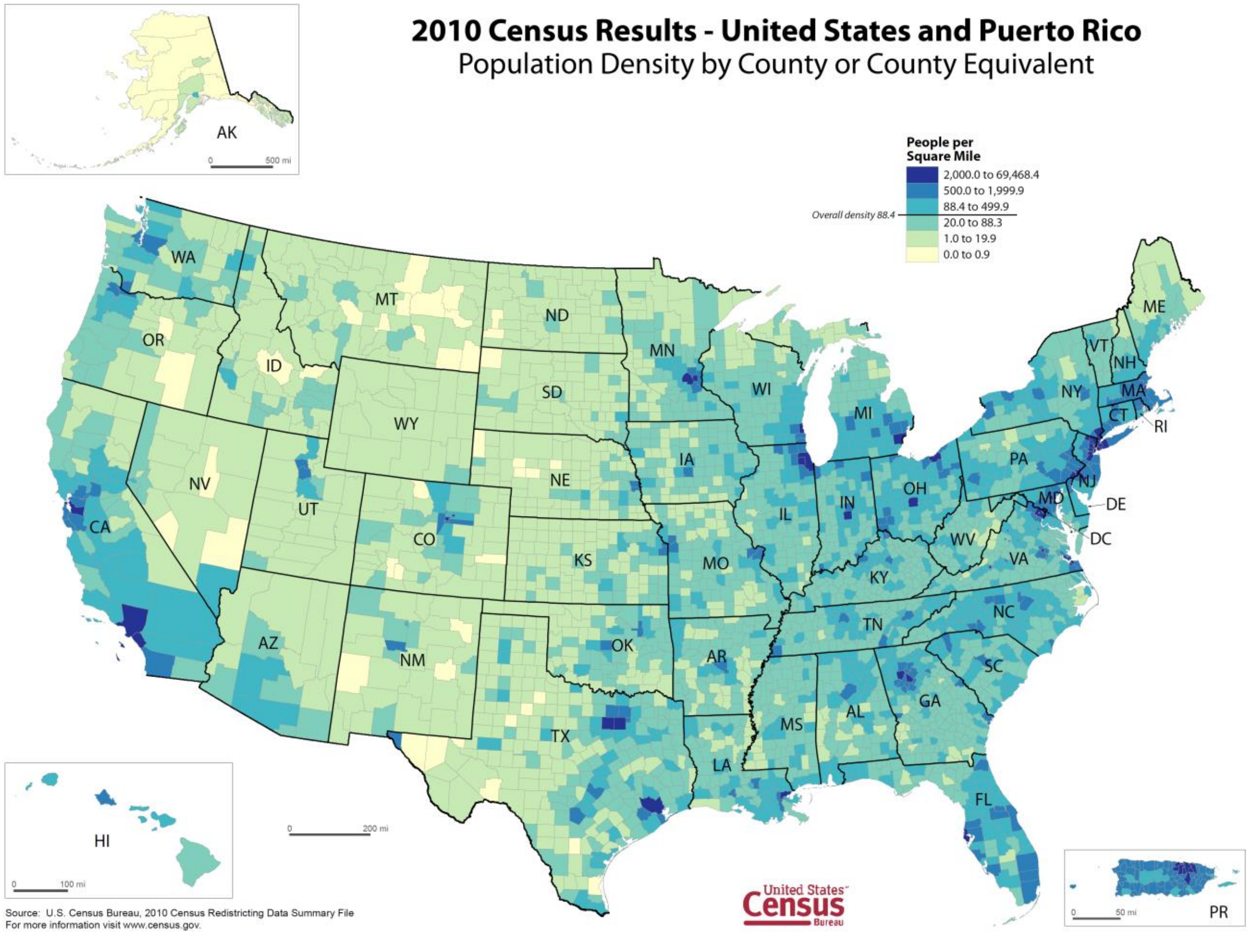
Figure 26. Projected Ethane Value Chain Production Capacity in the U.S.[153]



Incremental gains in ethane value chain production capacity after 2017 represent significant economic opportunity. Revenues projected from incremental petrochemical capacity growth (as depicted in Figure 26) between 2018 and 2040 total nearly $716 billion.[154] The projected revenues from the "unspecified" capacity additions total nearly $227 billion between 2018 and 2040.[155]

Demand for petrochemicals, particularly the derivatives, is generally less concentrated than the supply. For example, a greater number of manufacturing operations across the country make use of petrochemicals, such as the various types of PE, than there are PE producers and facilities. In the ethane value chain, PEs (such as HDPE, LLDPE, and LDPE) make up a significant proportion of the total output. Many of the uses of PEs (e.g., films, bags, food packaging) are highly correlated with population. Therefore, population density can be a proxy for general PE-based product demand. Figure 27 illustrates the U.S. population density based on U.S. Census data.[156]

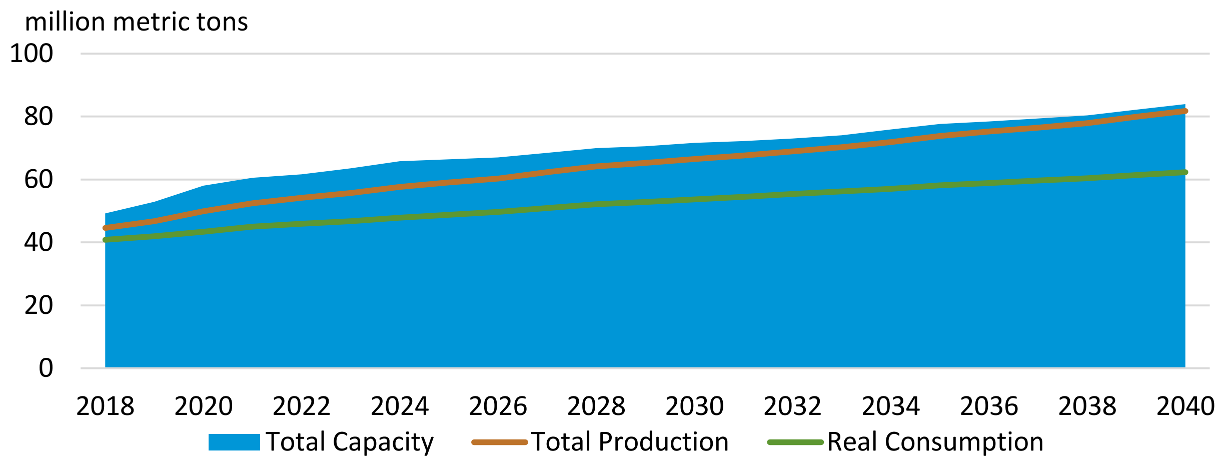
Figure 27. U.S. Population Density by County[157]



Although the vast majority of the PE production capacity is in the Gulf Coast, clearly the population is more distributed. With sufficient NGLs-based feedstock supply in Appalachia, the region may be able to produce petrochemicals in closer proximity to significant areas of demand such as the Midwest, Mid-Atlantic, and the Northeast.

The demand for many products made out of petrochemical feedstocks is closely tied to population. As shown in figure 28, the rise in production capacity of petrochemicals is expected to outgrow domestic demand. If the industry seeks to avoid a reduction in average utilization, surplus ethylene derivatives supply will need to find export markets.

Figure 28. Projected Total Capacity, Total Production, and Real Consumption in the U.S. for Ethylene Products[158, l]



The export outlets and international market destinations of products will join with other factors in guiding the development of future capacity. The development of new petrochemical capacity in Appalachia is not necessarily in conflict with Gulf Coast expansion. The Gulf Coast has existing capability for export; Appalachian capacity may serve regional demand for NGLs derivatives, freeing up Gulf Coast production for other markets, including exports overseas.

At the same time, Appalachia has proximity to domestic demand centers and potential export points on the mid-Atlantic coast and into Canada. Northern European destinations may be more easily served out of the East Coast versus the longer routing from the Gulf Coast. Pacific Basin and South American destinations may favor Gulf Coast exports. With exports expected to play an ever larger role in the domestic petrochemical industry, U.S. competitiveness relative to the rest of the world becomes increasingly important.

2. International Market

Global Supply. Worldwide ethylene production capacity is not nearly as geographically concentrated as in the U.S. While there are several regions with significant ethylene production capacity, there are still areas with limited facilities. Northeast Asia, which includes China, Japan, and South Korea, had the largest capacity in 2017 with 44 MMmt.[159]

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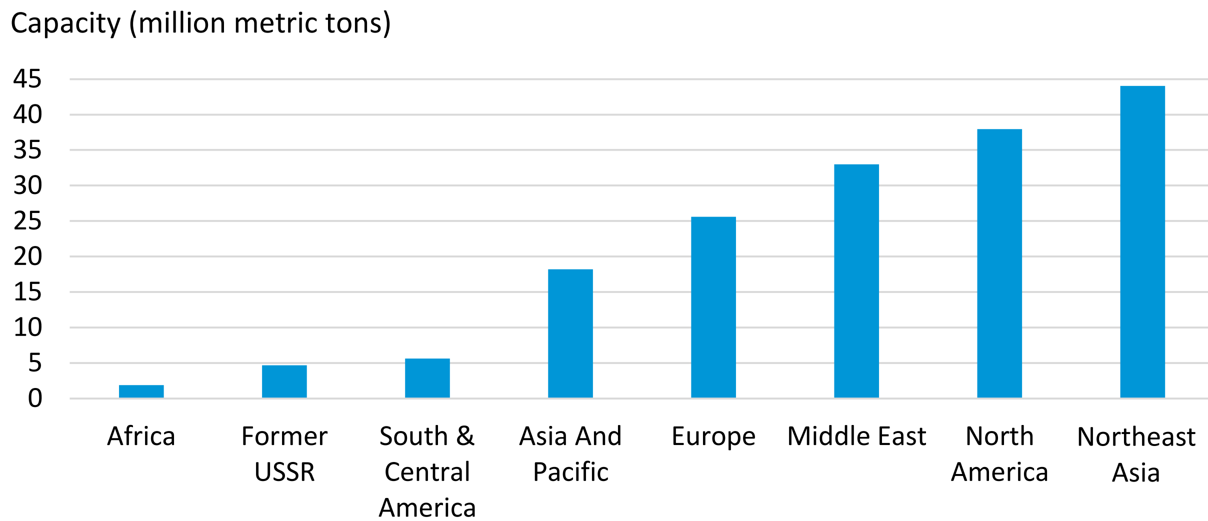
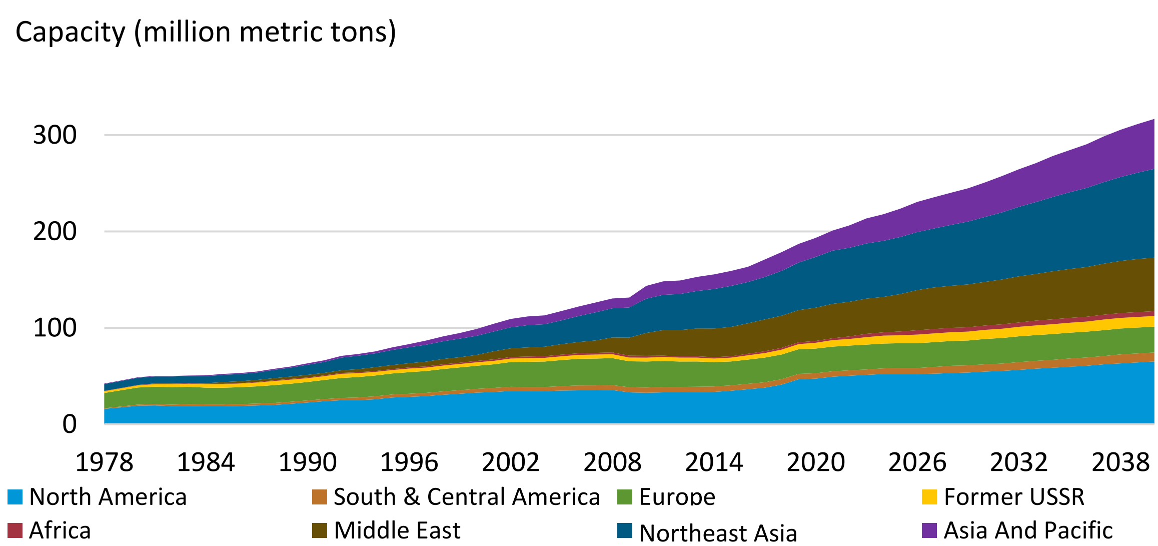
[l] Includes ethylene dichloride, ethyl benzene, ethylene glycols, ethylene oxide, high-density polyethylene, low-density polyethylene, linear olefins, and linear low density polyethylene. Real consumption refers to domestic consumption and does not include exports.

Figure 29. Ethylene Production Capacity by Global Area in 2017[160]



As shown in Figure 30, Northeast Asia has not always led the world in ethylene production capacity. From 2008 to 2017, global ethylene production capacity grew 31% from 130 MMmt to over 170 MMmt.[161] Over the same period, Northeast Asia grew 46%, from 30 MMmt to 44 MMmt, while overtaking North America.[162] Overall, strong growth is expected to continue with global capacity for ethylene production projected to grow 31% from 2017 to 2025 and a further 37% from 2026 to 2040. Northeast Asia and Asia & Pacific (which includes India) are expected to contribute significant growth. The Middle East, driven by feedstock availability, has grown its ethylene capacity substantially, more than doubling from 2008 to 2017 with expectations for continued expansion.[163]

Figure 30. Historical and Projected Ethylene Production Capacity by Global Area[164]

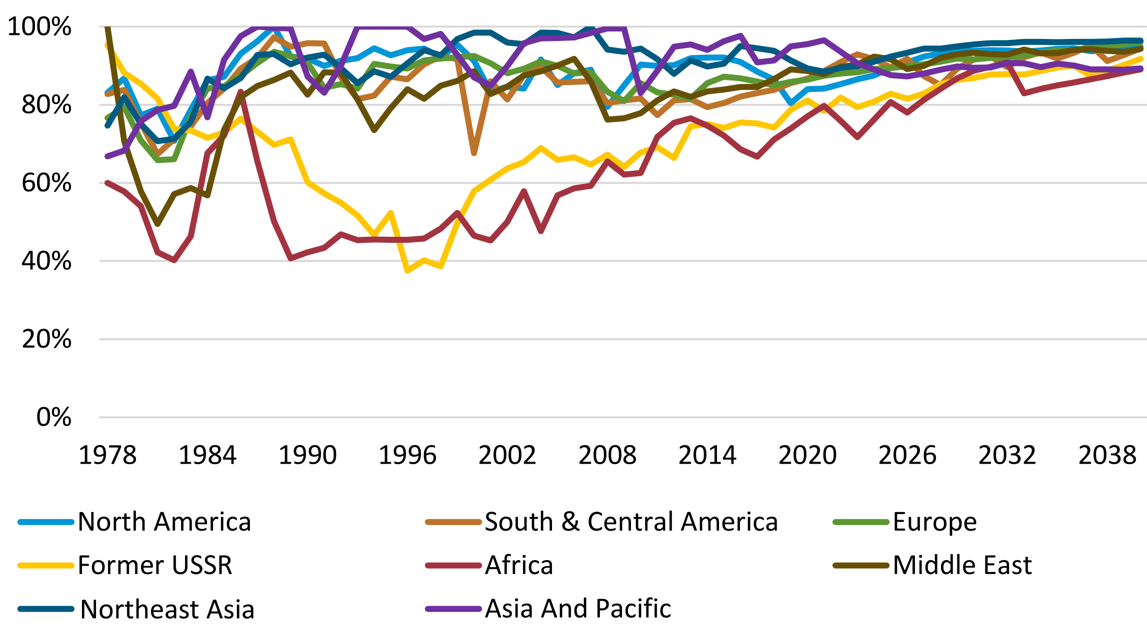


While ethylene capacity has grown generally over time, there have been some periods of capacity decline, usually during or after overall economic slowing or contraction. Just as capacity has increased generally over time, so has production, with the areas of largest capacity also producing the most.

Reliable, reasonably priced feedstock supplies of ethane and propane can drive future growth. China and other Asian countries with projected strong economic growth show the largest potential for petrochemical production. The U.S. could potentially increase its share in the petrochemical market place with its abundant supply of shale oil and natural gas providing a reliable and continued supply of NGLs.

Exports of U.S. petrochemical derivatives may face a challenge from global capacity surplus and oil-based derivatives resulting from expected supply of naphtha at stable prices over the next five to ten years (see Figure 31). The lower projected capacity utilization will also exert downward pressure on ethylene production and cost competitiveness in the global markets. Over the longer timeframe, this reduction in utilization is expected to reverse as growth in demand takes up slack in capacity for derivative production.

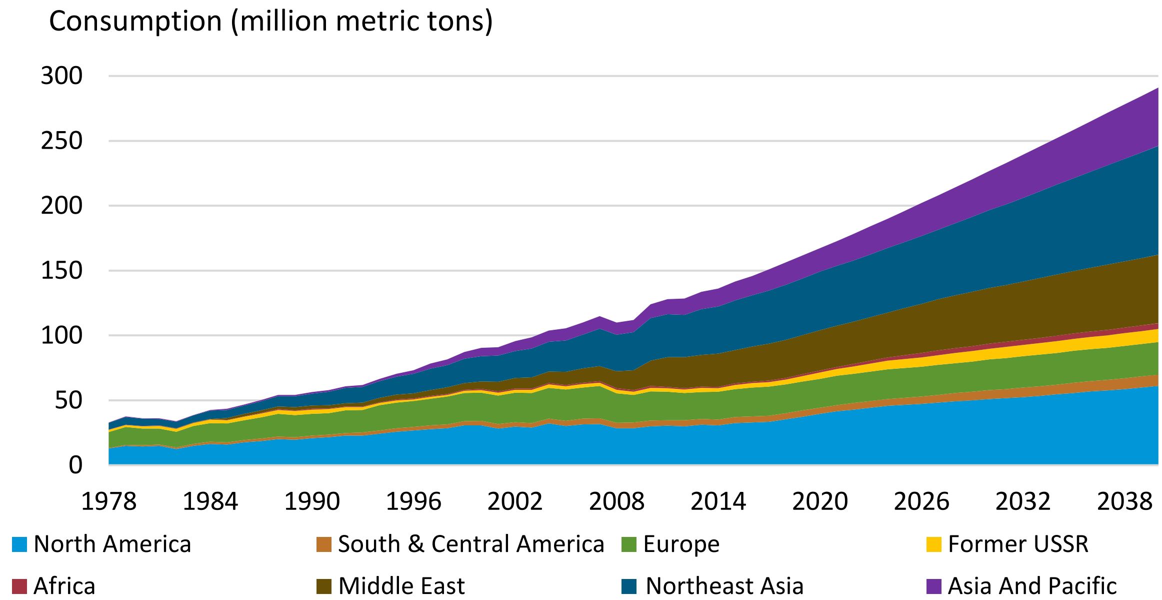
Figure 31. Historical and Projected Capacity Utilization for Ethylene Production[165]



On a global basis, feedstock for ethylene production can vary widely. Abundant quantities of ethane from shale gas in the U.S. are driving domestic ethylene production toward using the lighter feedstock. The Middle East is experiencing declining natural gas availability and is utilizing more liquid-based crackers that are integrated with their refinery operations. Europe and Asia are looking to increase feedstock flexibility with crackers with ethane feedstock capability besides the more traditional naphtha-based crackers.

Global Demand. Total world demand growth for ethylene is shown in Figure 32 below. Certain areas are expected to be in surplus while others in deficit. Overall comparisons of capacity to consumption may show limited differences, as the volume of projected trade in ethylene is generally low relative to the total capacity or consumption numbers. The transport of derivative petrochemicals is expected to be larger than for ethylene.[166]

Figure 32. Historical and Projected Ethylene Consumption by Global Area[167]



C. *Considerations for Future Infrastructure Development*

The following discussion outlines three potential paths future infrastructure development could follow. The paths are influenced by several factors, including: global capacity expansion, global demand growth, international aggressiveness in pricing for market share, domestic production trends, capital market preferences, domestic regional incentives, and technological change, among others. Underlying each scenario is the general assumption that shale production and the related supply of natural gas and NGLs for petrochemical feedstock will continue to grow and that the Marcellus and Utica shale plays will make major contributions to total domestic supply. The scenarios that follow focus on where the processing will predominantly occur.

In Scenario A, development of a petrochemical cluster in Appalachia is assumed to increase such that much of the incremental Appalachian supply is processed "locally." In Scenario B, the focus on continued development in the existing cluster of the Gulf Coast is assumed. Lastly, in Scenario C, incremental processing is assumed to occur elsewhere, facilitated by exports of the feedstock.

1. Scenario A: Processing in Appalachia

This scenario assumes industry individually pursues a partial or complete build out of a new petrochemical supply chain in the Appalachian region. The supply chain scope and the overall size would be smaller and less comprehensive than seen currently in the Gulf Coast. Under this scenario, the local and regional capital investment would be largest among the three scenarios. For this scenario to develop, the expected benefit would need to be compared to and outweigh the cost, both tangible benefits and otherwise.

Initial investment and infrastructure. The required investments to build a petrochemical hub in Appalachia would be significant. For example, Shell Chemicals' ethane cracker under construction in Pennsylvania is reported to cost $6 billion.[168] The new infrastructure would include gathering lines, processing plants, fractionation facilities, NGLs storage facilities, ethane crackers, and then some combination of plants for polyethylene, ethylene dichloride, ethylene oxide, and other infrastructure. It is likely that without building petrochemical plants that serve as demand for all components of the NGLs stream, some NGLs would still be transported out of the region. This would be more likely in the initial years as the petrochemical complex first develops.

Growth in the petrochemical industry would also impact other industries, and additional required supporting infrastructure would be needed. For instance, increased electricity demand could require additional power plant capacity; increased truck traffic could impact existing road infrastructure. These impacts could be mitigated to some degree through coordinated planning and infrastructure development.

New and expanded transportation infrastructure would be especially important to move intermediate or end use products from Appalachia to markets in the Midwest, Gulf Coast, Canada, or Northeast for consumption or export. These transportation systems would need to be created and/or expanded. New suppliers and contracts would have to be established.

The required large capital investments highlight the need for coordination across the petrochemical industry since their products are all highly interdependent on feedstock provided by others. Major petrochemical facilities take years to construct, and for the investments to make economic sense, the necessary market demand needs to exist when new plants come online.

Regional vs. national economic growth. Under this scenario, the economic benefit from significant growth in the petrochemical sector would be concentrated in Appalachia through jobs creation and economic multipliers, and this would benefit neighboring markets as well. For example, the Midwest could benefit from lower prices for delivered plastics; producing and processing ethane in Appalachia using new, more efficient plants and shorter transportation distances to the Midwest than from the Gulf Coast could lower costs and environmental impact. A new Appalachian petrochemical supply area would also be closer to demand in Ontario and other exports markets via marine transport, including Europe.

Security and supply diversity. Adding a new petrochemical supply source would improve the security of supply for market areas in the Midwest and potentially across the U.S. Adding another petrochemical cluster would increase the geographic diversity of petrochemical supply, which would be able to supply markets in case of supply interruptions in other regions. Development of an Appalachian cluster is not necessarily in conflict with Gulf Coast expansion, since Appalachian capacity may serve regional demand for NGLs derivatives, freeing up Gulf Coast production for other markets, including exports overseas.

2. Scenario B: Processing in the Gulf Coast Region

This scenario assumes a focus on building out gathering and gas processing plants to separate and ship out purity NGLs products rather than building out a local petrochemical industry. Increased NGL production would require new pipelines and possible new marine export terminals to be built to take NGL supply to the Gulf Coast and export markets, and these market opportunities would help expand capacity to handle greater feedstock volumes. The finished petrochemicals (e.g., plastic pellets, etc.) are then shipped back to the Mid-Continent/Mid-Atlantic or exported via the Gulf of Mexico. As such, this would increase the reliance on using chemical manufacturing at existing industrial centers in the Gulf Coast region.

Initial investment and infrastructure. Scenario B would result in considerably less regional investment in Appalachia. Under this scenario, most of the initial investment in Appalachia would concentrate on Y-grade (NGL mixed product) pipelines and storage capacity. The new transportation infrastructure would connect to existing infrastructure in the Gulf Coast (e.g., pipelines, fractionation, storage, petrochemical facilities, transportation, etc.). Growth of Gulf Coast petrochemical production capacity ramps up with the new purity product supply, affecting local markets and the labor pool.

Regional vs. national economic growth. In this scenario, economic growth would be split between Appalachia NGLs production and processing and Gulf Coast petrochemicals production. The construction of storage and pipeline infrastructure would provide increased economic activity initially, which would be followed by the gains from increased production. In the Gulf Coast region, the increase in NGL supply and associated increase in petrochemical manufacturing capacity would raise economic output and labor employment.

Security and supply diversity. In this scenario, there would be less U.S. security of supply for plastics markets since the Gulf Coast would continue to be the center for most petrochemical plants. Supply disruptions caused by hurricanes or other factors could impact the petrochemical supply chain across the country.

3. Scenario C: Processing Internationally

In this scenario, purity NGL products would be shipped from Appalachia for processing elsewhere. This scenario assumes that these shipments would be more distributed internationally to take advantage of existing, but underutilized, petrochemical processing capacity which has been idled due to high feedstock prices and competition for low cost suppliers from the Middle East. New pipelines and marine export terminals would be required to take Appalachian NGL supply to a variety of foreign processing and consumption centers. Exporting abroad would allow Appalachia producers and shippers to take advantage of existing underutilized European petrochemical capacity and European naphtha crackers which are now being converted to use the cheaper and more abundant ethane as feedstock.

Initial investment and infrastructure. Initial investments would focus on pipelines to move NGLs to Canada for plastics production and to East Coast ports for export to Europe. Existing port capacity may be constrained, requiring expansion, which may not be possible for some locations. Ports would likely need upgrades in order to efficiently handle the expanding flow of NGLs. Availability of suitable transport ships that meet port specifications may also be limited, at least initially.

Regional vs. national economic growth. In this scenario, economic growth would be more distributed with the investments required being more widely dispersed and of an overall lower level than the buildout of new U.S. petrochemical facilities. The potential for the export of large volumes of ethane and other NGLs would provide economic benefits, as well as positively impact the balance of trade.

Security and supply diversity. This scenario increases Appalachia producers' supply options as it would provide several outlets for their NGLs (e.g., ship to Canada, exports from the East Coast, and even exports from the Gulf Coast). If one route was constrained or out of service for some reason, the other markets could provide alternate routes for the transport of NGLs.

D. Other Regional Studies of Market Potential in Appalachia

Over the past few years, a number of studies have been released that examine the opportunity for increased petrochemical activity in Appalachia tied to the region's abundant ethane supply. A few notable studies are highlighted below.

1. *Benefits, Risks, and Estimated Project Cash Flows: Ethylene Project Located in the Shale Crescent USA versus the U.S. Gulf Coast*

In March 2018, IHS Markit released a study on the Shale Crescent USA region of Ohio, Pennsylvania, and West Virginia.[169] Based on proprietary IHS Markit data, a major focus of the study compared a hypothetical investment of almost $3 billion in an ethylene/polyethylene plant in the region versus the U.S. Gulf Coast over a 20-year timeframe. The study points to the access of low-cost ethane and proximity to polyethylene consumption as drivers for financial advantage in the Shale Crescent USA region. Findings of particular note by the IHS Markit study include:

- The Shale Crescent USA Region will supply 37% of U.S. natural gas production by 2040.
- There is a significant financial advantage for the hypothetical investment in the region versus the Gulf Coast.
- In its base case, and using a 15% discount rate, the analysis predicts a net present value (NPV) in 2020 on earnings before interest, taxes, depreciation, and amortization of $930 million over the life of the project compared to $217 million for a similar Gulf Coast project.
- Under a "stress" test that included higher capital costs and lower operating rates, a Shale Crescent USA project resulted in negative NPV returns in only 1% of 10,000 simulations.
- The expected returns for a project in the region versus that of the Gulf Coast are higher under all analyzed scenarios.

The publicly available synopsis of the study closes with the statement: "The comparative financial advantage for a Shale Crescent project would be further enhanced if more-than-anticipated transportation facilities, natural gas and NGL storage, and pipeline infrastructure occurs in the region."[170]

2. *The Potential Economic Benefits of an Appalachian Petrochemical Industry*

In May 2017, the American Chemistry Council (ACC) released a study titled *The Potential Economic Benefits of an Appalachian Petrochemical Industry*.[171] This report was the fifth ACC study released over the past few years examining the potential economic and employment benefits of natural gas development from shale. This report analyzed the potential economic impacts of the development of petrochemical and plastics industries in the Appalachian region.

The ACC report identified the following benefits of the Appalachian region as a petrochemical hub:

- Proximity to abundant NGL resources from the Marcellus/Utica and Rogersville shale formations;
- Proximity to manufacturing markets in the Midwest and along much of the East Coast;
- Opportunity to strengthen the U.S. economy by providing employment and supply diversity; and
- Opportunity to enable high-value ethane use to create U.S.-made products.[172]

The study assessed that the abundant supply of NGLs in the region could supply at least 6 world-scale petrochemical complexes, in addition to a number of smaller facilities.[173] With this level of petrochemical activity, the ACC report identified the following benefits to the Appalachian region as shown in Table 5.

Table 5. ACC Study Potential Economic Impacts[174]

Potential Economic Impacts of An Appalachian Chemical Industry (Permanent, By 2025)				
Capital Investment ($2016)	**Direct Output ($2016)**	**Employment**	**Payroll ($2016)**	**Federal, State, and Local Tax Revenue**
$32.4 billion in petrochemicals, resins and derivatives **$3.4 billion** in plastic products	**$23 billion** in chemicals + plastic resins **$5.4 billion** in plastics compounding + plastics products	**25,664** direct jobs (chemical and plastics products manufacturing) **43,042** indirect (supply chain) jobs **32,112** "payroll-induced" jobs in local communities where workers spend their wages	**$1.7 billion** direct **$3.0 billion** indirect (supply chain) **$1.5 billion** payroll-induced	**$1.7 billion** in federal tax revenue annually **$1.2 billion** in state and local tax revenue annually
TOTAL: ***$35.8 billion***	***TOTAL: $28.4 billion***	***TOTAL: 100,818 jobs***	***TOTAL: $6.2 billion***	***TOTAL: $2.9 billion***

3. *Prospects to Enhance Pennsylvania's Opportunities in Petrochemical Manufacturing*

In March 2017, IHS Markit prepared a report for the Team Pennsylvania Foundation titled *Prospects to Enhance Pennsylvania's Opportunities in Petrochemical Manufacturing*.[175] The focus of the report was on the impact and potential opportunities for petrochemical industrial development in Pennsylvania, supported by growing natural gas and associated NGLs production in Pennsylvania and the region. Key findings from the report are listed below.

- Natural gas, and associated NGL production, will continue to grow in the region, providing a cost-competitive feedstock to the petrochemical industry. IHS Markit estimates sufficient ethane availability, after satisfying demand from existing takeaway commitments and the Shell Chemicals project under construction, to provide feedstock for four more "world-scale" crackers in the region by the 2026–2030 time frame.
- Because of the region's lack of pipeline connectivity to the major market center at the U.S. Gulf Coast, prices for ethane and propane in Appalachia are bound to remain discounted relative to Mont Belvieu hub prices. Ethane discounted at 16 cents per gallon (c/gal) below Gulf Coast.

- Polymer producers in the Appalachian region will have the dual advantage of lower-cost feedstock and better proximity to end-use markets. Established competitors may challenge in-region production for market share with competitive pricing and broader range of offerings. U.S. polyethylene producers in general will be highly competitive internationally, allowing exports to rise "from 34% of production to 41 percent of production in 2020." Some new plants, and some existing plants, may primarily target the export market rather than seek sales in the U.S.
- IHS Markit estimates $6 billion has been invested in the region between 2010–2016, and a further $7.3–$10 billion will be invested through 2025 in NGLs-related assets, including natural gas processing plants, pipelines, fractionators, storage, and other related infrastructure.

VII. Benefits of Geographic Diversity

The Congressional request for this report included examination of the energy security benefits of the establishment of an ethane storage and distribution hub. It should be noted that because ethane's main use is as a petrochemical feedstock, ethane supply does not impact energy security considerations in the manner which other hydrocarbons, such as natural gas, do.

Since the onset of the shale revolution, the amount of ethane being produced in the Appalachian Basin has outpaced the growth in associated infrastructure. As discussed in Section V, 95 percent of U.S. ethylene production capacity currently exists in Louisiana and Texas. This concentration of assets and operations may pose a strategic risk to the U.S. economy moving forward as extreme weather events impacting petrochemical and plastics production on the Gulf Coast can limit the availability of feedstocks to manufacturers across the United States.

To give a recent extreme weather example, in August 2017, many refineries and petrochemical facilities in the U.S. Gulf Coast shut down due to concerns about flooding related to Hurricane Harvey. Because most U.S. production and consumption of ethylene occurs in Texas and Louisiana, 54 percent of U.S. ethylene production and 36% of ethylene consumption capacity went offline.[176] More than half of the U.S. polyethylene production capacity was shut down.[177] Additionally, railway service to the plants was disrupted due to flooding.[178]

A second Gulf Coast extreme weather example is from 2005, when disruptions from Hurricane Katrina led to reported price spikes of 20-30 percent of resins used to make plastics.[179] In contrast, the price impacts to other industries and industrial activities based in the region were far less adverse. For example, concrete only increased 1.8 percent and plywood 2 percent.[180] These costs impact firms that manufacture plastic goods as well as those who use those plastic goods to store and transport their products.

Petrochemical expansion beyond the Gulf Coast would increase geographic diversity. This geographic diversity could provide manufacturers with flexibility and redundancy of where they purchase their feedstock and how it is transported to them. Moreover, this flexibility and redundancy, as well as the overall increase in U.S. feedstock production, could mitigate the potential for any feedstock price spikes that could be caused by a severe weather event in any one region within the U.S.

In addition to reducing systemic risks of severe weather in any one region, increased NGLs production in the Appalachian region could reduce transportation constraints that can adversely affect manufacturers in the region, as well as across the Midwest and mid-Atlantic. Much of the existing downstream chemicals and plastics manufacturing base stretches from

Wisconsin and Michigan to Indiana, Ohio, Kentucky, West Virginia, Tennessee, and the Carolinas.

The increase in the geographic diversity of production that would result from expanded petrochemical activity in Appalachia would enhance the reliability of the petrochemical and plastics manufacturing supply chain as a whole. It would provide the U.S. economy with more supply chain options to deal with unexpected plant shutdowns and transportation constraints.

VIII. Concluding Remarks

The Unites States is endowed with significant NGLs resources, and the application of unconventional production techniques has unlocked the potential for these resources to be brought to market. The largest growth in ethane production over the next two decades will come from the Permian basin in the Southwestern U.S. and the Marcellus and Utica basins in Appalachia. Ethane production in Appalachia is projected to continue its rapid growth in the coming years, reaching 640,000 barrels per day in 2025 – more than 20 times greater than regional ethane production in 2013.

Industry has made significant investments in natural gas and NGLs infrastructure to support the boom in production in Appalachia over the past decade. Between 2010 and 2016, natural gas processing capacity increased tenfold, and fractionation capacity in the Appalachian region increased from 41,000 b/d in 2010 to nearly 850,000 b/d in 2016, and may grow as high as 1.1 million b/d in 2019. Underground storage projects are being considered, and a world-scale ethane cracker is already under construction in Pennsylvania.

A NGLs hub requires a concentration of physical assets that connect to supply and demand sources via different transport, storage, and distribution options. Storage of NGLs is necessary for a hub since produced volumes typically exceed the pipeline takeaway capacity and processing capacity. Storage helps mitigate production volatility and in turn reduces risk for those end users that need a steady and reliable stream of feedstock, including the petrochemical industry.

Appalachia's abundant resources coupled with extensive downstream industrial activity may offer a competitive advantage that could enable it to displace marginal producers and help the U.S. gain global market share in the petrochemical industry. Nearly one-third of U.S. activity in the petrochemical ecosystem occurs within 300 miles of Pittsburgh, with over $300 billion of net revenue, 900,000 workers, and 7,500 establishments. U.S. petrochemical manufacturing capacity and growth is poised to continue expanding given the expectation of shale production, though the geographic distribution is evolving and not yet clear. Projected, but unspecified to a particular region, incremental petrochemical capacity will generate nearly $227 billion in revenue between 2018 and 2040.

Today, over 95% of U.S. ethylene production capacity is located in Texas or Louisiana. Expanding the petrochemical asset base beyond the Gulf Coast would enhance geographic diversity of this industrial sector and support reliability in the petrochemical industry. The development of new petrochemical capacity elsewhere is not necessarily in conflict with Gulf Coast expansion; new capacity may serve regional demand for NGLs derivatives, freeing up Gulf Coast production for other markets, including exports overseas.

Abbreviations and Units

ADG	Appalachia Development Group LLC
AEO	Annual Energy Outlook
AONGRC	Appalachian Oil and Natural Gas Consortium
ATEX	Appalachia-to-Texas Express
b/d	Barrels per day
Bcf/d	Billion cubic feet per day
C_2H_4	Ethylene
C_2H_6	Ethane
c/gal	Cents per gallon
DEC	New York State Department of Environmental Conservation
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EPP	Enterprise Product Partners LP
FID	Final investment decision
GDP	Gross domestic product
HDPE	High-density polyethylene
HGL	Hydrocarbon gas liquids
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
LPG	Liquefied petroleum gas
LPO	U.S. Department of Energy Loan Program Office
ME2	Mariner East II
ME2x	Mariner East IIx
MMmt	Million metric tons
mt/y	Million tons per year
NGL(s)	Natural gas liquid(s)
NETL	National Energy Technology Laboratory
NGPL(s)	Natural gas plant liquid(s)
NPV	Net present value
PDH	Propane dehydrogenation
PE	Polyethylene
R&D	Research and development
Tcf	Trillion cubic feet

tpa	Tons per annum
TEPPCO	TE Product Pipeline Company
UMTP	Utica-Marcellus-Texas Pipeline
UTOPIA	Utica to Ontario Pipeline

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[119] NOVA Chemicals' 1.8 billion pound/year Corunna cracker came online in 1977 and relied on oil-based naphtha as its primary feedstock until 2006 and its partial feedstock source until 2014 when it converted to ethane using Sarnia's pipeline and storage infrastructure. Currently NOVA receives all its ethane from the Marcellus/Utica via the Mariner West pipeline.
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