



U.S. DEPARTMENT OF  
**ENERGY**

# Natural Gas Liquids Primer

*With a Focus on the Appalachian Region*

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Washington, DC 20585

## Executive Summary

The ongoing renaissance in oil and natural gas production in the United States has provided economic benefits across the country through higher employment and lower energy prices. The growth of production has occurred in regions of the country with significant resources in shale formations, which are unlocked through unconventional production techniques. One such region is Appalachia with the Marcellus and Utica shale formations.

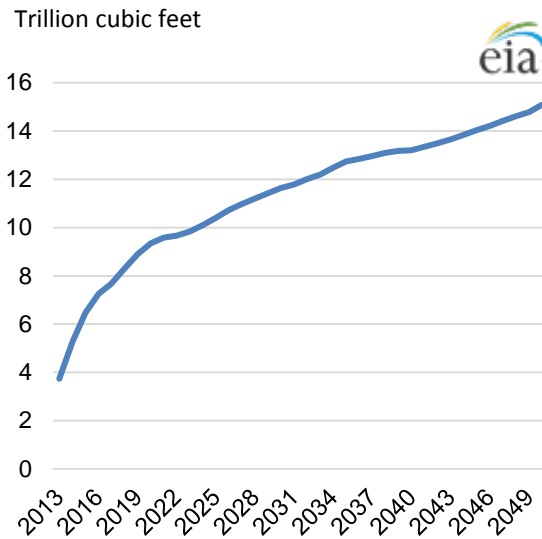
The Appalachian region<sup>1</sup> has experienced near-exponential growth in natural gas production (see Figure ES-1), and that production is expected to increase for decades to come. The U.S. Energy Information Administration (EIA) forecasts that natural gas production in Appalachia will increase over 350 percent from 2013 to 2040. The natural gas produced in Appalachia contains valuable resources in the form of natural gas liquids (NGLs), including ethane and propane. When separated from the natural gas stream, ethane and propane are key feedstocks for the petrochemical industry to produce compounds for making plastics. Appalachian NGL production is projected to increase over 700 percent in the 10 years from 2013 to 2023 (see Figure ES-2).

Leaders across the Appalachian region have identified the potential economic opportunity these significant NGL resources present. To contribute to this dialogue, the U.S. Department of Energy (DOE) created this primer to educate the public on NGLs – what they are, how they are used, recent market developments, and the supporting infrastructure in the region. This document includes the most recent information from DOE and EIA on Appalachian NGL supply, demand, and infrastructure.

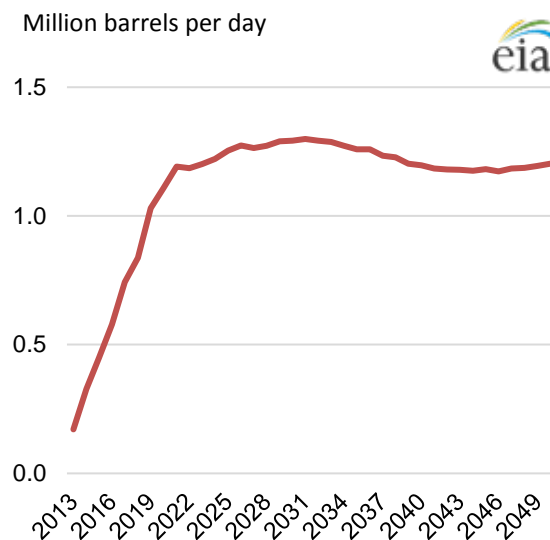
Industry has made significant investments in natural gas and NGL infrastructure to support the boom in production in Appalachia this decade.

New investments to take advantage of the NGL resources in the region have been identified by industry, and forecasts for production over the decades to come highlight the opportunity for additional investments across the NGL supply chain.

**Figure ES-1: Appalachian Natural Gas Production**



**Figure ES-2: Appalachian Natural Gas Liquids Production**





# NATURAL GAS LIQUIDS PRIMER

*With a Focus on the Appalachian Region*

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# I. Introduction

The application of horizontal drilling and hydraulic fracturing 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. This oil and gas production renaissance has created new economies in regions of the country that previously had little conventional production, such as Ohio, Pennsylvania, and West Virginia. The Appalachian region has experienced near-exponential growth in natural gas production over the past decade; Pennsylvania alone produces more natural gas than all but five countries.<sup>2</sup>

Natural gas production in the Appalachian region yields an added benefit in the form of natural gas liquids (NGLs). 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. Significant volumes of NGLs are being produced in the Appalachian region. These resources are often shipped to other domestic markets for use or left unseparated in the natural gas stream, representing unrealized potential.

The opportunity to take advantage of the full economic value of NGLs produced in Appalachia has been identified by regional leaders. The Department of Energy (DOE) has prepared this document to educate the public and enhance the discussion regarding NGL resources and related infrastructure in the Appalachian region. Unless otherwise noted, forecasts and projections in this document are from the U.S. Energy Information Administration. The Office of Oil and Natural Gas in DOE's Office of Fossil Energy prepared this primer. The following sections will define NGLs and their uses, forecast regional natural gas and NGL production, provide an overview of regional infrastructure for NGL production and use, and highlight infrastructure developments in the region.

## II. What are natural gas liquids?

Natural gas liquids are versatile products used in every end-use sector—residential, commercial, industrial (manufacturing and agriculture), transportation, and electric power. The table below lists the chemical composition, uses, products, and sectors for NGLs.<sup>3</sup>

**Table 1. Natural gas liquids, uses, products, and consumers**

<b>NGL</b>	<b>Chemical formula</b>	<b>Uses</b>	<b>End-use products</b>	<b>End-use sectors</b>
<b>Ethane</b>	$C_2H_6$	Petrochemical feedstock for ethylene production; power generation	Plastics; anti-freeze; detergents	Industrial
<b>Propane</b>	$C_3H_8$	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
<b>Butanes: normal butane and isobutane</b>	$C_4H_{10}$	Petrochemical and petroleum refinery feedstock; motor gasoline blending	Motor gasoline; plastics; synthetic rubber; lighter fuel	Industrial and transportation
<b>Natural gasoline (pentanes plus)</b>	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

### ***A. Ethane***

Ethane is mainly used to produce ethylene, which is then used by the petrochemical industry to produce a range of intermediate products, most of which are converted into plastics. Ethane consumption in the United States has increased over the past several years because of its increased supply and lower cost relative to other petrochemical feedstocks like propane and naphtha. Ethane can also be used directly as a fuel for power generation, either on its own or blended with natural gas.

Because demand for ethane is almost entirely in the petrochemical sector, and because this product is difficult to transport by any mode other than in dedicated pipelines, supply and demand for ethane must be closely matched. The increase in the supply of ethane starting in 2008 has resulted in some natural gas processors choosing not to recover the ethane that is produced with raw natural gas. Instead, this ethane is left in the natural gas that enters the interstate natural gas pipeline system. This process is referred to as ethane rejection, because the producer rejects the ethane stream into the dry natural gas instead of recovering it along with other NGLs.

### ***B. Propane***

Most of the propane consumed in the United States is used as a fuel, generally in areas where the supply of natural gas is limited or not available. This use is highly seasonal, with the largest consumption occurring in the fall and winter months. Propane sold as a fuel for the consumer market is generally defined as HD-5, which contains a minimum of 90% propane by volume, with small quantities of other hydrocarbon gases. HD-10, which contains up to 10% propylene, is the accepted standard for propane in California.

There are two general market categories for propane: consumer (primarily as fuel) and non-consumer (primarily for non-fuel or feedstock uses). There are four major consumer uses of propane:

- In homes, for space heating and water heating; for cooking; for drying clothes; and for fueling gas fireplaces, barbecue grills, and backup electrical generators.
- On farms, for heating livestock housing and greenhouses, for drying crops, for pest and weed control, and for powering farm equipment and irrigation pumps.
- In businesses and industry, to power fork lifts, electric welders, and other equipment.
- As a fuel for on-road internal combustion engine vehicles such as cars, school busses, or delivery vans, and non-road vehicles such as tractors and lawn mowers.

The non-consumer market for propane is the petrochemical industry. The primary use of propane in the petrochemical industry is as a feedstock, along with ethane and naphtha, in petrochemical crackers to produce ethylene, propylene, and other olefins. Propane can also be used as a dedicated feedstock in the petrochemical industry for on-purpose propylene production. Propylene and the other olefins may be converted into a variety of products, mostly plastics and resins, and also glues, solvents, and coatings.

### ***C. Butanes***

Although some normal butane is used as a fuel for lighters, most of it is blended into gasoline, especially during the cooler months. Because demand for isobutane exceeds supply, normal butane is also converted into isobutane through isomerization. Normal butane can also be used as a feedstock in the petrochemical industry. When normal butane is used in petrochemical cracking, the process yields (among other chemicals) butadiene, which is a precursor to synthetic rubber.

Isobutane, whether from natural gas plants, refineries, or isomerized from normal butane, is used to produce alkylates, which increase octane in gasoline and control the volatility of gasoline. High-purity isobutane can also be used as a refrigerant.

### ***D. Natural Gasoline (Pentanes Plus)***

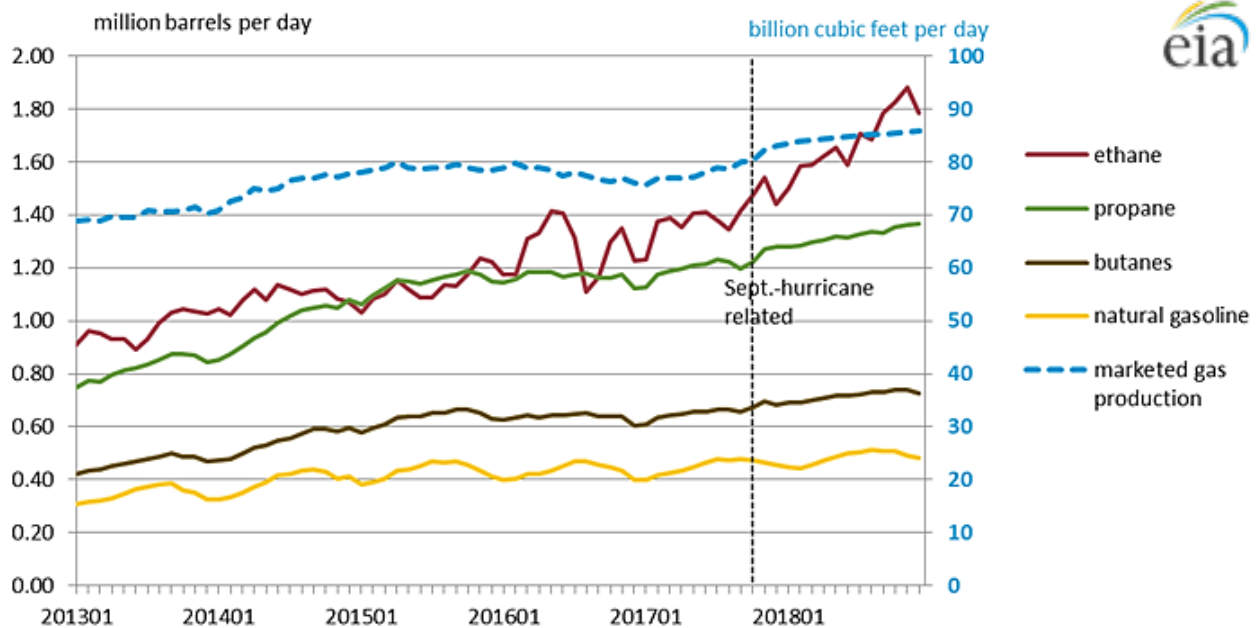
Natural gasoline (also known as pentanes plus) can be blended into the fuels used in internal combustion engines, particularly motor gasoline. In the United States, natural gasoline is added to fuel ethanol as a denaturant to make the ethanol undrinkable, which is required by law. Some ethanol producers use natural gasoline to make E85.

About half of U.S. natural gasoline production is exported to Canada where it is used as a diluent to reduce viscosity of heavy crude oil, so that the crude oil can be more easily moved in pipelines and railcars.

### III. Domestic Natural Gas Liquids Market

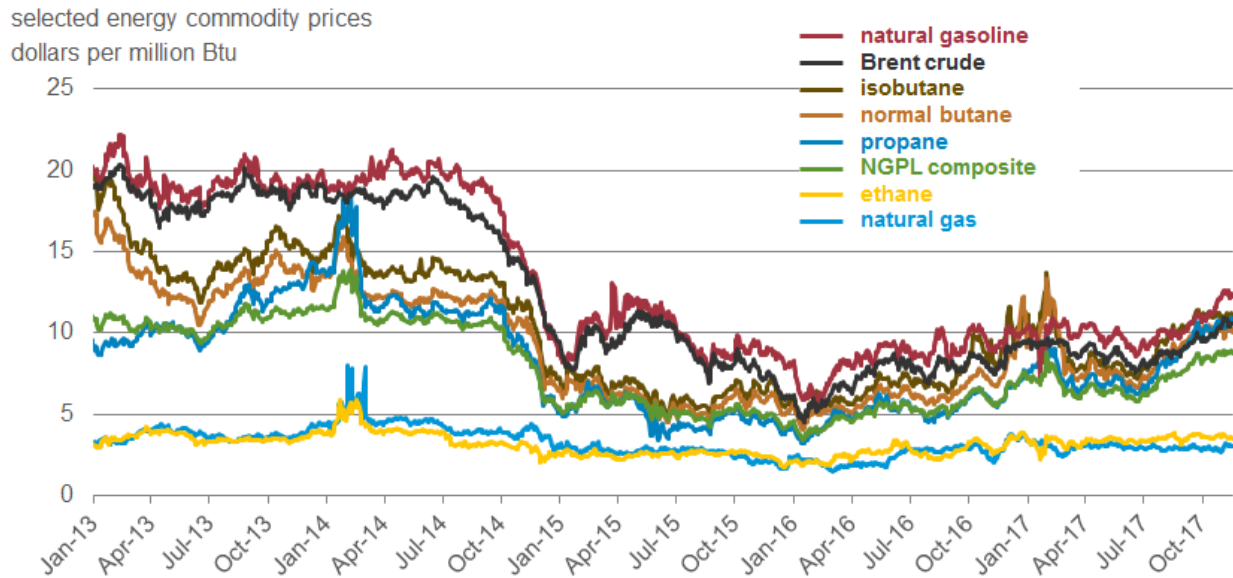
U.S. liquid fuels production increased by 5.5 million barrels per day (b/d) between 2009 and 2016, from 8.0 million b/d to 13.5 million b/d. Increase in NGL production accounted for 29% of this growth. By definition, NGL production happens at natural gas processing plants and petroleum refineries, but between 2009 and 2016, all of the growth in NGL production occurred at natural gas processing plants as a byproduct of processing the growing supply of natural gas from shale gas and tight oil formations.

**Figure 1. Natural Gas Plant Production of NGLs<sup>4</sup>**



As depicted in Figure 2 below, domestic spot prices of NGLs generally fall between crude oil and natural gas spot prices on a heat-content basis (\$/million British thermal units (MMBtu)). Propane, butane, and natural gasoline spot prices, which have historically moved with crude oil prices, have stayed consistently above the Henry Hub natural gas price since 2008, providing positive margins when these products were recovered at natural gas plants. On the other hand, an oversupply of ethane kept ethane prices at or below the Henry Hub natural gas price from mid-2012 to late-2015. When ethane margins are negative, producers have an incentive to reject ethane, leaving it in the dry pipeline natural gas stream where it sells for its fuel value. However, U.S Gulf Coast ethane prices went above Henry Hub natural gas prices on September 22, 2015, and margins have been mainly positive through 2017, as new petrochemical demand and exports reduced the oversupply of ethane.



**Figure 2. NGL Prices Compared to Crude Oil and Natural Gas<sup>5,a</sup>**

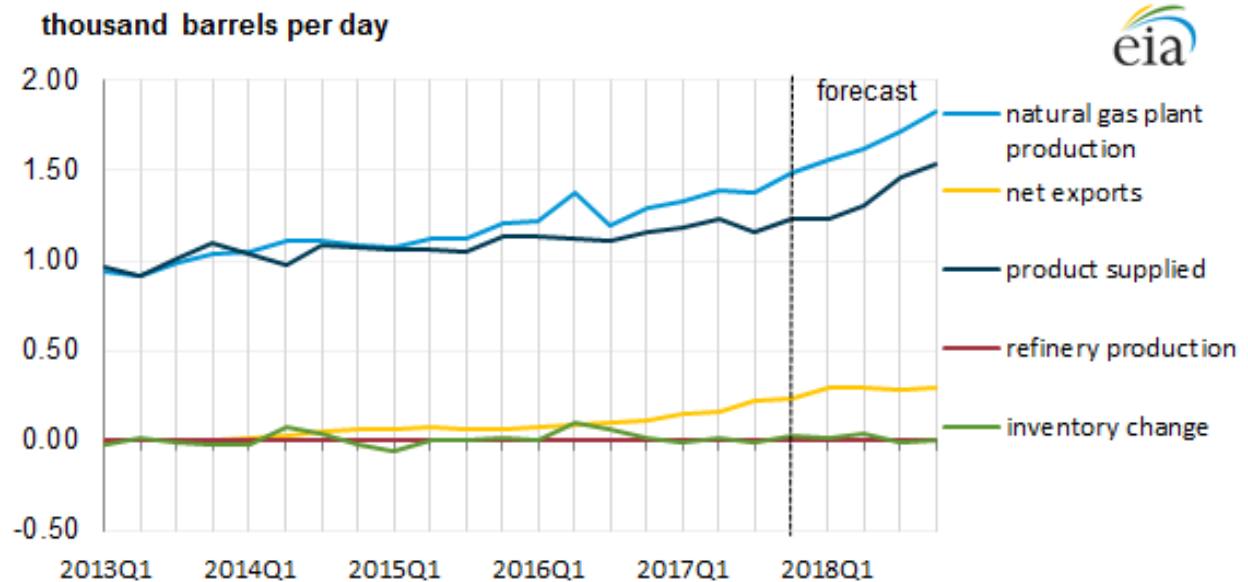
### A. Ethane Outlook<sup>6</sup>

Ethane consumption, which remained relatively flat between the last quarter of 2013 through mid-2015 (see Figure 3 below), is expected to increase significantly after growing just 100,000 b/d between mid-2015 and mid-2017. Ethane consumption domestically is forecasted to increase by 375,000 b/d from the last quarter of 2017 to the end of 2018.

Exports are expected to also lift total ethane demand. After the first exports by pipeline started flowing to Canada in 2014, exports of ethane expanded from essentially zero to 65,000 b/d by the end of 2015. Overseas exports of ethane out of the U.S. began in the first quarter of 2016, with the first shipment of ethane to Norway out of the Sunoco Logistics' Marcus Hook, Pennsylvania terminal outside Philadelphia, leading to further growth. From the start of 2016 to the third quarter of 2017 total U.S. ethane exports rose by over 160,000 b/d. Growth in ethane exports is expected to continue, increasing by another 73,000 b/d through the end of 2018.

Resulting from this rapid growth in demand for ethane, from both domestic U.S. consumers and international markets, Ethane production at natural gas plants, which was relatively flat from late 2013 to mid-2015, is projected to continue increasing through the forecast period. After growing by 260,000 b/d from the fourth quarter of 2016 to the third quarter of 2017, ethane production is forecasted to grow by a further 450,000 b/d to the end of 2018.

<sup>a</sup> All prices are daily end-of-day spot prices; natural gas is Henry Hub, and NGL components are Mt. Belvieu. NGPL Composite calculated based on calorific contribution of each purity to total NGPL barrel heat value.

**Figure 3. Ethane supply and disposition, quarterly 2014-18<sup>7</sup>**

Annual average gas plant production of liquids is projected to grow 690,000 b/d by the last quarter of 2018, from 3.73 million b/d in 2017, with increased ethane production accounting for two-thirds of this growth. Over the past several years, the amount of ethane contained in raw natural gas has exceeded U.S. domestic capacity to consume and export it. This excess supply kept ethane prices relatively low, hovering at or below the price of natural gas on a heat-content equivalent basis (\$/MMBtu). The lower prices created an incentive for producers to reject ethane into pipeline natural gas to capture its value as a fuel, as opposed to recovering it at gas plants and marketing it as a separate product for use in petrochemical manufacturing. As expanding ethane-consuming petrochemical and export capacity reduces the ethane oversupply in 2017-19, ethane prices are expected to generally remain above natural gas prices in \$/MMBtu, and ethane recovery is expected to rise to meet domestic and export demand growth.

The first half of 2017 saw two new petrochemical crackers come online and capacity expansions at two others completed. Construction challenges, in no small part due to the impacts of Hurricane Harvey, caused delays at various other projects, which are now expected to be completed over the course of 2018, with others slated for completion further out in the forecast.

Exports of ethane have grown in 2017, including volumes leaving the Morgan's Point, Texas terminal in increasing to nearly 100,000 b/d by the middle of 2017. This growth in export volumes, as well as the increase in domestic consumption resulting from abovementioned project completions, were sufficient to drive up ethane recovery at natural gas processing plants to 1.38 million b/d, and push ethane wholesale prices above natural gas on a heat-content equivalent basis starting in February 2017, where they have remained ever since.

As domestic U.S. petrochemical demand for ethane continues to grow through 2018 and 2019, and export volumes reach an expected 300,000 b/d plateau, ethane recovery is projected to more closely align with total available ethane (produced + currently rejected). This market rebalancing is in turn expected to push ethane prices higher relative to natural gas, improving margins for producers, and allowing further improvements in NGL infrastructure to move forward, including new pipelines, de-ethanization plants, and storage capacity that allow more ethane to be separated from natural gas and transported to demand centers.

### **Natural Gas Plant Production of Ethane**

As the lightest molecule (aside from methane, the main component of natural gas), ethane requires more energy to recover and more specialized handling after recovery than other NGLs. The additional costs imposed on natural gas processors require a price that provides for sufficient recovery of costs to cover the production and transportation of ethane. Low demand growth and weak prices over the 2013-16 time period provided a disincentive for ethane recovery at natural gas plants and encouraged producers to reject some ethane into pipeline gas to capture its value as a fuel at natural gas prices (see Figure 2 above).

Many of the petrochemical and export projects announced since 2012 are now reaching the commissioning phase, driving ethane demand higher. New and expanded petrochemical cracking capacity raised annualized domestic ethane demand by approximately 150,000 b/d, while rising exports contributed another 75,000 b/d to total demand for ethane. Natural gas plant production of ethane responded, expanding by nearly 200,000 b/d between January and June, before declining in August as a result of Hurricane Harvey impacts. Ethane production and prices are expected to rise further on the back of continuing growth in petrochemical and export demand, with continuing growth in ethane infrastructure allowing this new production to reach new markets, where it can fetch a higher price.

Increased ethane recovery is expected to result in ethane production (excluding rejection) growth that is much stronger than natural gas production growth, with annual ethane production rising 49% between 2015 and 2018 and marketed natural gas production rising just under 8%. Annual ethane production is projected to increase by 124,000 b/d in 2017 and by 287,000 b/d in 2018, compared with annual average growth of 70,000 b/d between 2008 and 2016. Growth is expected to be widespread, with contributions from the Appalachian basin complemented by higher recoveries in the Gulf Coast region and the Rockies.

**Table 2. Ethane supply and disposition, 2014-18<sup>8,b</sup>**

	Millions of barrels per day				Forecast 2018
	2014	2015	2016	2017	
<b>Gas Plant Production</b>	1.09	1.13	1.27	1.40	1.68
<b>Refinery and Blender Net Production</b>	0.01	0.01	0.00	0.01	0.00
<b>Net Imports</b>	-0.04	-0.06	-0.09	-0.19	-0.29
<b>Refinery and Blender Net Inputs</b>	0.00	0.00	0.00	0.00	0.00
<b>Stock Build (Draw)</b>	0.01	-0.01	0.04	0.02	0.02
<b>Consumption</b>	1.04	1.07	1.13	1.20	1.39

### Domestic Consumption of Ethane

Annualized ethane consumption is forecasted to rise by 256,000 b/d, from 1.13 million b/d in 2016 to 1.39 million b/d in 2018. Ethane is used almost exclusively as a feedstock for ethylene production at petrochemical plants, a use that is expected to expand as new ethylene plant capacity comes online. The relatively low cost of U.S. ethane led to a wave of investment in ethylene plant projects, including plant restarts, capacity expansion and feedstock conversions at existing plants, and new ethylene plants. These investments are expected to increase domestic ethane throughput capacity by nearly 450,000 b/d by the end of 2018.

A number of projects to restart or expand the capacity of ethylene-producing plants to use ethane as their feedstock increased ethane throughput capacity by about 140,000 b/d between 2013 and 2015, and another 55,000 b/d between the start of 2016 and last quarter of 2017. Most of this new capacity was from expansion projects scheduled to come online late in 2015, which had a delayed impact on feedstock demand that began to materialize starting in the second quarter of 2016. Just one major capacity expansion, of LyondellBasell's Channelview cracker, came online in 2017, adding 12,000 b/d of ethane demand, while a restart of the Carlyss cracker by Indorama Ventures, initially slated for 2017, is now expected to occur in 2018.

<sup>b</sup> EIA uses product supplied as a proxy for consumption. Annual averages.

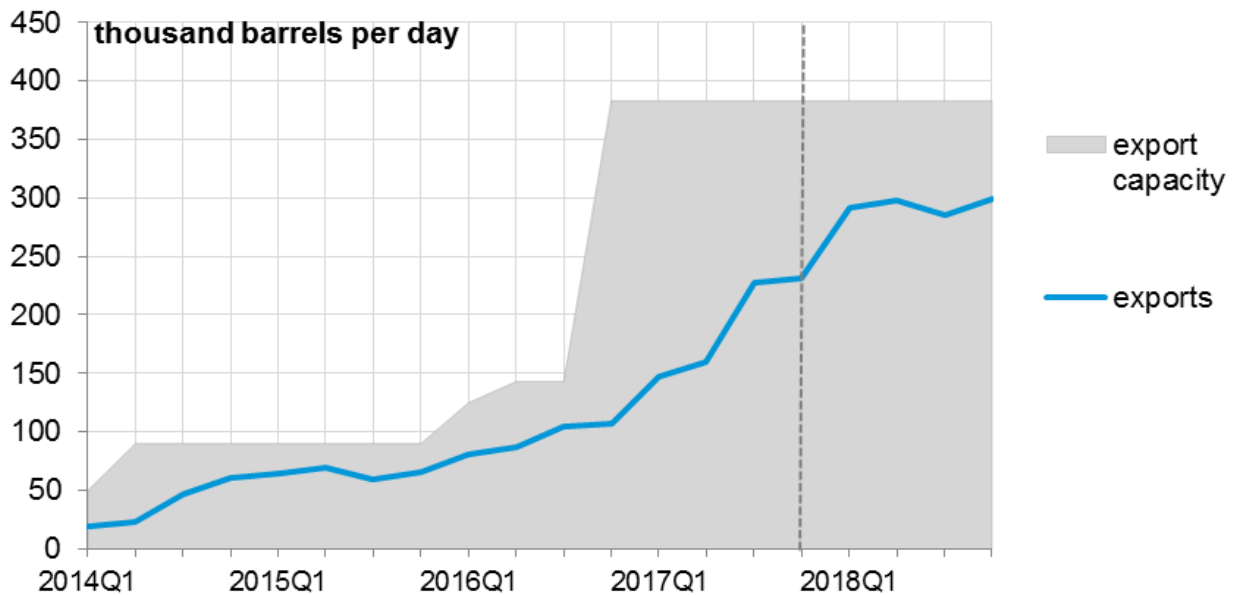
The first new petrochemical cracker since 2001 in the United States was completed in February 2017 – the OxyChem/MexiChem petrochemical cracker at Ingleside, Texas. In March 2017, Dow Chemical Company completed its new cracker at Freeport, Texas. Together, the two plants added 545,000 mt/y and 1.5 million mt/y of ethylene production capacity, respectively, accounting for over 120,000 b/d of new ethane demand.

Four more new ethylene crackers (from Chevron Phillips (CP) Chemicals, ExxonMobil, Formosa, and Shinetsu) are under construction and are expected to begin operating in 2018. The 2018 completions of new crackers, plus the Indorama Ventures restart, are expected to expand ethane throughput capacity by approximately 325,000 b/d in 2018. The new plants are designed to consume predominantly light feedstock, and ethane is expected to constitute most of their feed.

**Net exports of ethane**

In 2014, the United States switched from being a net importer of ethane to a net exporter after the opening of two new ethane pipelines that began transporting ethane from North Dakota and southwestern Pennsylvania to Canada. Annual average ethane net exports is expected to increase from 60,000 b/d in 2015 to 230,000 b/d in 2017, then to a plateau of 300,000 for 2018, as new export facilities allow ethane to reach foreign markets.

**Figure 4. Ethane export capacity and net exports, 2014-18<sup>9</sup>**



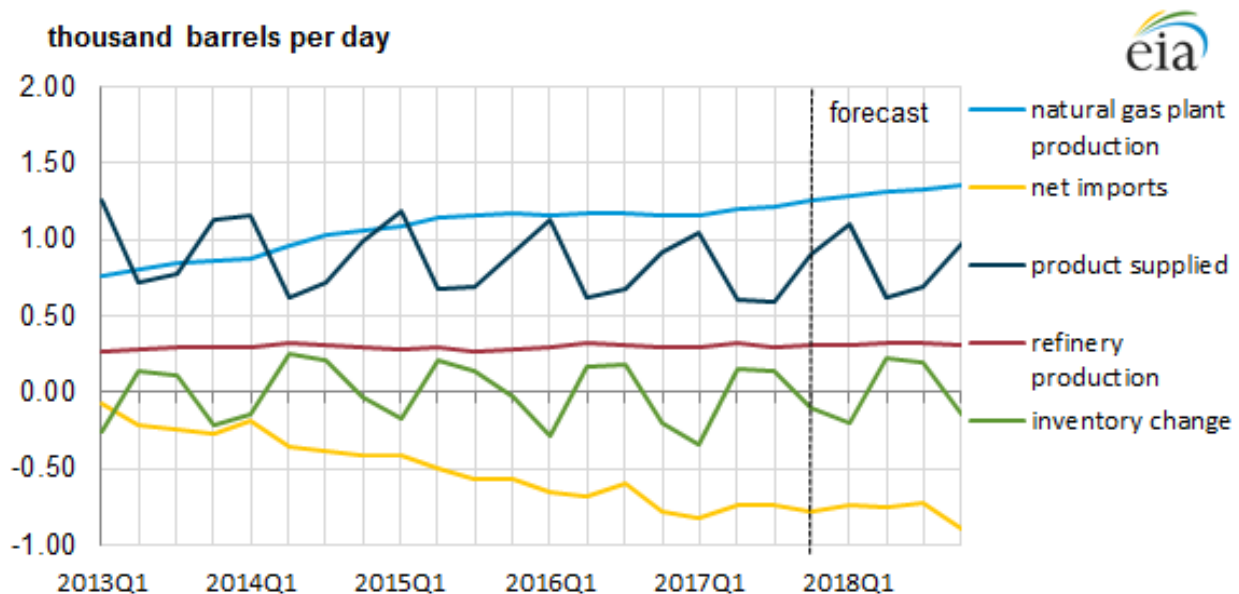
Early in 2016, the United States began exporting ethane to Europe from Sunoco’s Marcus Hook facility near Philadelphia, Pennsylvania. Under a 15-year contract, new purpose-built tankers move the ethane from Marcus Hook to Scotland and Norway for use in INEOS petrochemical plants. Regular exports of ethane from this facility are expected to begin reaching Sweden by mid-2018. In the third quarter of 2016, Enterprise Product Partners (EPP) commissioned its new ethane export facility at Morgan’s Point, Texas, which has a nameplate capacity to export

up to 240,000 b/d. This new terminal is currently exporting on average 100,000 b/d of ethane to destinations as remote as India and Brazil, as well as Fife, Scotland, in addition to the same destinations served by Marcus Hook in Northern Europe. Companies around the world have modified their facilities to accept this waterborne U.S. ethane. Reliance Industries, a major Indian refiner and petrochemical producer, built an import terminal and ethane pipeline, and ordered the construction of six very large ethane carriers (VLEC) to transport ethane to India. Each such vessel is capable of transporting over 800,000 standard barrels of ethane, with on average two of these ships loading at Morgan’s Point every month.

**B. Propane Outlook<sup>10</sup>**

The outlook for propane is marked by continued growth in gas plant production, albeit at a slower pace than in recent years, relatively flat domestic consumption levels, and continued growth in net exports (see Figure 9 below). Natural gas plant production of propane is projected to increase by 100,000 b/d in 2017 and another 100,000 b/d in 2018, after remaining essentially flat for the duration of 2016. After a 40,000 b/d annual decline in 2017, propane consumption, measured as product supplied, is expected to rise in 2018 on the back of more normal winter weather, rising to an annual average of 1.04 million b/d. Net exports, which increased from just under 200,000 b/d in 2013 to 680,000 b/d in 2016, are expected to flatten at approximately 770,000 b/d through 2017 and 2018 on an annualized basis.

**Figure 5. Propane gas plant and refinery production, imports, consumption, exports, and inventory change, 2013-18<sup>11</sup>**



**Natural Gas Plant Production of Propane**

Gas plant production of propane more than doubled between 2008 and 2015, with most of the growth occurring since 2011. The rate of growth in gas plant propane production, like that of

other natural gas plant liquids, outpaced that of natural gas, as increased natural gas processing and fractionation capacity allowed producers to separate more liquids from raw natural gas production. Growth in marketed natural gas production flattened at around 77 Bcf/d throughout 2015 and 2016, while production of propane slowed to just 2% in 2016 and 4% in 2017, after rising 16% in 2015. By the end of 2017, however, with rising exports, natural gas production began to increase again, and This trend is expected to continue throughout the forecast period. This growing natural gas production is expected to lead to a rebound in the growth rate of propane production to an average of 10% in 2018. The forecast for gas plant production of propane averages 1.36 million b/d in the fourth quarter of 2018, 200,000 b/d above production reported in the first quarter of 2017.

### **Domestic Consumption of Propane**

In 2015, the United States consumed 830,000 b/d of propane for a combination of uses. In the United States, propane is used mainly for space heating and as a feedstock for petrochemical plants, and to a lesser extent for agricultural applications and transportation. Propane's use as a heating fuel is mainly responsible for the seasonal pattern in its consumption, which peaks in the winter (fourth and first quarters) (see Figure 5 above). The combination of relatively mild weather in the past winter depressing demand for propane as a heating fuel, along with estimated decline in the use of propane as a petrochemical feedstock due to elevated domestic propane prices, translates into a decrease of 40,000 b/d in U.S. domestic demand.

As a feedstock, propane is used by the petrochemical industry to produce ethylene and propylene for chemicals and plastics. Some ethylene-producing plants can process propane into ethylene, propylene, and a slate of other olefins. As these plants become more reliant on ethane feedstock, propylene production at ethylene plants is expected to decline. To offset the decline in ethylene cracker propylene production, petrochemical companies have invested in propane dehydrogenation (PDH) plants that are dedicated to producing propylene from propane feedstock.

The United States currently has two PDH plants. The first plant, with an estimated propane feedstock capacity of 30,000 b/d, was opened by Petrologistics in 2010, and has since been sold to Flint Hills. A second plant, owned by Dow Chemical, with a propane feedstock capacity of 35,000 b/d, began commercial operation in December 2015. The Enterprise Product Partners' PDH plant at Mont Belvieu, Texas, which is currently undergoing commissioning and is expected to be fully operational in January 2018, is expected to be the last such plant completed in the U.S. over the next several years. Like the Dow PDH plant, the Enterprise-operated plant's feedstock requirement is estimated at 35,000 b/d of propane. As stated above, the construction of new PDH plants may result in a net reduction in petrochemical propane consumption, because a PDH plant produces more propylene per barrel of propane feedstock than an ethylene plant.

### **Net Exports of Propane**

On a net basis, propane net exports are projected to increase to 680,000 b/d in 2016 (Table 5) and to 770,000 b/d in 2017 and 2018, reflecting the completion of most export terminal projects.

On an annual basis, imports have been relatively steady, reflecting flat Canadian production and seasonal U.S. demand for heating-season supply. Prior to 2012, in years when demand surged past volumes available from domestic production and imports from Canada, overseas imports filled the gap. Since 2012, however, as U.S. domestic propane production began to expand, imports from overseas producers were reduced to just a few cargos to regions not well served by domestic supplies, such as New England or Hawaii. At 120,000 b/d in 2017 and 2018, imports of propane are forecasted to reflect surplus Canadian production.

Exports of propane had been relatively steady for the ten years between 1999 and 2008, hovering each year between 30,000 b/d and 50,000 b/d, reflecting seasonal imbalances and some re-exports to Canada's eastern provinces. By 2009 export volumes began to grow, exceeding 100,000 b/d in 2010. In 2011, the U.S. became a net exporter of propane on an annual basis, as the 124,000 b/d of propane exports surpassed the 82,000 b/d of propane imports – nearly all from Canada. By 2012, the U.S. became a year-round net exporter of propane, and exports have grown since, reflecting both increasing domestic production and growing capacity to export.



**Table 3. Propane supply and disposition, 2014-18<sup>12,c</sup>**

	Millions of barrels per day				Forecast
	2014	2015	2016	2017	2018
<b>Gas Plant Production</b>	0.98	1.14	1.17	1.21	1.32
<b>Refinery and Blender Net Production</b>	0.31	0.28	0.31	0.30	0.32
<b>Net Imports</b>	-0.33	-0.51	-0.68	-0.77	-0.77
<b>Refinery and Blender Net Inputs</b>	NA	NA	NA	NA	NA
<b>Stock Build (Draw)</b>	0.09	0.05	-0.04	-0.04	0.02
<b>Consumption</b>	0.87	0.86	0.83	0.79	0.85
<b>PDH feed capacity (end of year)</b>	0.03	0.07	0.07	0.10	0.10
<b>Propane/butane export capacity (end of year)</b>	0.60	1.14	1.29	1.29	1.57

The relatively low cost of U.S. propane spurred international demand and changed international trade patterns. Growth in propane exports is expected to be mainly driven by petrochemical demand in Asia and to a lesser extent Europe. U.S. wholesale propane prices are expected to increasingly reflect international-market prices, as domestic export capacity, combined with a near-doubling of the world's liquefied petroleum gas shipping fleet and the opening of the wider locks of the Panama Canal, have resulted in significant reductions in costs associated with reaching distant markets.

### Propane Inventories

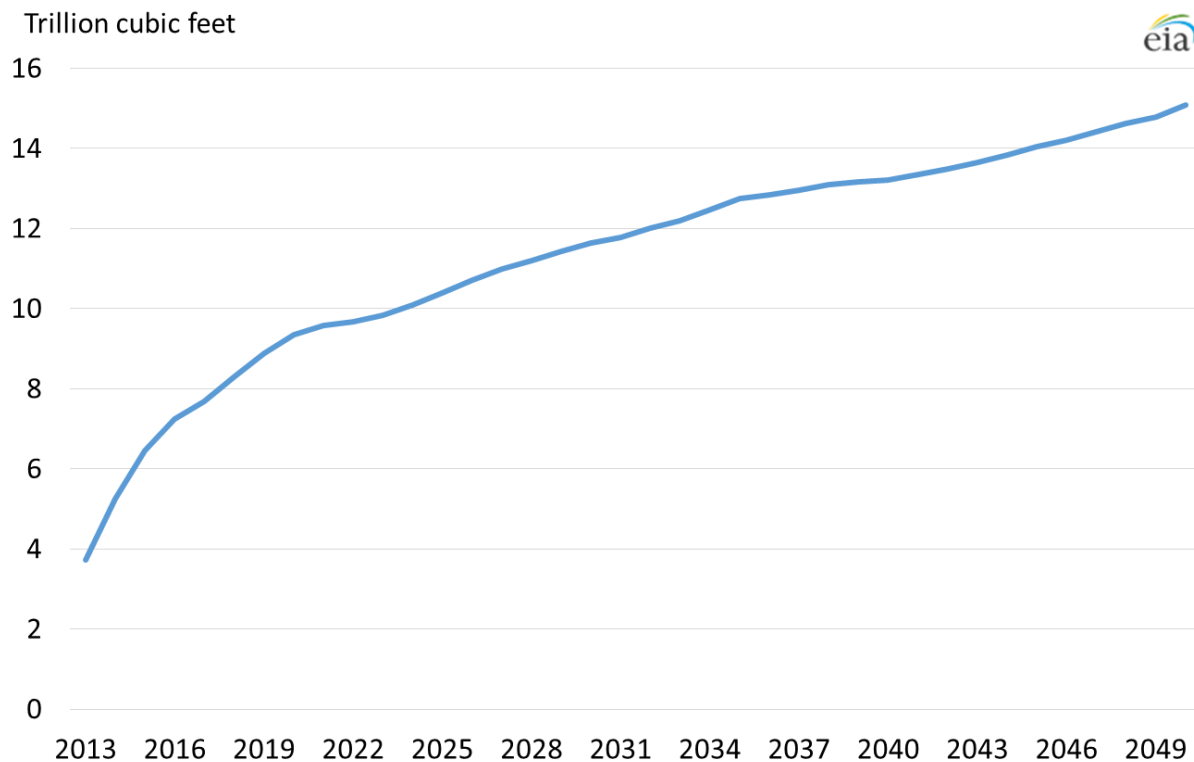
Inventories of propane, which have expanded significantly earlier in the decade, are expected to decline, on an annual basis, though still remain above pre-2013 levels. After hovering below 50 million barrels in 2010 and 2014, propane inventories grew to over 70 million barrels in 2014, and exceeded 91 million barrels in 2015. In 2016, on the back of strong export growth, inventories began to decline again, falling to 77 million barrels by year-end 2016, and are expected to fall below 62 million barrels by year-end 2017. In 2018, as U.S. prices approach international prices and the arbitrage opportunity for exporters recedes, inventories are forecasted to begin building again, albeit at a measured pace, to end the year at just below 70 million barrels.

<sup>c</sup> Annual averages. Excludes propylene. EIA uses product supplied as a proxy for consumption.

## IV. Natural Gas and Natural Gas Liquids Resources in Appalachia

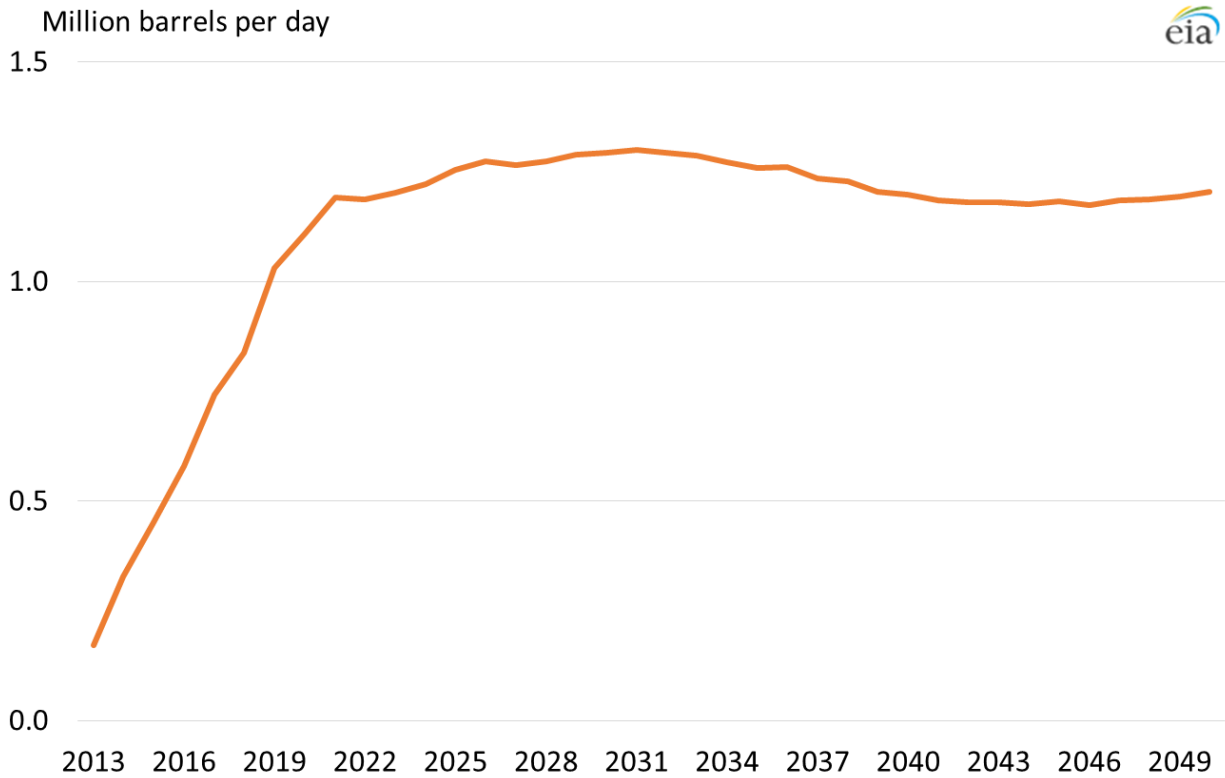
The Energy Information Administration forecasts substantial growth in natural gas and NGL production in Appalachia over the coming decades.

**Figure 6. Appalachia Natural Gas Production**<sup>13</sup>



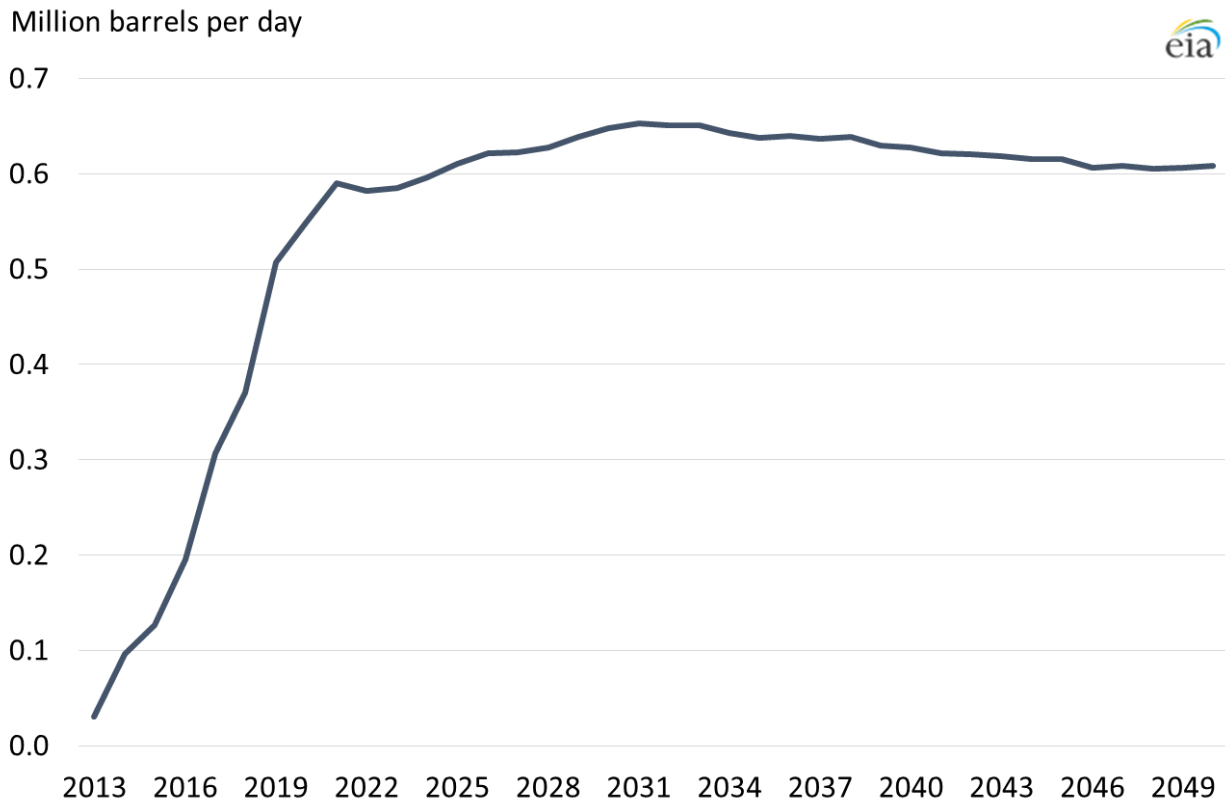
Natural gas production in the Appalachian region is projected to continue very steady growth in the short and long-term. Natural gas output is projected at 8 trillion cubic feet (Tcf) in 2017 and expected to increase 60% by 2020. Output in 2050 is projected at 18.7 Tcf.

**Figure 7. Appalachia NGL Production<sup>14</sup>**



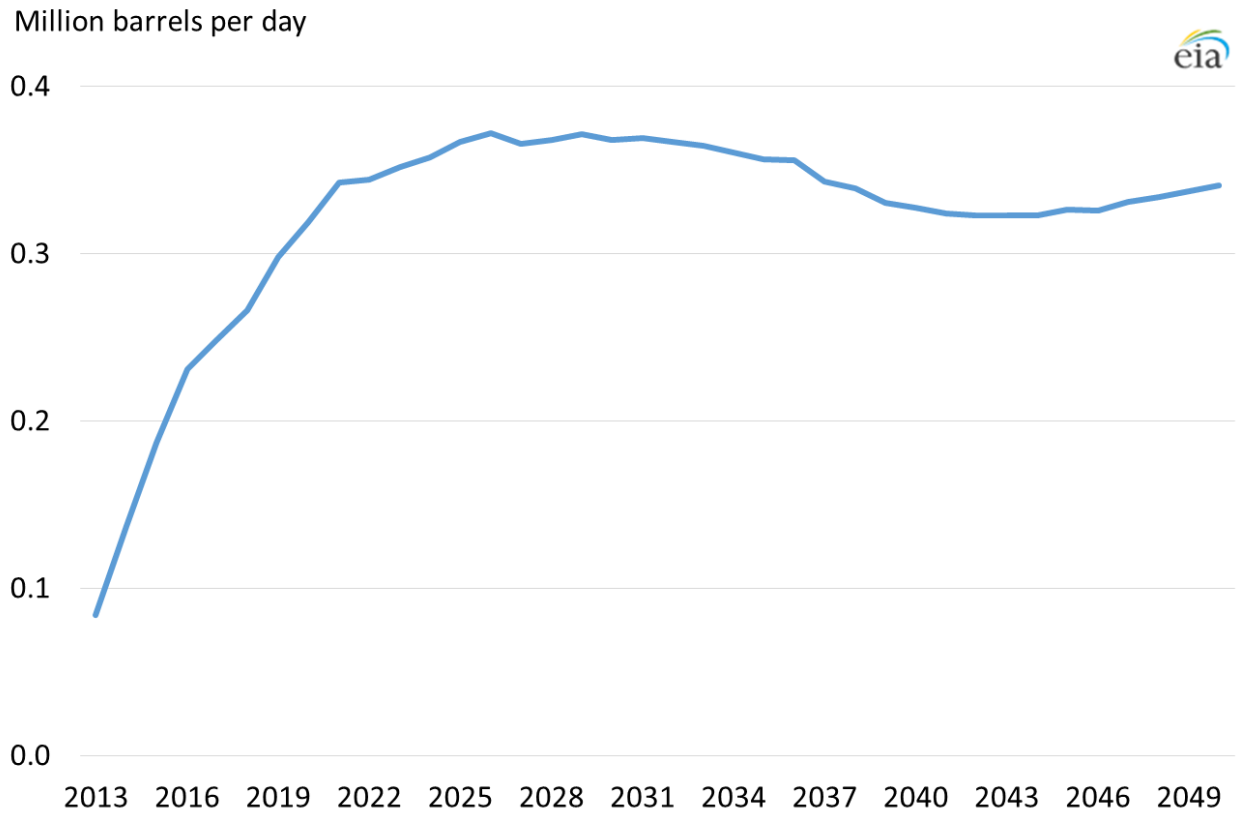
NGL output will continue to grow through 2025 as producers target wet gas areas, and then experience a plateau and eventual gradual decline to 2050. NGL output from 2017 to 2025 will more than double from 403,000 b/d in 2017 to 1.3 million b/d in 2030. NGL output is projected to reach 1.2 million b/d in 2050.

**Figure 8. Appalachia Ethane Production<sup>15</sup>**



Ethane production in the region is forecasted to continue its rapid growth in the coming years. Projected production in 2025, at over 600,000 b/d, is nearly 20 times greater than regional ethane production in 2013.

**Figure 9. Appalachia Propane Production<sup>16</sup>**



Propane production in Appalachia nearly tripled in the three years from 2013 to 2016. Peak propane production in the region is forecasted to occur in 2026 with an annual production of 372,000 b/d.

## V. Natural Gas Liquids Infrastructure in Appalachia

The supply chain facilitating natural gas liquids production and use involves several distinct activities and related infrastructure. This section details those activities – from production wells to petrochemical plants – and describes existing and proposed infrastructure in Appalachia related to NGLs.

### *A. Wellhead Production*

The Appalachian region, consisting of the currently-producing Marcellus and Utica basins shales as well as the undeveloped Rogersville shale, has experienced massive production growth in recent years. Natural gas production in the Marcellus/Utica region increased from 2.0 billion cubic feet per day (Bcf/d) in January 2010 to 24.2 Bcf/d in August 2017, which is roughly one-third of all U.S. dry natural gas production.

NGLs are found in raw natural gas and produced when extracted in a gas processing plant. NGL output in the Marcellus/Utica region rose by 530,000 barrels per day (b/d) between January 2010 and August 2017, from an estimated 20,000 b/d. This Appalachian production growth accounts for a third of total U.S. increase in NGL production during this time.

Production in the western Marcellus/Utica region has mostly been focused on wet gas zones. Wet gas zones produce dry methane gas co-mixed with heavier NGL hydrocarbons. These complex wet gas areas – which yield larger quantities of ethane, propane, butanes, and natural gasoline – bring more value to producers than dry gas zones. Figures 10 and 11 below depict the geographic extent of the Marcellus and Utica plays as well as where producing wells are located.

Figure 10. Marcellus Wells<sup>17</sup>

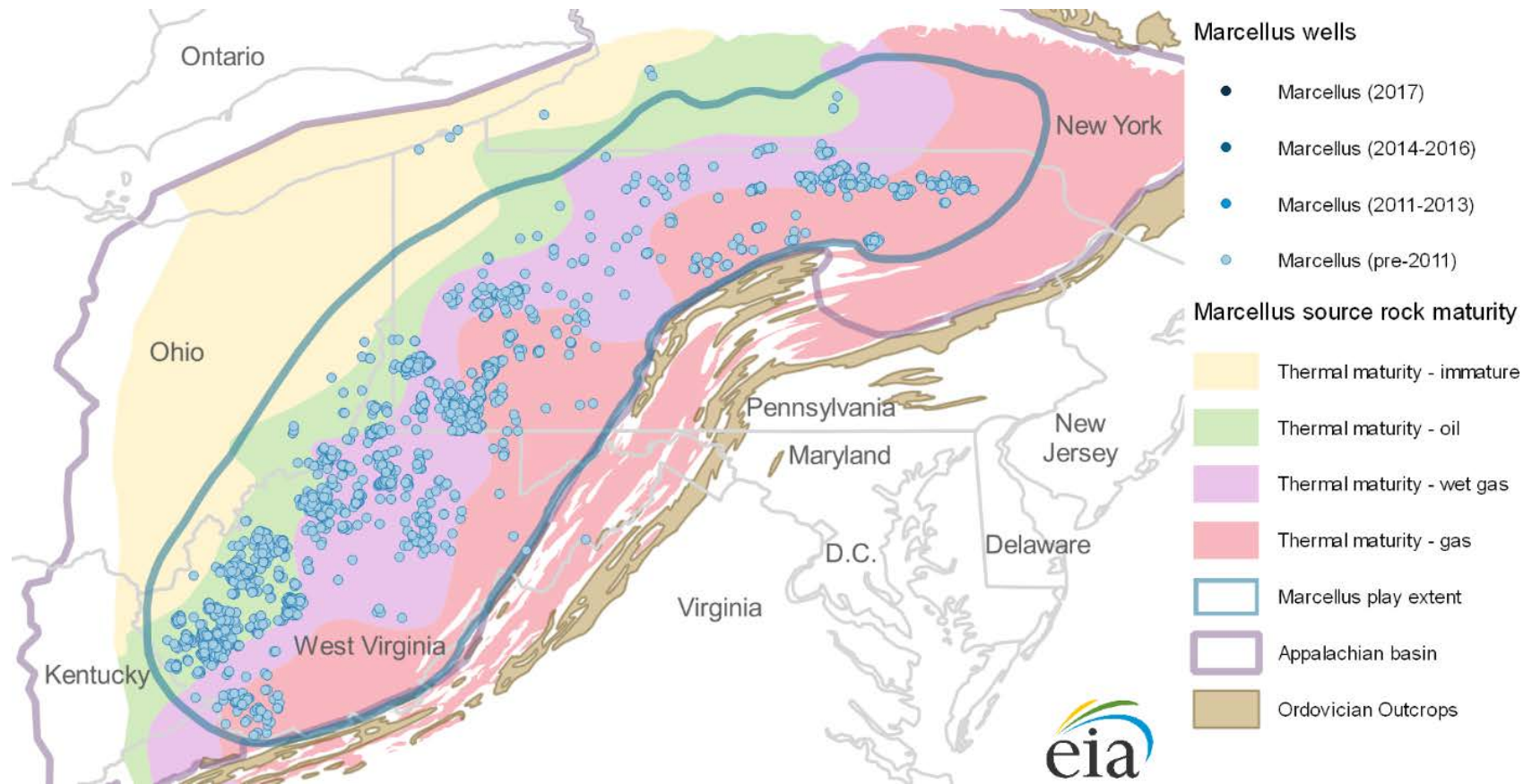
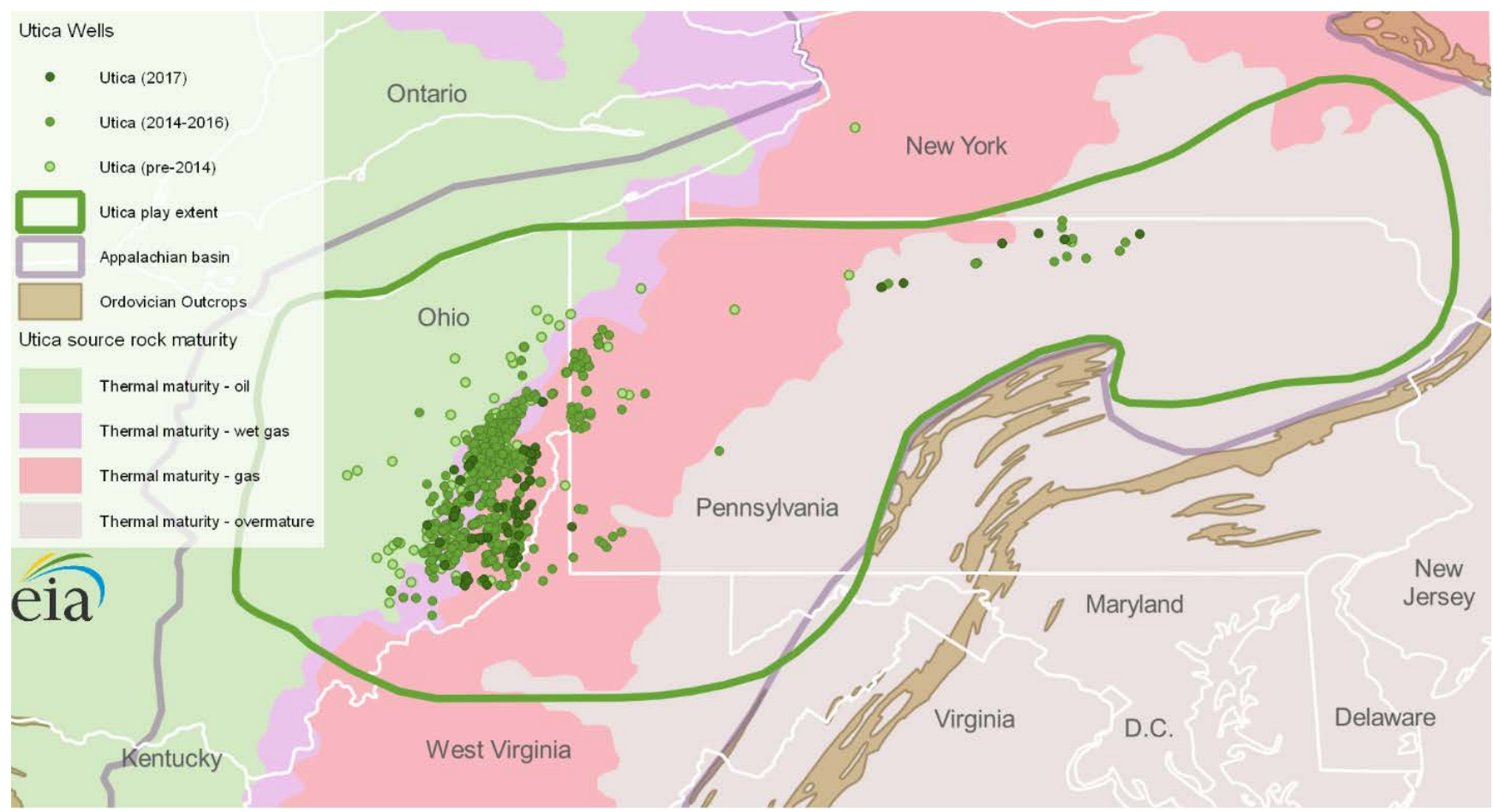


Figure 11. Utica Wells<sup>18</sup>





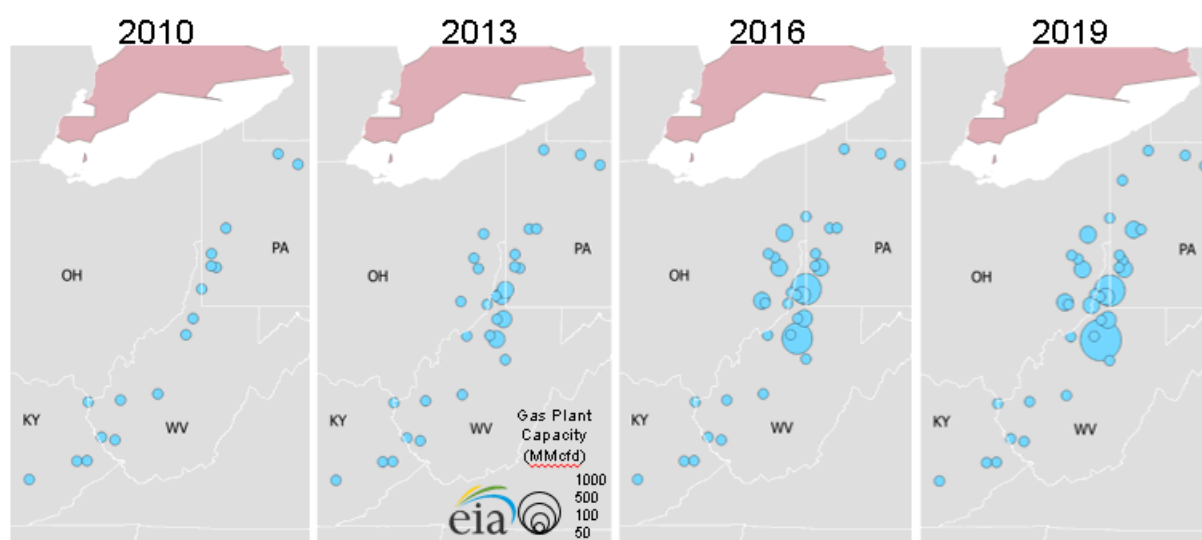
## B. Natural Gas Processing

Natural gas processing plays a key role in the natural gas supply chain by treating the produced “raw” gas so it can be sent into a pipeline without causing excessive corrosion or mechanical issues. Natural gas processors typically remove water, CO<sub>2</sub>, sulfur, and other contaminants from the raw natural gas, and separate “dry” natural gas from NGLs, which can cause mechanical issues during pipeline transit and problems for natural gas consumers requiring a fuel with a particular heat content. Extracted NGLs are then sold at prices higher than those they would receive if marketed at their natural gas heat value (\$/MMBtu).

Accompanying the growth in natural gas output in Appalachia has been an unprecedented buildout of gas processing capacity in the states overlaying the formations. 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 (see Figure 12 below). The additional capacity to process natural gas has in turn accelerated production of both natural gas and NGLs.

The new processing plants being constructed are modern, efficient units that use powerful compressors and chillers that cool natural gas to cryogenic temperatures (approx. –120°F) to separate the dry natural gas from the liquids. There are other technologies processors can use to separate the gas and liquids streams, but cryogenics allows for the highest percentage of liquids recovery. Additionally, plants with cryogenic units recover more propane (all heavier NGLs are always recovered) and can more easily adjust their equipment to extract more or less ethane from the natural gas stream in response to the commodity price. When the price of ethane is low – near or below the price of natural gas on a heating-value-equivalent basis, many processors may choose to leave ethane in the natural gas stream (referred to as ethane rejection) and sell it as natural gas.

**Figure 12. Gas processing plants in the Appalachian region<sup>19</sup>**



### C. NGL Fractionation

After raw natural gas is processed, NGLs leave the gas processing plant as a mix called Y-grade, and are then further refined or “fractionated” into distinct products of ethane, propane, normal butane, and isobutane, and natural gasoline. Fractionation can take place at a co-located fractionator or at a stand-alone fractionator connected to multiple gas processing plants by pipelines.

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 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 (see Figure 13 below). Figure 14 depicts the locations of gas processing plants and fractionators, both operating and planned, in the region.

**Figure 13. NGL Fractionation plants in the Appalachian region<sup>20</sup>**

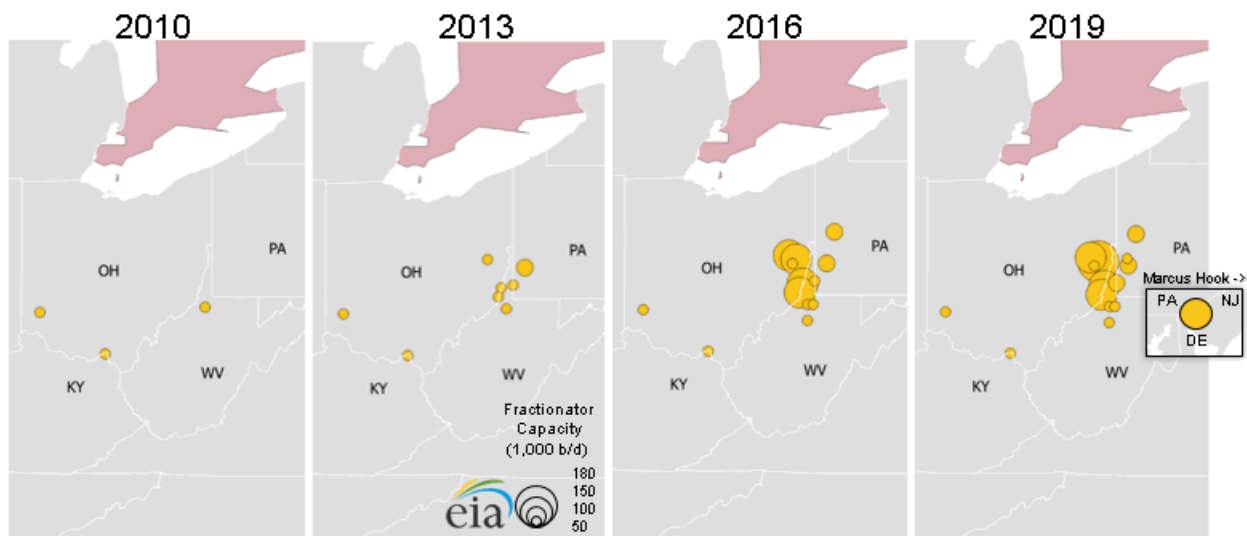
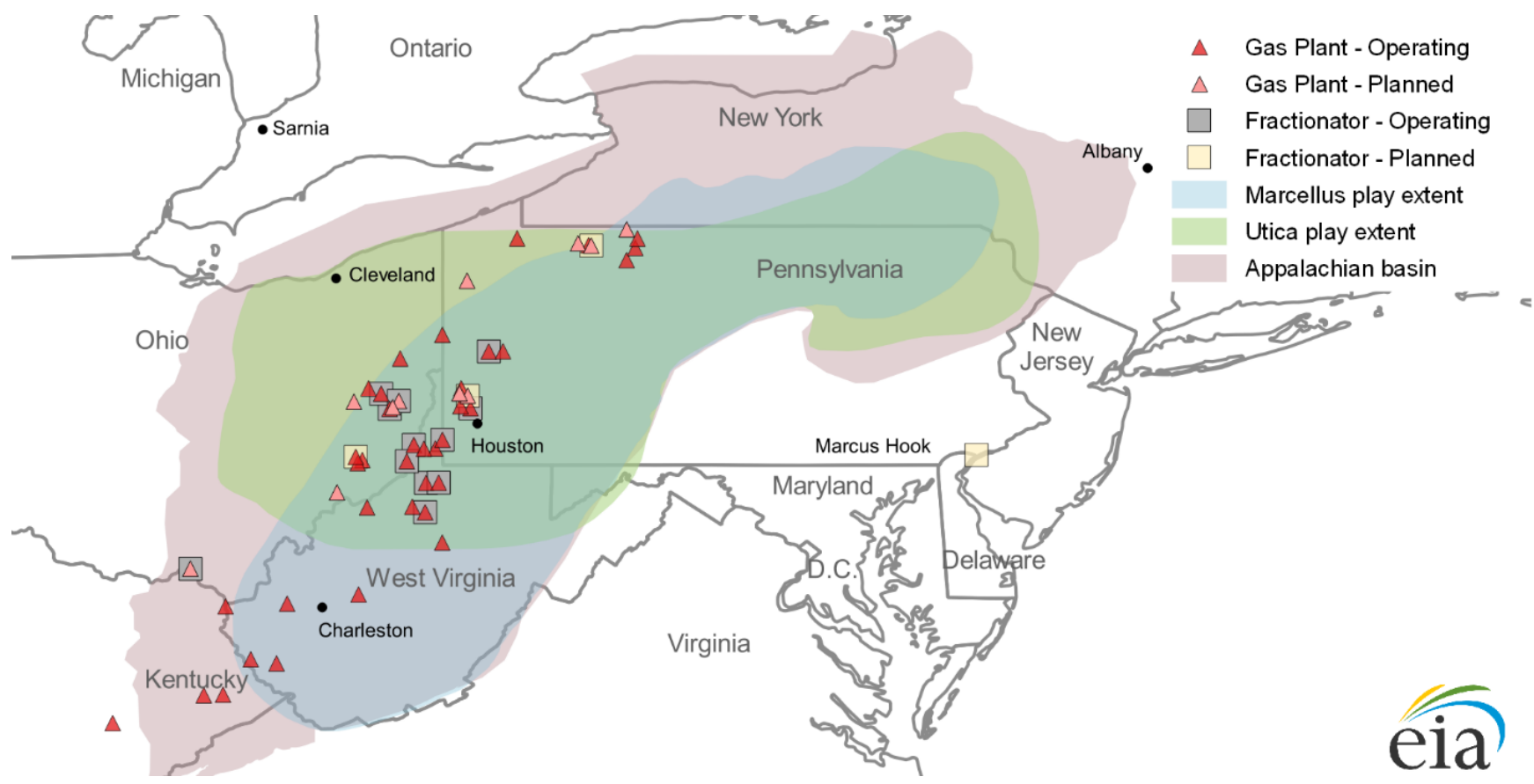


Figure 14. Location of Gas Processing Plants and Fractionators in Appalachia



**D. NGL Transportation**

In the Appalachian region, the increase in shale gas production since 2010 has spurred development of new midstream infrastructure, including pipelines and natural gas processing plants. At current levels, the NGL output exceeds in-region demand, necessitating transportation to other demand regions. Most NGLs in the U.S. are transported by pipeline; however, options for natural gas producers and processors in the Marcellus/Utica region to move NGLs to other markets via pipeline remain limited, and a significant share of production moves by rail. This has reduced the profitability of liquids production, especially after the 2014 oil-price decline, leading producers to focus on production areas where liquids do not constitute a large component of the produced gas stream. Currently, there are five pipelines that can move NGL production within and out of the region, with others in the planning or construction stage. Figure 15 below depicts NGL pipeline and cracking capacity by project and projected in-service date; figure 16 below shows the geographic locations of existing and proposed NGL pipelines in the region.

**Figure 15. Appalachia NGL Pipeline and Cracking Capacity, Existing and Announced<sup>21</sup>**

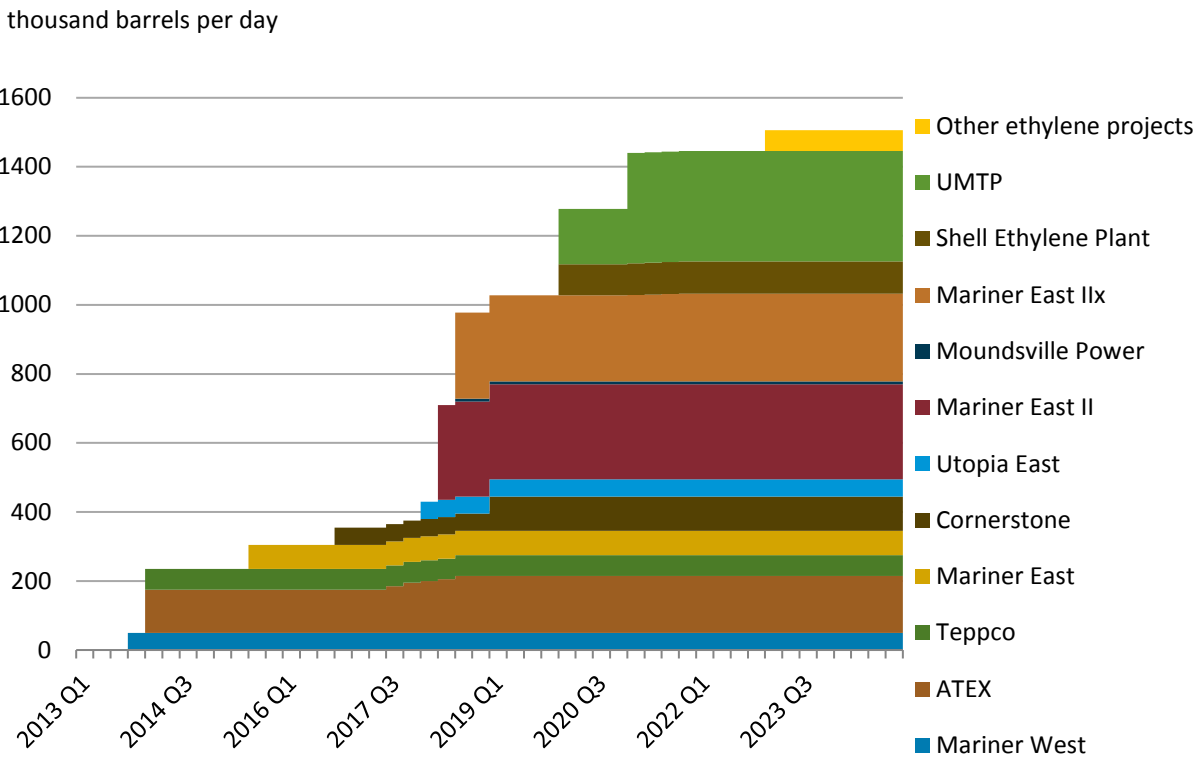
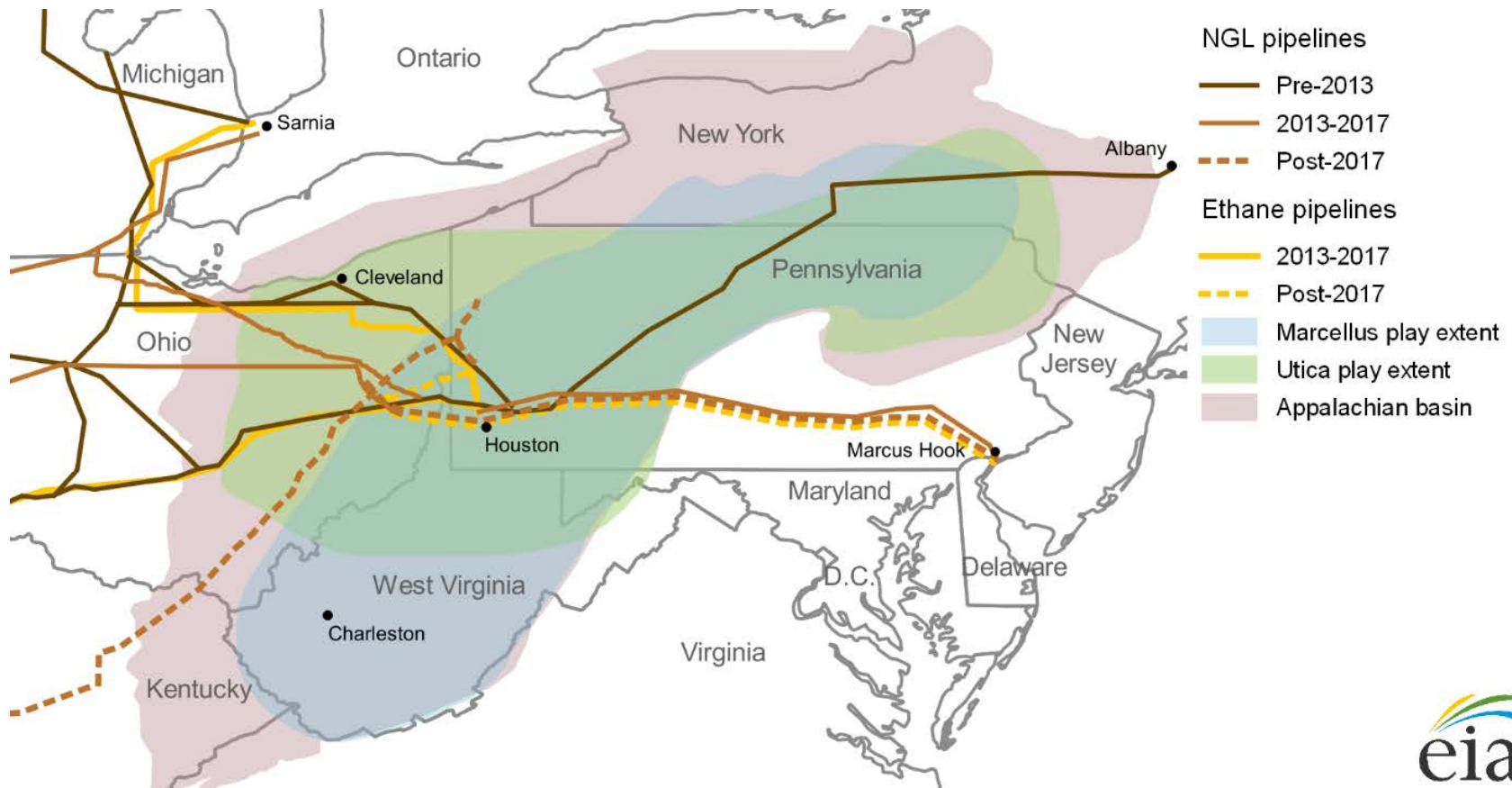


Figure 16. Appalachia NGL Pipelines, Existing and Announced<sup>22</sup>



## Existing and under construction pipelines

- The Enterprise Product Partners' (EPP) Appalachia-to-Texas Express (ATEX) pipeline, in service since early 2014, has allowed for the movement of up to 125,000 b/d of ethane out of the region to the Gulf Coast.<sup>23</sup> Enterprise is expanding capacity on the 14-inch ATEX line through additional pumping up to 145,000 b/d by end of 2017, and to 165,000 b/d by 2018 Q3. Anchor shippers on the line include Range Resources and Antero Resources. Should the need arise, ATEX may also offer the option of moving ethane north, from the Gulf Coast to Calvert City, Kentucky, where Westlake operates the only currently-active petrochemical cracker in the region.<sup>24</sup>
- In addition to ATEX, EPP owns and operates the TE Product Pipeline Company (known as TEPPCO), which can receive approximately 60,000 b/d of propane at Houston, Pennsylvania for shipment north as far as Selkirk, New York. TEPPCO, which originally consisted of a 16-inch line and a 14-inch line with receipts starting at Mt. Belvieu and other Gulf Coast originations, now moves products just on the 16-inch line. In 2014 TEPPCO suspended service on the 14-inch line, repurposing it for south-bound ethane shipment (see ATEX above). As a result of the 14-inch line repurposing, service for many products had been reduced. The pipeline connects to multiple storage facilities: Crestwood's Bath, New York storage facility, EPP's Watkins Glen, New York and Hartford Mills, New York terminals, and previously served the Todhunter, Ohio storage terminal.<sup>25</sup> It also allows for propane deliveries (with limited on-site storage) at Coshocton, Ohio, Dubois and Greensburg, Pennsylvania, and Oneonta and Selkirk, New York.
- Marathon Logistics (MPLX) completed the Cornerstone pipeline in September 2016, currently capable of moving natural gasoline and condensate from Cadiz, Ohio, via Scio, Ohio, to Canton, Ohio.<sup>26</sup> Product shipped on the pipeline can then move further west on Marathon's existing pipelines, reaching refineries in western Ohio and Michigan. Interconnections also allow shipments further west, and Kinder Morgan has reported receiving condensate and natural gasoline at its New Wabash Interconnect in St. Anne, Illinois into its Cochin pipeline for diluent use in Western Canada. Marathon's open season documentation allowed for the possibility of shipping natural gasoline, condensate, diluent, as well as butanes on the line.<sup>27</sup> A further expansion of the Marathon system, called the Utica Build-Out Project, would expand capacity to 160,000 b/d and provide refineries in the region with a local source of butanes, which are now generally shipped in from the Gulf Coast on the TEPPCO pipeline. Marathon is also mining a 1.4 million barrel butane storage cavern below its Robinson, Illinois refinery, due for completion in 2018.<sup>28,29</sup>
- Sunoco Logistics operates two pipelines originating in western Pennsylvania.<sup>30</sup> The Mariner West pipeline, completed in December 2013, has the capacity to move up to 50,000 b/d of ethane to Sarnia, Ontario, where it serves the feedstock requirements of NOVA Chemicals' Corunna cracker, with some volumes also available for Imperial's

Sarnia cracker.<sup>31</sup> The 70,000 b/d Mariner East Phase I pipeline is capable of shipping ethane and propane to Marcus Hook, Pennsylvania, where Sunoco Logistics operates an export terminal capable of loading cryogenic ethane and refrigerated propane to overseas destinations.<sup>32</sup>

Sunoco is in the process of building out its Mariner East system with a 20-inch, 275,000 b/d Mariner East II (ME2) and 16-inch, 250,000 b/d Mariner East IIx (ME2x).<sup>33</sup> ME2 is now expected to be completed in 2018 Q2, whereas ME2x is expected to be completed in 2018 Q3. The two new pipes, in combination with Mariner East I, will operate as a system, capable of moving nearly 600,000 barrels of liquids, from ethane up to condensate and refined petroleum products, east from Scio, Ohio and Natrium, West Virginia, via Houston, Pennsylvania out to open water at Marcus Hook.

- Due for completion around the turn of the year, the Utopia East pipeline has an initial capacity of 50,000 b/d of ethane, running northwest out of Cadiz and the Scio gas processing plant in Harrison County, Ohio, and terminating at an interconnect with the remnant of the Cochin pipeline in Riga, Michigan.<sup>34</sup> The Cochin pipeline, once a significant source of propane shipped from Western Canada to terminals throughout the Midwest, was repurposed to flow from the Kankakee terminal in Illinois north, delivering diluent for the shipment of Canadian bitumen. The segment between Kankakee and St. Anne, Illinois was recently brought back into service to allow for shipments of Marcellus/Utica condensate that are now injected from the Marathon pipeline system (see Cornerstone above), while the section from St. Anne to Marysville, Michigan remains abandoned. The new Utopia pipeline will bring back into service the stretch from Riga, Michigan to Windsor, Ontario, crossing the St. Claire River (and the U.S./Canada border) to Sarnia.<sup>35</sup> The pipeline consists of 150 miles of new-built 12-inch pipe from Harrison County to Seneca County, Ohio, 63 miles of 12-inch pipeline acquired from a third party from Seneca County, Ohio to Riga and 56 miles of 12-inch pipeline from Riga to Windsor, Ontario that was previously part of the Cochin pipeline. Line-fill is to begin in December 2017 and deliveries are to begin in January 2018. NOVA Chemicals, Canada's largest petrochemical company, is the anchor shipper on the line, using ethane shipped on Utopia to supplement receipts of ethane on the Mariner West pipeline.

**Table 4. NGL pipelines, capacities, and in-service dates**

Pipeline	Total Capacity (thousand b/d)	In-Service Date
Mariner West	50	December 2013
ATEX	125	January 2014
Teppco	60	January 2014
Mariner East	70	September 2015
Cornerstone	50+	September 2016
Mariner East II	275	<i>Planned October 2016 Now 2018 Q2</i>
Mariner East IIx	250	<i>Planned January 2017 Now 2018 Q3</i>

### ***E. NGL Storage***

Storage of NGL is necessary since produced volumes typically exceed the pipeline takeaway capacity and processing capacity. Large volumes of NGL 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.

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.<sup>36</sup>

EPP has invested in expanded access and deliverability at its Harford Mills, New York site, which is connected to the TEPPCO pipeline.<sup>37</sup> 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.

Crestwood’s proposed Finger Lakes NGL Storage Facility at Watkins Glen, New York, has been held in regulatory stasis for over 7 years, first filing a request to convert the depleted salt caverns to hydrocarbon storage in 2009, and satisfying all New York State DEC requirements by mid-2013.<sup>38</sup> 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.<sup>39</sup> As originally proposed, the facility would have been capable of holding 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 just



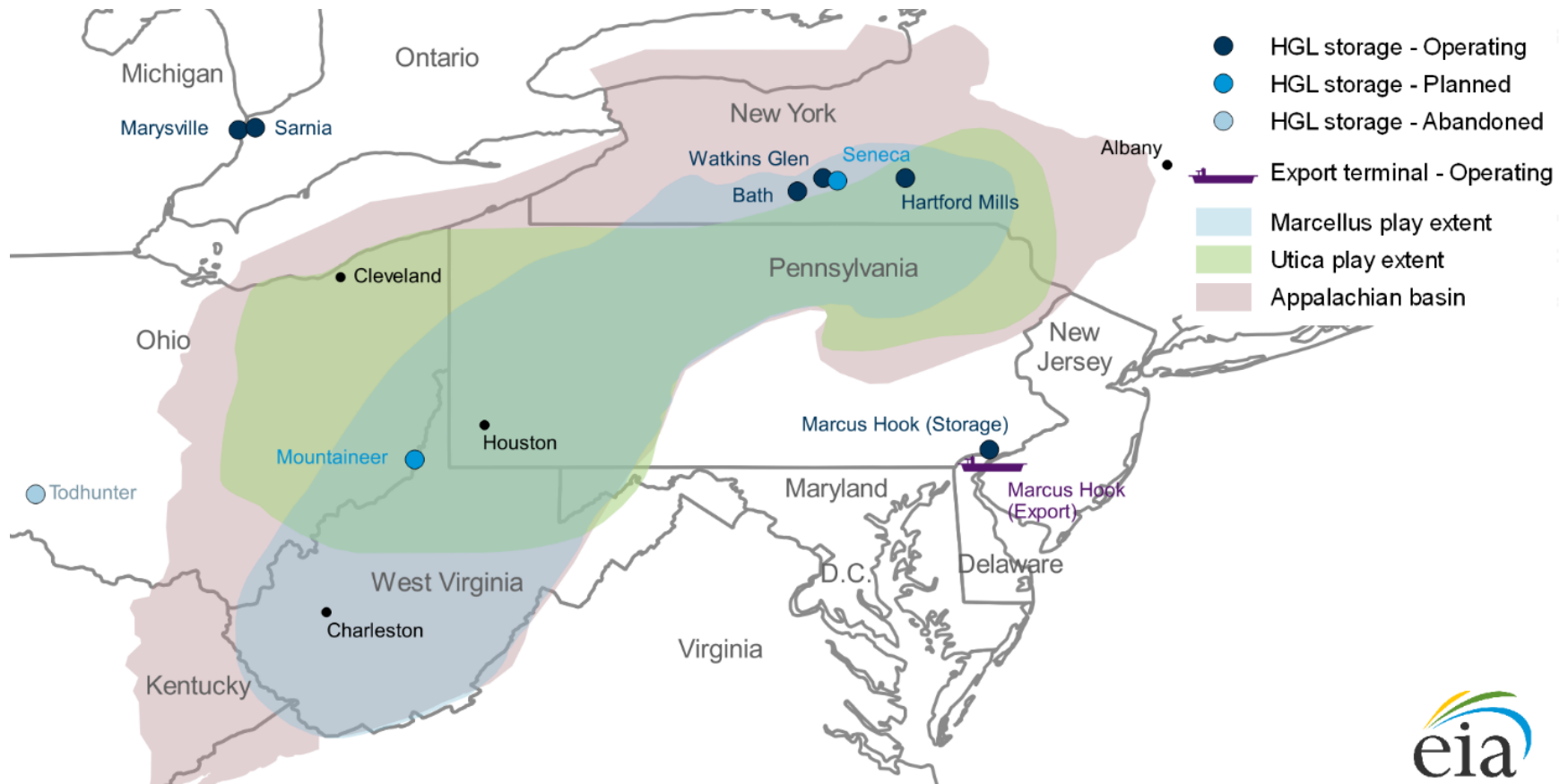
storing propane, and in only the larger, 1.5 million barrel cavern.<sup>40</sup> It has also shifted away from building the terminal with rail and truck access with pipeline access now the only option. In September 2017 one of the last challenges to Crestwood's DEC application was struck down, allowing the project to possibly proceed.<sup>41</sup>

Sunoco's site at Marcus Hook, Pennsylvania, sits 300 feet above 5 granite caverns capable of storing a combined 2 million barrels of NGL and olefins.<sup>42</sup> These caverns were mined in the 1950s, 60s, and 70s, and were an integral part of operations at the shuttered Marcus Hook refinery.<sup>43</sup> Now, the caverns provide storage services for the Paulsboro, New Jersey refinery across the Delaware River. The smallest cavern, at approximately 200,000 barrels, now belongs to Braskem and is integrated into their polypropylene plant operations. The remaining capacity, at around 1.8 million barrels, belongs to Sunoco. The largest cavern can hold approximately 1 million barrels.

As part of the Mariner East project, storage at the site was expanded. Initial phase of the project, which accompanied the Mariner East pipeline reversal and repurpose for NGPL service, included a 300,000 barrel ethane tank and a 500,000 barrel propane tank.<sup>44</sup> 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).<sup>45</sup> Completion of work on site was to be completed in time for the commissioning of the ME2 and ME2x pipelines in late 2017. While the pipeline is delayed, it is likely that the storage will be delivered on time.

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 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.<sup>46</sup> The storage facility will serve as a centrally-located storage point for NGL in the Appalachia region with rail and loading capacity as well as two 10-inch bi-directional pipelines to Blue Racer's nearby Natrium fractionator.<sup>47,48</sup> Initial storage is set 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 up to its permitted 3.25 million barrels capacity.

Figure 17. NGL Storage and Export Facilities<sup>49</sup>



### F. Ethylene Crackers

After NGLs are processed at the gas processing plant 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<sub>2</sub>H<sub>6</sub>) molecule into ethylene (C<sub>2</sub>H<sub>4</sub>), which is used by the petrochemical industry as a building block in the production of plastics and other petrochemical intermediate products.

Unique to the region, gas processing plants in Appalachia extract most ethane separately from the remaining NGL stream and have been increasing their capacity to do so faster than fractionation capacity overall. 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. 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.

**Table 5. Proposed Appalachian ethylene crackers**

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

First proposed in 2012, Shell Chemicals’ project is the first ethylene cracker project in the Appalachian region to move to the final investment decision stage (FID); it is also the biggest.<sup>50</sup> 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).<sup>51</sup> 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 four other cracker projects proposed for the region, local demand for NGL feedstock, primarily ethane, could be as high as 244,000 b/d – nearly as much as current capacity for moving all liquids out of the region.

In addition to Shell, PTT Global, in a joint venture with Marubeni, has proposed building a petrochemical cracker at Shadyside in Belmont County, Ohio. The companies have repeatedly delayed making FID, and have most recently postponed making the decision until end of 2017.<sup>52</sup> The cracker would in all likelihood be around 1 million metric tons, translating into 60,000 b/d of ethane feedstock demand. Like Shell’s, the project would include some kind of derivatives production – probably polyethylene but also possibly monoethylene glycol. PTT

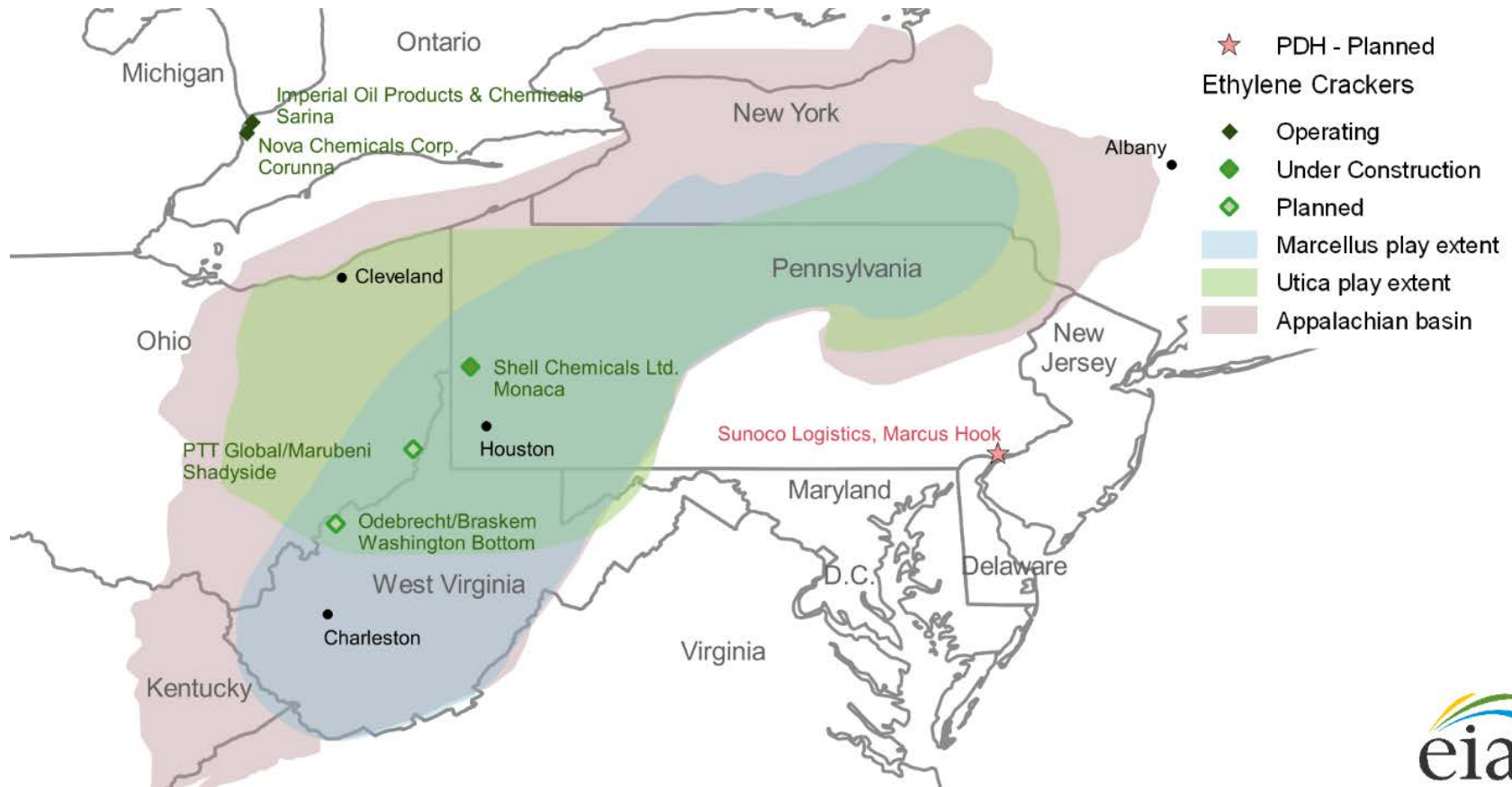
Global's experience in petrochemicals and Marubeni's (a Japanese trading house) access to capital and interest in U.S. shale investments, provide optimism that this project will eventually move forward.

The Ascent Project, Odebrecht/Braskem's cracker proposed for Washington Bottom in Wood County, West Virginia, was an early candidate for success.<sup>53</sup> 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.<sup>54</sup> The 1.05mil mt/y cracker is paired with HDPE and LDPE lines that generate polyethylene pellets for the 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.<sup>55</sup> 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 potential for two other cracker projects, Aithner Chemicals at South Charleston in Kanawha County, West Virginia, and Appalachian Resins at Salem Township in Monroe County, Ohio, is highly uncertain.<sup>56, 57</sup> The Aithner 500k mt/y cracker and the Appalachian Resins 600k mt/y project have not secured interest in funding or offtake agreements.<sup>58</sup> The current pricing environment, where the oil to gas price margin has narrowed, makes smaller projects that lack the capital of multinational corporations very risky for investors to take on.

The sole existing petrochemical cracker in the region is the Westlake 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 to the plant.<sup>59</sup> 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 in excess of \$300 million.<sup>60</sup> 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 18. Ethylene Crackers and Propane Dehydrogenation Plants**



### ***G. Propane Dehydrogenation***

Propane dehydrogenation (PDH) is the process of directly converting propane into propylene through specialized catalysts. Propylene is the second most common petrochemical molecule after ethylene, and is converted by the petrochemical industry primarily into plastics. The Appalachia region currently has no existing PDH capacity and little propylene production, causing propane to be shipped to other chemical processing regions and propylene for polypropylene production to be shipped in by rail.

Sunoco Logistics has proposed building a propane dehydrogenation (PDH) plant at its Marcus Hook, Pennsylvania site.<sup>61</sup> The PDH unit, of up to 1 million mt/y of capacity, would aim to convert propane to propylene, and supply this propylene as well as potentially alkylate – a high-octane gasoline blending component – to plants within a 600-mile radius. This project has made little headway to date given no progress on offtake agreements for the propylene.

## VI. Concluding Remarks

The Appalachian region is endowed with significant NGL resources projected to be economically recoverable over at least the next three decades. Since the boom in natural gas production – unlocked by technological innovation – industry has invested billions of dollars in natural gas and NGL infrastructure in Appalachia. Increased recovery of ethane, instead of rejecting it in the dry natural gas stream, presents opportunities for new downstream investments using ethane as a feedstock.

This primer addressed fundamental aspects of the NGL market and supply chain in Appalachia. There are opportunities for further analysis related to NGL resources in Appalachia. DOE has identified the following areas that may merit further in-depth study.

### **NGL Downstream Market Scenario Analysis**

- Explore scenarios for the development of a regional petrochemical industrial center. Analyze how ethylene and propylene markets may develop in the future to drive new investments in petrochemical plants and supporting infrastructure.
- Evaluate the potential downstream economic impacts of NGL utilization on the local, regional, and national economy.
- Study the impact additional U.S. NGL and product exports may have on international markets. Will new markets emerge and new trade patterns be established with increased U.S. NGL production and petrochemical plant capacity?

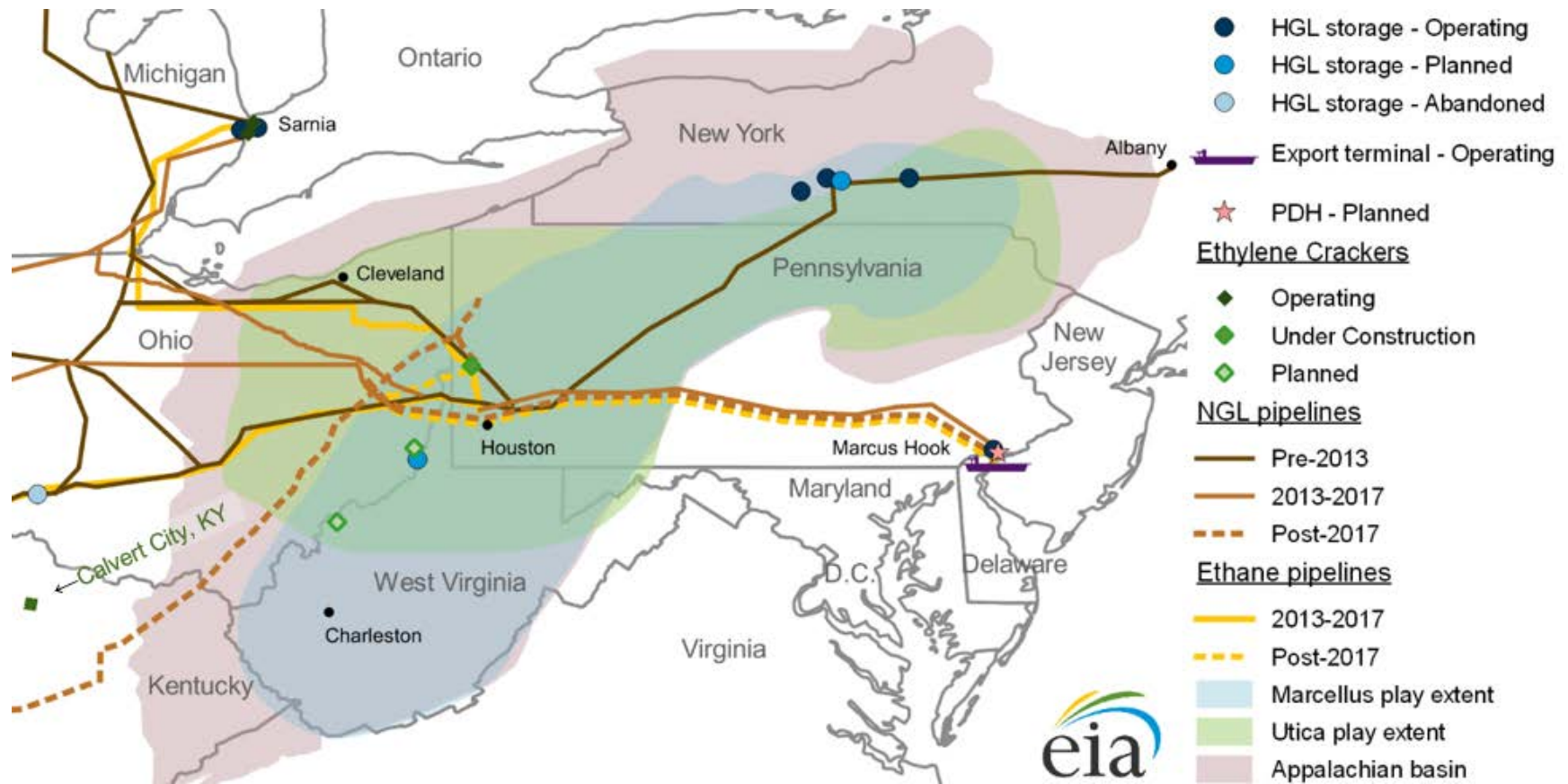
### **Reliability and Resilience**

- Define resilience for the NGL supply chain and petrochemical industries. Identify aspects of the natural gas and NGL system that contribute to reliability and resilience.
- Develop methods to evaluate the energy security implications of the domestic NGL supply chain and U.S. petrochemical plant capacity. Identify appropriate metrics to evaluate the energy security of the nation's NGL and petrochemical systems.

### **Research and Development Opportunities**

- Explore technologies and techniques to enhance the recovery efficiency of unconventional natural gas production.
- Conduct research in materials, technologies, and methods for improved conversion of natural gas and NGLs into feedstocks and products.
- Explore technologies to enhance the safety and efficiency of NGL storage, including the development of new materials and sensors to detect and prevent losses.

# Appendix A: Pipelines, Storage, Export, and Petrochemical Plant Map<sup>62</sup>





## Appendix B: Abbreviations and Units

<b>ATEX</b>	Appalachia-to-Texas Express
<b>B/d</b>	Barrels per day
<b>Bcf/d</b>	Billion cubic feet per day
<b>C<sub>2</sub>H<sub>4</sub></b>	Ethylene
<b>C<sub>2</sub>H<sub>6</sub></b>	Ethane
<b>CO<sub>2</sub></b>	Carbon Dioxide
<b>DOE</b>	Department of Energy
<b>EIA</b>	Energy Information Administration
<b>EPP</b>	Enterprise Product Partners
<b>FID</b>	Final Investment Decision
<b>HDPE</b>	High-density Polyethylene
<b>HGL</b>	Hydrocarbon Gas Liquids
<b>LDPE</b>	Low-density Polyethylene
<b>ME2</b>	Mariner East II
<b>ME2x</b>	Mariner East IIx
<b>MMBtu</b>	Million British thermal units
<b>MPLX</b>	Marathon Logistics
<b>mt/y</b>	Million tons per year
<b>NGL(s)</b>	Natural Gas Liquid(s)
<b>PDH</b>	Propane Dehydrogenation
<b>Tcf</b>	Trillion cubic feet
<b>TEPPCO</b>	TE Product Pipeline Company
<b>VLEC</b>	Very Large Ethane Carriers

## Endnotes

<sup>1</sup> Data used in the charts showing Appalachian production include all of the East region of the U.S. as defined by the United States Energy Information Administration (EIA) for the purpose of modeling in the Oil and Gas Supply Module of the Annual Energy Outlook (<https://www.eia.gov/outlooks/aeo/assumptions/pdf/oilgas.pdf>). The Appalachian region is defined as the Marcellus, Utica and Rogersville basins which lie within the borders of Kentucky, Ohio, Pennsylvania, and West Virginia. In 2016, natural gas production in these four states accounted for 97% of total East region production. While data in the charts represent the entire region, the figures are an appropriate representation of Appalachian production.

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<sup>3</sup> Information in Section II is from: EIA: "Hydrocarbon Gas Liquids Explained: Uses of Hydrocarbon Gas Liquids," December 2015, [https://www.eia.gov/energyexplained/index.cfm?page=hgls\\_uses](https://www.eia.gov/energyexplained/index.cfm?page=hgls_uses).

<sup>4</sup> Short-Term Energy Outlook (STEO), November 2017." November 7, 2017. Accessed November 2017. [https://www.eia.gov/outlooks/steo/pdf/steo\\_full.pdf](https://www.eia.gov/outlooks/steo/pdf/steo_full.pdf). And EIA internal analysis.

<sup>5</sup> U.S. Energy Information Administration, analysis based on Bloomberg data, November 21, 2017.

<sup>6</sup> Short-Term Energy Outlook (STEO), November 2017." November 7, 2017. Accessed November 2017. [https://www.eia.gov/outlooks/steo/pdf/steo\\_full.pdf](https://www.eia.gov/outlooks/steo/pdf/steo_full.pdf). And EIA internal analysis.

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<sup>9</sup> Ibid.

<sup>10</sup> Ibid.

<sup>11</sup> Ibid.

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<sup>13</sup> "Annual Energy Outlook 2017." January 5, 2017. Accessed November 2017. <https://www.eia.gov/outlooks/aeo/>.

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<sup>17</sup> U.S. Energy Information Administration; well locations based on DrillingInfo data updated Nov. 2, 2017.

<sup>18</sup> U.S. Energy Information Administration; well locations based on DrillingInfo data updated Nov. 2, 2017.

<sup>19</sup> U.S. Energy Information Administration, Survey EIA-757 Data; Company public filings and press releases.

<sup>20</sup> Ibid.

<sup>21</sup> U.S. Energy Information Administration, based on company press releases and public filings.

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