U.S. DEPARTMENT OF ENERGY

U.S. Ethane: Market Issues and Opportunities

Report to Congress

September 2022

United States Department of Energy
Washington, DC 20585

Message from the Secretary

As called for by the Consolidated Appropriations Act, 2021 (P.L. 116-260), and explanatory statement (166 Cong. Rec. H7879, H8363 (Dec. 21., 2020)), the Department of Energy is submitting a report on Ethane Long-Term Trends. This report is being provided to the following Members of Congress:

- **The Honorable Patrick Leahy**
  Chair, Senate Committee on Appropriations

- **The Honorable Richard Shelby**
  Vice Chair, Senate Committee on Appropriations

- **The Honorable Rosa L. DeLauro**
  Chair, House Committee on Appropriations

- **The Honorable Kay Granger**
  Ranking Member, House Committee on Appropriations

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

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

- **The Honorable Marcy Kaptur**
  Chairwoman, Subcommittee on Energy and Water Development, and Related Agencies
  House Committee on Appropriations

- **The Honorable Mike Simpson**
  Ranking Member, Subcommittee on Energy and Water Development, and Related Agencies
  House Committee on Appropriations

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

- **The Honorable Cathy McMorris Rodgers**
  Ranking Member, House Committee on Energy and Commerce

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

- **The Honorable Frank Lucas**
  Ranking Member, House Committee on Science, Space, and Technology

- **The Honorable Joe Manchin**
  Chairman, Senate Committee on Energy and Natural Resources

- **The Honorable John Barrasso**
  Ranking Member, Senate Committee on Energy and Natural Resources

If you have any questions or need additional information, please contact me or Ms. Rebecca Ward, Deputy Assistant Secretary for Senate Affairs or Mr. Michael Harris, Legislative Affairs Advisor (House), Office of Congressional and Intergovernmental Affairs, at (202) 586-5450, or Ms. Katie Donley, Deputy Director of External Coordination, Office of the Chief Financial Officer, at (202) 586-0176.

Sincerely,

Jennifer Granholm

Foreword

The United States (U.S.) Department of Energy (DOE) produced this Report to Congress in response to a request under the Consolidated Appropriations Act, 2021 (Public Law 116-260), specifically the Energy and Water Development and Related Agencies Appropriations Act, 2021 – Division D, and explanatory statement (166 Con. Rec. H7879, H8363 (Dec. 21, 2020). The report focuses on projected long-term trends for the domestic production, consumption, and export of ethane, and prospective opportunities and risks associated with U.S. petrochemical manufacturing that utilizes ethane as a feedstock.

According to the U.S. Energy Information Administration (EIA), domestic ethane production has nearly doubled since 2013, from 0.95 million barrels per day (b/d) to 1.85 million b/d at the outset of 2021 (1). In addition, U.S. ethane exports reached a record high in March 2021 (2). As a result of this rapid growth, EIA is forecasting continued ethane production growth in response to U.S. and global petrochemical industry demand through 2023. In the long term, however, ethane production may decline if there is a shift away from petrochemical products, both in the U.S. and internationally.

Consistent with the congressional request, this report focuses on the transportation, storage, and distribution of ethane after it has been produced, including its use as a petrochemical feedstock domestically and its status as a valued commodity for export. The report does not cover natural gas liquid (NGL) extraction at the wellhead or ethane production occurring within natural gas processing plants. This report also focuses some of its analysis on the Appalachian region, which has been identified for holding significant potential for future U.S. petrochemical development, rather than the U.S. Gulf Coast, which is already a mature petrochemical manufacturing hub.

This report builds upon previous DOE reports investigating ethane's energy and economic development potential within Appalachia, including the *Appalachian Energy and Petrochemical Renaissance* (published in June 2020, required by Executive Order 13868, "Promoting Energy Infrastructure and Economic Growth") and the *Ethane Storage and Distribution Hub in the United States* (published in November 2018, pursuant to House Report 114-532 that accompanied the 2017 Energy and Water Development Appropriations Bill).

President Biden's Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," directs federal agencies to make securing environmental justice and economic opportunity for disadvantaged communities a priority. This includes investing and building a clean energy economy in communities that are economically reliant on fossil fuel production, and addressing the disproportionate health, environmental, economic, and climate impacts of pollution on disadvantaged communities.

In keeping with Executive Order 14008, DOE included an analysis in this report of environmental and community impacts of ethane development. DOE also hosted a virtual public meeting on August 24, 2021, to solicit data, information, and perspectives on ethane development from a broad range of individual stakeholders, including residents of local communities adjacent to petrochemical plants. These stakeholder inputs provided DOE with valuable perspectives and will help to inform clean energy strategies and future technology investments that yield sustainable solutions and help to shrink the environmental and climate footprint of energy and associated product development and delivery.

Preface

This report has been produced in response to a congressional request to assess the long-term trends related to the domestic production and consumption of ethane, the export of ethane, and the opportunities related to—and economic benefits of—investments in further domestic use of ethane. To produce this report, the United States (U.S.) Department of Energy (DOE) analyzed U.S. ethane production trends and related infrastructure issues, U.S. ethane consumption, exports of U.S. ethane, and the potential economic impacts associated with expanded U.S. domestic use of ethane. The analysis considered ethane's current domestic value chain, domestic and global as well as historic and projected market growth, and environmental impacts associated with the expanding role of ethane in petrochemical manufacturing. Key findings include the following:

- Similar to expected growth in natural gas production, the volume of U.S. natural gas plant liquid (NGPL)[1] production is anticipated to increase approximately 20 percent over the next three decades—with ethane production continuing to account for over 40 percent of U.S. NGPLs by volume through 2050 (3).
- Approximately 80 percent of U.S. annual ethane production is currently consumed by the domestic petrochemical industry; however, the United States is also the top global ethane exporter, and ethane exports are expected to grow by 20 percent between 2020 and 2022 to meet growing customer demand from Canada, China, Europe, and India (4) (5).
- The United States has a competitive advantage over other countries with its lower cost structure for ethylene and its derivatives due to its reliance on abundant, domestically produced ethane as a feedstock. As ethane availability in the United States increases along with natural gas production, downstream product development that includes ethylene and derivatives, as well as the export of these products, represents a key opportunity to increase manufacturing industrial output and jobs. This analysis found that there is a potential opportunity cost associated with exporting available ethane instead of using it domestically to manufacture ethylene derivatives.
- China has imposed and adjusted tariffs on polyethylene imported from the United States multiple times since the onset of the trade tensions that began in 2018, and U.S. polyethylene exports to China have decreased significantly due to the hikes in tariffs that reached 25–30 percent for some derivative products.
- Community and non-governmental organization (NGO) stakeholders continue to express concern that steam crackers are a source of hazardous air pollutants (HAP), including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and volatile organic compounds (VOC), and that they contribute to ever expanding global carbon dioxide (CO_2) emissions. Stakeholders have suggested changes to regulations that could mitigate some impacts, and industry is also developing technical solutions for generally shrinking the environmental footprint of petrochemical manufacturing. Stakeholders have also expressed concerns about the

[1] NGPLs are the wet natural gas byproduct of natural gas processing, and include a mix of ethane, propane, and butanes.

environmental impacts of upstream natural gas production; these impacts are not addressed in this report. On these issues, DOE and the Environmental Protection Agency (EPA) have published studies, some of which will be cited in this report.

To further inform the study, the Office of Fossil Energy and Carbon Management held a public meeting in August 2021 to obtain data, information, and perspectives from community stakeholders, including local communities near petrochemical plants. Several key themes emerged and are discussed in an appendix to this report detailing various perspectives raised during the meeting.

List of Acronyms

°C	Degrees Celsius
°F	Degrees Fahrenheit
$	U.S. dollar
2012$	2012 dollars
ACC	American Chemistry Council
AEO	Annual Energy Outlook
AFPM	American Fuel & Petrochemical Manufacturers
b/d	Barrels per day
bbl	Barrel
bcf	Billion cubic feet
BLS	Bureau of Labor Statistics
BRI	Belt and Road Initiative
Btu	British thermal unit
C x I	Commodity-by-industry
CA	California
CAA	Clean Air Act
CEPM	Center for Energy Policy and Management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Ac
CFR	Code of Federal Regulations
CO_2	Carbon dioxide
DOE	Department of Energy
DSI	Dry sorbent injection
EDC	Ethylene dichloride
EIA	Energy Information Administration
E/P	Ethane/propane
EPA	Environmental Protection Agency
FDI	Foreign Direct Investment
FECM	DOE Office of Fossil Energy and Carbon Management
FERC	Federal Energy Regulatory Commission
FL	Florida
GDP	Gross domestic product
GHG	Greenhouse gas
HAPs	Hazardous air pollutants
HDPE	High-density polyethylene
HGL	Hydrocarbon gas liquid
HTS	Harmonized Tarif System
IA	Iowa
IL	Illinois

IMO	International Maritime Organization
IO	Input-output
ISO	International Organization for Standardization
KY	Kentucky
LA	Louisiana
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
LPG	Liquefied petroleum gas
LRG	Liquefied refinery gas
$M	Million U.S. dollars
MIC 2025	Made in China 2025
MT	Montana
NAICS	North American Industry Classification System
N, N_2	Nitrogen
ND	North Dakota
NETL	National Energy Technology Laboratory
NGL	Natural gas liquid
NGPL	Natural gas plant liquid
NIOSH	National Institute for Occupational Safety & Health
NGO	Non-governmental organization
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides
OH	Ohio
OK	Oklahoma
ORVI	Ohio River Valley Institute
OSHA	Occupational Safety and Health Administration
PA	Pennsylvania
PADD	Petroleum Administration for Defense District
PERI	Potomac Economic Research Institute
PNTR	Permanent Normal Trade Relations
ppm	Parts per million
PVC	Polyvinylchloride
RWFI	Regional Workforce Initiative
SO_2	Sulfur dioxide
SOx	Sulfur oxides
STEO	Short-Term Energy Outlook
SWPA	Southwestern Pennsylvania
TEAM	Tristate Energy and Advanced Manufacturing
TX	Texas

U.S.	United States
VOC	Volatile organic compound
WV	West Virginia
WTO	World Trade Organization

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Executive Summary

The United States (U.S.) Department of Energy (DOE) prepared this document at the request of Congress for a report assessing the long-term trends related to the domestic production and consumption of ethane, the export of ethane, and the opportunities created by—and economic benefits of—investments in further domestic use of ethane.

Over the last 15 years, technological advances that allowed for the economic extraction of hydrocarbons from U.S. shale resources—geologic formations containing significant accumulations of oil and natural gas—led to a large increase in U.S. crude oil and natural gas production. This presented an economic opportunity for the United States to bolster its energy security, become a net exporter of energy, and establish additional energy production and petrochemical processing capacity. Between 2008 and 2020, annual U.S. field production of crude oil increased from five million barrels per day (b/d) to 11.3 million b/d (6); during the same period, annual U.S. dry natural gas production increased from 20.2 trillion cubic feet per year (Tcf/yr) to 33.5 Tcf/yr (7). These significant increases have made the United States the world's largest producer of both crude oil and natural gas (8).

In addition to natural gas and crude oil, most shale plays yield valuable natural gas plant liquids (NGPL),[2] with ethane—a critical petrochemical feedstock used to produce compounds for making plastics and resins—accounting for more than 40 percent of the total volume of NGPLs. This report examines potential U.S. economic opportunities to leverage domestic ethane resources in the domestic and global petrochemicals industry. The U.S. petrochemical market had an estimated value of $95 billion in 2020, while the global market's size was estimated at $549 billion in 2020 and projected to reach $860.8 billion in 2028 (9). On an annual basis, U.S. and global market revenues are projected to grow by 6.3 percent and 6.4 percent respectively through 2028. Ethylene, a derivative, is the leading product segment of the petrochemical industry (9).

To produce this report, DOE analyzed U.S. ethane production trends and related infrastructure issues, U.S. ethane consumption, exports of U.S. ethane, global imports of U.S. produced ethane, and the potential economic impacts associated with expanded U.S. domestic use of ethane. The analysis considered ethane's current domestic value chain and the historic and projected global and domestic ethane market growth to inform its estimates. This report also includes a section focused on the environmental impacts of the increased use of ethane in petrochemical manufacturing.

Ethane is primarily produced from either crude oil/condensates or wet (i.e., unprocessed) natural gas. Processing crude oil and lease condensate through refining and condensate splitting produces liquefied refinery gas (LRG). LRGs are a mix of output molecules including ethane, propane, and

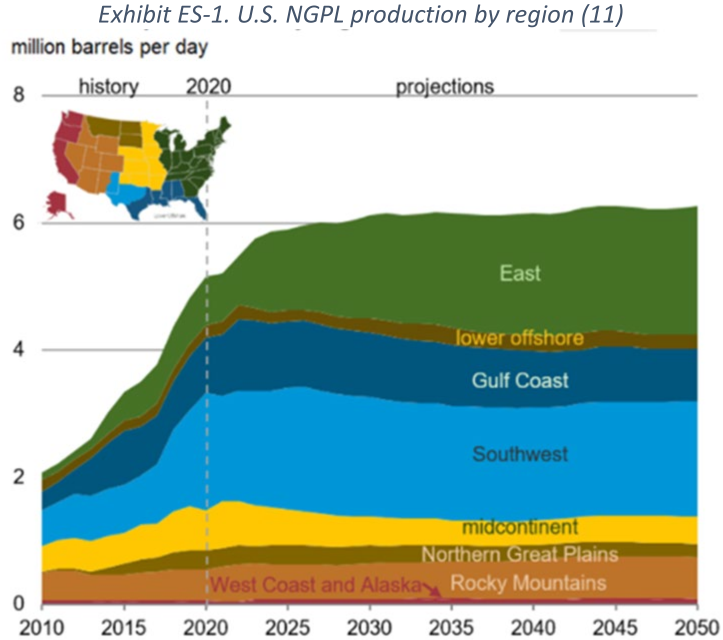
[2] Natural Gas Plant Liquids include ethane, propane, natural butane, isobutane, and natural gasoline.

butane in addition to olefins, such as ethylene (a primary component in petrochemical manufacturing) and propylene. Alternatively, natural gas processing separates dry gas (methane), commonly called "natural gas," from heavier compounds found in wet natural gas, called NGPLs (primarily ethane, propane, and butanes).[3] The term natural gas liquid (NGL) is used to specifically distinguish ethane, normal butane, isobutane, propane, and natural gasoline (pentanes plus) from olefins. In 2020, approximately 0.4 percent of U.S. ethane was produced from LRG, while over 99 percent of U.S. ethane was produced at natural gas processing plants (10). Given the large share of ethane produced from the natural gas value chain, the primary focus of this report is on U.S. ethane derived from the NGPL production pathway.

1. *Production, Supply, and Demand for U.S. Ethane*

The U.S. Energy Information Administration (EIA) in the Annual Energy Outlook 2021 (AEO2021) indicates U.S. NGPL production more than doubled between 2010 and 2020, with projected growth (under energy policy assumptions at that time) of approximately 20 percent between 2020 and 2050 (Exhibit ES-1) (3). Continued development of the Marcellus and Utica shale plays in the eastern United States is the primary driver of growth in total U.S. natural gas production.

Exhibit ES-1. U.S. NGPL production by region (11)

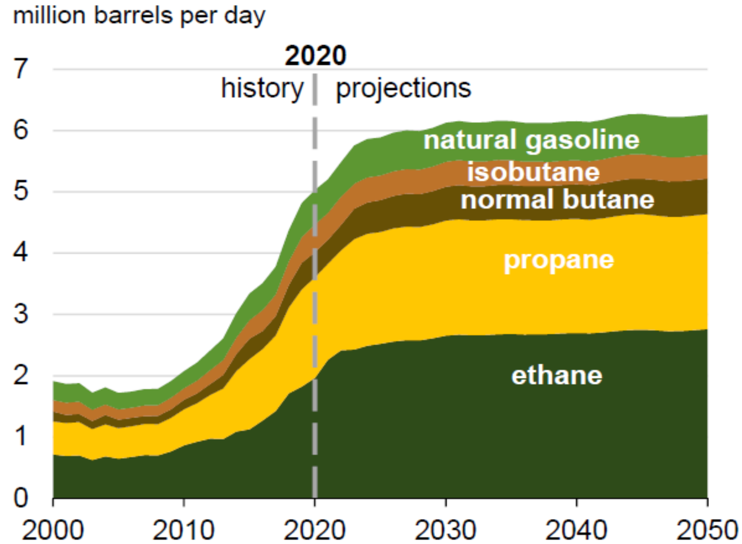


Production of ethane grew by 182,000 b/d, or about 9.9 percent between 2019 and 2020 (Exhibit ES-1) (11). Natural gas processing plant operators have some discretion in determining the quantities of ethane to recover from raw natural gas, as a response to market prices. Within certain technical limitations, producers may exercise the option to either reject or recover ethane. When ethane prices are low relative to dry natural gas prices, natural gas processing plant operators may choose to reject the ethane, leaving it in processed natural gas to the extent allowable (provided the processed natural gas still meets pipeline specifications after the ethane is rejected), and sell it into the natural gas market at its heating value. When ethane prices are higher than natural gas prices, there is an incentive for natural gas processing plant operators to recover the ethane and other NGPLs and sell them to petrochemical manufacturers (12).

[3] Hydrocarbon gas liquids (HGLs) refers to all heavier compounds extracted from dry gas, inclusive of both NGPL and LRG.

AEO2021 projects that rising demand and continuing growth in U.S. natural gas production will increase U.S. ethane production from 2.01 million b/d in 2020 to 2.76 million b/d by 2050, as shown in Exhibit ES-2 (11). As natural gas production moves to areas with "dryer" gas (where the share of NGPLs is lower), NGPL production is anticipated to flatten out between 2030 and 2050 (11).

Exhibit ES-2. U.S. NGPLs production by type AEO2021 reference case (13)



Ethane is primarily used to produce ethylene, a critical component of the chemical industry used to produce a range of intermediate chemical compounds, most of which are converted into plastics.

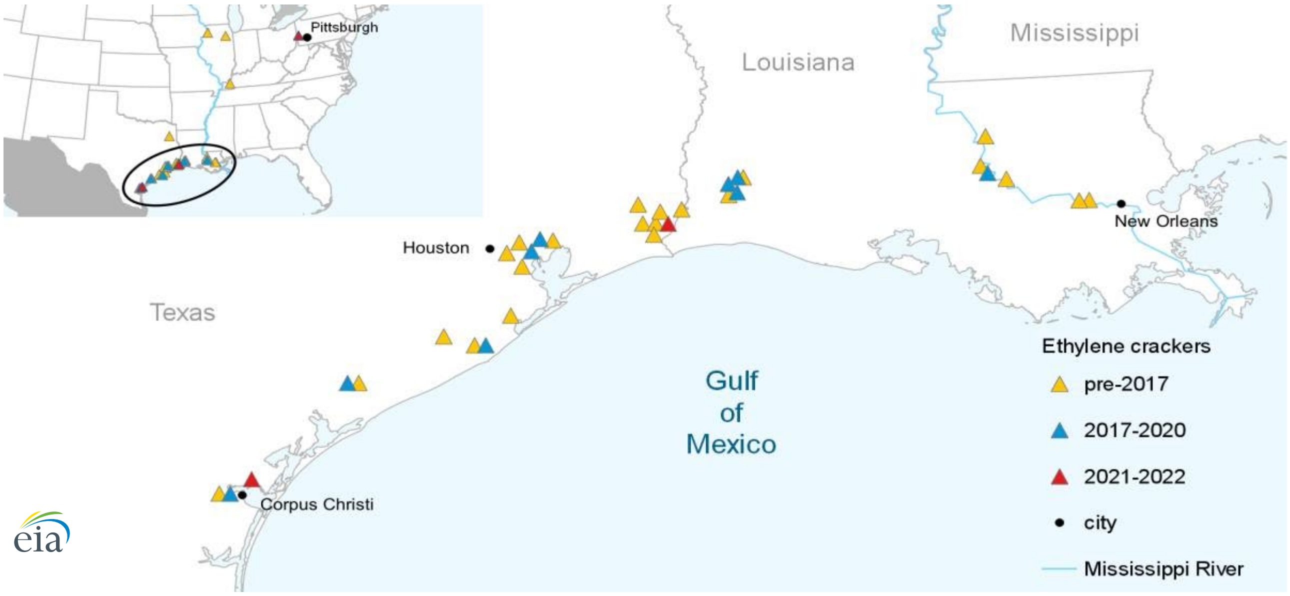
Most ethylene is produced via a process called steam cracking, where the feedstock (mostly ethane, sometimes naphtha or propane) is heated to high temperatures over a catalyst. The naphtha feedstock typically comes from petroleum refineries, while ethane is becoming increasingly used as a feedstock in the United States due to the rise in domestic natural gas production from shale resources (14).

The market currently values ethane due to the high yield of ethylene compared to other feedstocks and the relative price of natural gas. The yield of ethylene from the cracking of naphtha, a crude oil derivative, ranges 29–34 percent, whereas cracking ethane yields 80–84 percent (15).

U.S. ethylene production was estimated at 31.4 million metric tons in 2019 while total production capacity stood at 36.3 million metric tons (16) (17). Production capacity is forecast to increase nearly 50 percent from 2019 to 2035 (16). Feedstock demand for ethane in the production of ethylene is projected to grow by 800,000 b/d between 2020 and 2030 and domestic ethane is projected to satisfy this demand in its entirety (16).

Exhibit ES-3 shows a map of current and planned (as of May 2021) ethylene crackers.

Exhibit ES-3. Map of established sites with ethylene crackers (steam crackers) and planned ethylene crackers as of May 2021 (1)



EIA projects three new steam crackers are on schedule to become operational by the second quarter of 2022 (1): Baystar, Gulf Coast Growth Ventures, and Shell Chemical Appalachia (1). According to ExxonMobil, the Gulf Coast Growth Ventures steam cracker officially came online January 20, 2022 (18). Both Baystar and Gulf Coast Growth Ventures are located in Texas, while Shell Chemical Appalachia is located in Pennsylvania (1). These crackers are represented by the red triangles in Exhibit ES-3. Together, they are projected to increase U.S. capacity to produce ethylene to approximately 43.5 million metric tons per year (1).

U.S. demand for ethylene currently exceeds that of other top petrochemicals and is forecast to grow by 45 percent between 2020 and 2028 and by 51 percent between 2019 and 2035 (16). Ethylene demand is driven by the demand for its derivatives among which the demand for polyethylene is the highest, followed (16) by ethylene dichloride (EDC) and ethylene oxide.

EIA projects that, on average, during the 2017-2027 period global market volumes of ethylene, polyethylene, and EDC will rise. Ethylene is projected to grow by over 34 percent from 2022 to 2028; during the same period, polyethylene is projected to grow by over 36 percent and EDC by 23 percent. U.S. market revenue from ethylene is projected to rise by approximately $47 billion from 2022 to 2028. During the same period, positive growth rates are projected for the top ethylene derivatives.

2. Pricing Trends

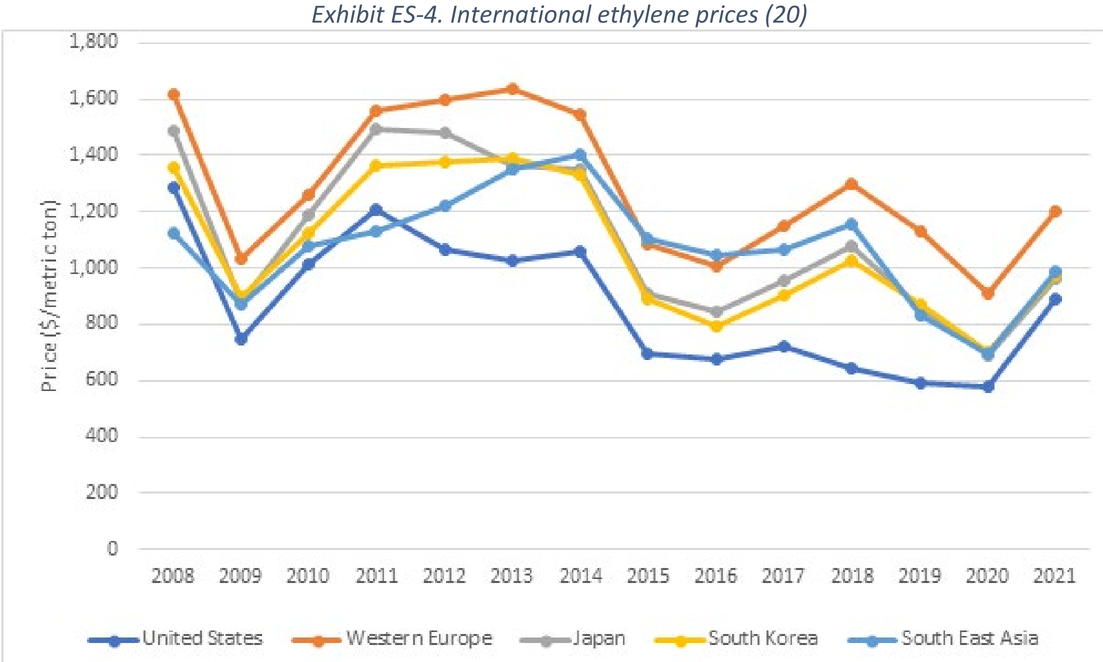
A. Ethane

Starting in mid-2012, ethane prices began to closely track natural gas prices. Spot prices of ethane dropped from a high of nearly $0.97 per gallon in October 2011 to a low of $0.09 per gallon in March 2020 to about $0.36 per gallon in September 2021 (19).

B. Ethylene

Ethylene prices in the United States, Europe, and Asia follow a similar trend over the years 2008–2021 (Exhibit ES-4). From 2011 to 2014, global ethylene prices continued to rise while U.S. prices fell due to the economic advantage of abundant, low-cost ethane feedstock derived from increased production of natural gas from liquids rich shale formations. Ethylene spot prices in the United States continue to be significantly lower than elsewhere in the world.

Exhibit ES-4. International ethylene prices (20)



In addition to an overview of long-term trends associated with ethane production and consumption, this report also addresses specific questions from the congressional request, which are summarized below.

What is the potential value (direct investment, direct and indirect job creation, tax generation, etc.) of domestic manufacturing growth based on available domestic ethane supply?

Increased domestic manufacturing activity based on available ethane supply will, with everything else remaining constant, increase gross domestic product (GDP). This will lead to job creation and generate additional tax revenue. For this report, the National Energy Technology Laboratory

(NETL) performed an analysis to provide additional insights regarding the likely effects of increased domestic petrochemical manufacturing, due to the increasing availability of ethane, on employment. The results suggest, on a national basis, that the individual industries involved in the ethane value chain[4] could support up to 13 jobs for every $1 million in industry output that they generate.

In addition, there have been several analyses that focus on the local economic impact of petrochemical facilities. A 2019 study, titled "Economic Impacts of Ethylene Cracker Facilities,"[5] analyzes the economic impact on employment and earnings in counties that had steam cracker plants (21). The authors included counties containing an operational steam cracker plant and those bordering a county containing an operational steam cracker plant. Results show that counties containing steam cracker plants have approximately 10.8 percent higher per capita employment and 12.8 percent higher per capita earnings, respectively, than those without steam cracker plants. Results also show that bordering counties have negative impacts to net employment and positive impacts to earnings. However, industries such as petrochemical and plastics manufacturing in bordering counties experience positive impacts to net employment despite an overall drop in net employment for these counties. There is also statistical evidence that earnings in counties with a steam cracker plant increase as employment in petrochemicals, plastics, and resins manufacturing increases (21).

Independent analyses commissioned by Gulf Coast Growth Ventures on a steam cracker plant in Texas, and a separate analysis by Shell on the Shell steam cracker plant in Pennsylvania, suggest positive impacts to employment growth and government revenue (100) (16). Gulf Coast Growth Ventures estimates that their newly operational steam cracker plant in Texas will create nearly 6,000 jobs and generate $22 billion in economic gains for the state during the construction phase, with an additional 600 permanent jobs and a projected average annual salary for employees of $90,000 per year. Shell's new steam cracker plant in Pennsylvania is also projected to have large positive impacts on both employment and government revenue for Pennsylvania from its anticipated 4.5 years of major construction and 40-year operational life cycle to follow. It is

[4] Industries involved in the ethane value chain include Oil and Gas Extraction; Support Activities for Mining; Basic Chemical Manufacturing; Pipeline Transportation; Warehousing and Storage; Textile Product Mills Manufacturing; Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Manufacturing; Paint, Coating, and Adhesive Manufacturing; Soap, Cleaning Compound, and Toilet Preparation Manufacturing; Plastics Product Manufacturing; Rubber Product Manufacturing; Water Transportation; Scenic and Sightseeing Transportation; and Support Activities for Transportation.

[5] "Economic Impacts of Ethylene Cracker Facilities", published in the Pennsylvania Economic Review in 2019 by Washington and Jefferson College economics professors Dr. Robert Dunn and Dr. Leslie Dunn, originated as part of a grant from the Richard King Mellon Foundation through Washington and Jefferson College's Center for Energy Policy and Management (CEPM) (235). The Richard King Mellon Foundation is the largest foundation in Southwestern Pennsylvania (SWPA), with a 2020 year-end endowment of $3.1 billion and grants and investments awards totaling $130 million. The Richard King Mellon Foundation describes itself as investing "in the competitive future and quality of life of SWPA, and in the protection, preservation and restoration of America's environmental heritage" (236). Washington and Jefferson College's CEPM was formed in 2012 during SWPA's shale gas boom and was designed to be a "center of excellence dedicated to fostering the development of energy policy that has a place for all energy sources and promotes economic growth while minimizing environmental impacts." The CEPM has trained more than 1,000 students, faculty, staff, citizens, and public officials through seminars and workshops on various energy production, conservation, transmission, and consumption knowledge. The CEPM "does not advocate for or against any particular policy" (237).

projected to generate $73 million from construction and $683 million from operations in state income taxes (22) (23).

However, there is conflicting evidence on petrochemical facilities providing the benefits evidenced in these studies. For example, a 2020 report from the Institute for Energy Economics and Financial Analysis (IEEFA) addresses projected impacts from Shell's Beaver County cracker plant, concluding the plant will likely be less profitable than expected and face an extended period of financial distress due to a steep decline in the price of plastics, an oversupply in the plastics market, high levels of competition in the plastics market, unsustainably low ethane prices that are predicted to rise, and a predicted decline in the use of primary plastics in favor of recycled plastics (24). A 2021 study from the Ohio River Valley Institute (ORVI) also emphasizes that despite large increases in GDP in Appalachian natural gas producing counties in Ohio, Pennsylvania, and West Virginia from 2008 to 2019, personal income, jobs, and population have all decreased in these counties over the same period. These metrics are also growing slower than both the national average and state level averages for Ohio, Pennsylvania, and West Virginia, respectively, over the same period, despite natural gas production in the region surpassing the highest estimated totals by 35 percent (25).

In addition, a letter addressed to governors Tom Wolf of Pennsylvania, Mike DeWine of Ohio, and Jim Justice of West Virginia from a group of leading economists and engineers in the Appalachian region also echoes concerns referenced in the two previous studies. In this letter, the authors cite evidence of failed ethane cracker plant construction projects such as ASCENT in West Virginia, the failure of the proposed Appalachian Storage Hub to attract private investors, and economic and technological barriers such as ethane oversupply and domestic manufacturing complications as evidence that projected economic and employment benefits from petrochemical manufacturing are not likely to occur (26).

The Potomac Economic Research Institute, a consultancy affiliated with the University of Massachusetts, published a series of papers that propose an alternate path for economic growth and job creation in Ohio, Pennsylvania, and West Virginia.[6] The papers make the case that investing government funds in clean energy can produce better economic outcomes in these regions than relying on petrochemical investments.

In terms of the previously mentioned analysis from NETL, direct and indirect jobs created in response to domestic manufacturing growth based on available domestic ethane supply were estimated using projected input-output (IO) accounts produced by the Bureau of Labor Statistics (BLS) following the assumption that domestic ethane production would increase and be used to supply ethylene derivatives, which would be used by downstream industries. Ethylene derivates supplied by domestic ethane resources were assumed to substitute for 30, 60, or 90 percent of

[6] These papers—"Impacts of the Reimagine Appalachia & Clean Energy Transition Programs for West Virginia," "Impacts of the Reimagine Appalachia & Clean Energy Transition Programs for Pennsylvania," and "Impacts of the Reimagine Appalachia & Clean Energy Transition Programs for Ohio"—are available at https://peri.umass.edu/publication/item/1032-green-new-deal-for-u-s-states.

projected imports of ethylene derivatives between 2025 and 2029. Results suggested approximately 1,700 to 8,800 new jobs (direct and indirect jobs) could be created depending on what percentage of projected imports were replaced and in which year. Industries which would gain jobs included, but were not limited to, those industries engaged in the manufacturing of the derivatives, which includes those manufacturing resin, synthetic rubber, artificial synthetic fibers and filaments, and chemicals, and wholesale trade industries.

Given demonstrated historical investment in ethane-based domestic manufacturing, and assuming it will continue given sufficient projected ethane supply, what is the opportunity cost of exporting available ethane supply in support of foreign manufacturing?

This question seeks an assessment of the potential opportunity cost of exporting available ethane in support of foreign manufacturing versus utilizing available ethane domestically. To shed light on this question, this report provides estimates of the potential number of direct and indirect jobs and labor income forgone if increased production of domestic ethane is exported instead of being used as feedstock by domestic industries.

When used to manufacture downstream products, ethane is piped into a steam cracker that uses steam to crack ethane into ethylene. Ethylene can be developed into different derivative compounds which, in turn, can be used to manufacture a wide variety of products (54). Three ethylene derivatives are considered for this analysis: low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), and high-density polyethylene (HDPE). These three derivatives are used frequently by domestic industries to produce a variety of end-use products including, but not limited to, plastic bags, wraps, and films, as well as bottles, pipes, diapers, trash bags, and toys. In 2019, imports of these three derivatives represented approximately 10, 18, and 12 percent, respectively, of available domestic supply, and imports are projected to continue to occur through 2035 (16). As such, a primary assumption of the analysis performed was that domestic production of the ethylene derivatives would substitute for the need to import these derivatives.

Data for the analysis included modified versions of the projected IO accounts and estimated values for labor income and employment by industry provided by BLS (2). The period for which the analysis was conducted was 2025–2029. Three export demand and three domestic production scenarios were considered. A high-level overview of the scenarios is included below.[7]

1. Scenario 1: Increased domestic production of ethane is assumed to be used to meet export demand (i.e., the demand of foreign countries for ethane produced domestically).
    a. Scenario 1a: Ethane exports increase by 20 percent from their projected base amount
    b. Scenario 1b: Ethane exports increase by 30 percent from their projected base amount

[7] For more information on the assumptions underlying each scenario see Section IV.

   c. Scenario 1c: Ethane exports increase by 40 percent from their projected base amount
2. Scenario 2: Increased domestic production of ethane is assumed to be used to support the domestic manufacturing of three ethylene derivatives: LDPE, LLDPE, and HDPE and the domestic production substitutes for projected imports.
   a. Scenario 2a: 30 percent of projected ethylene derivative imports are replaced by domestic production
   b. Scenario 2b: 60 percent of projected ethylene derivative imports are replaced by domestic production
   c. Scenario 2c: 90 percent of projected ethylene derivative imports are replaced by domestic production

The difference in the amount of labor income and jobs generated between the scenarios provides the basis for the opportunity cost estimates. Results are presented in Exhibit ES-5 and Exhibit ES-6.

Exhibit ES-5. Results of the opportunity cost calculations performed, as measured by the difference in the potential number of jobs created annually (2025–2029)

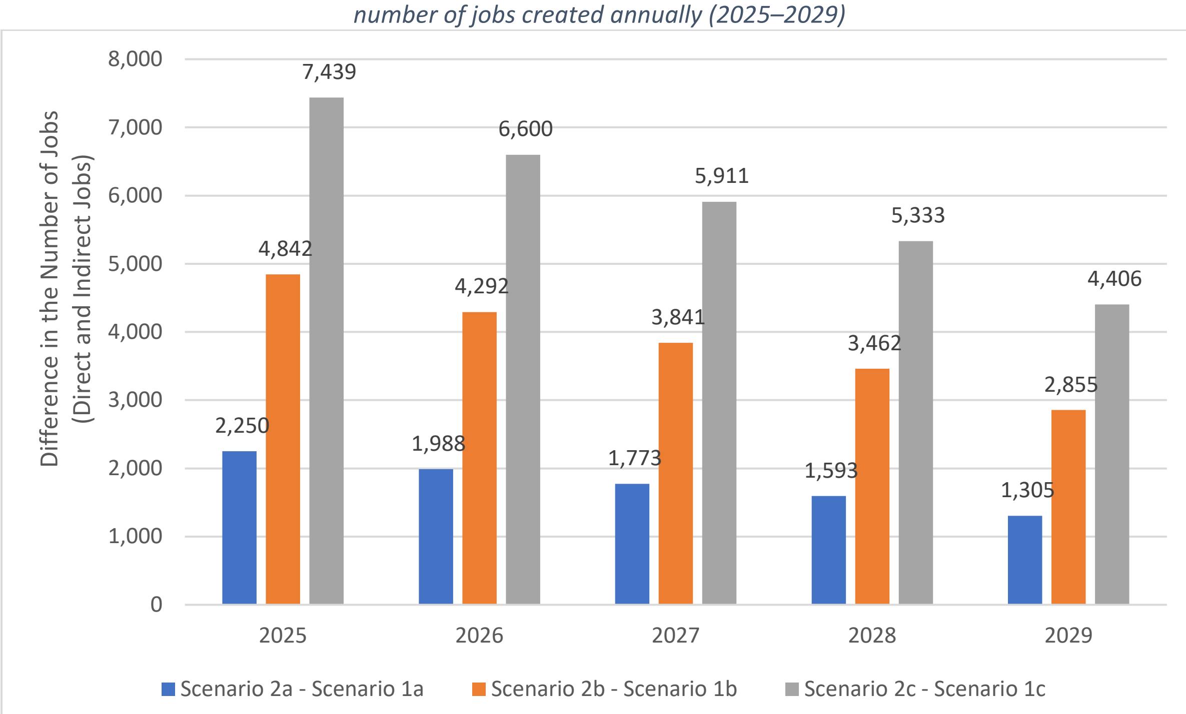
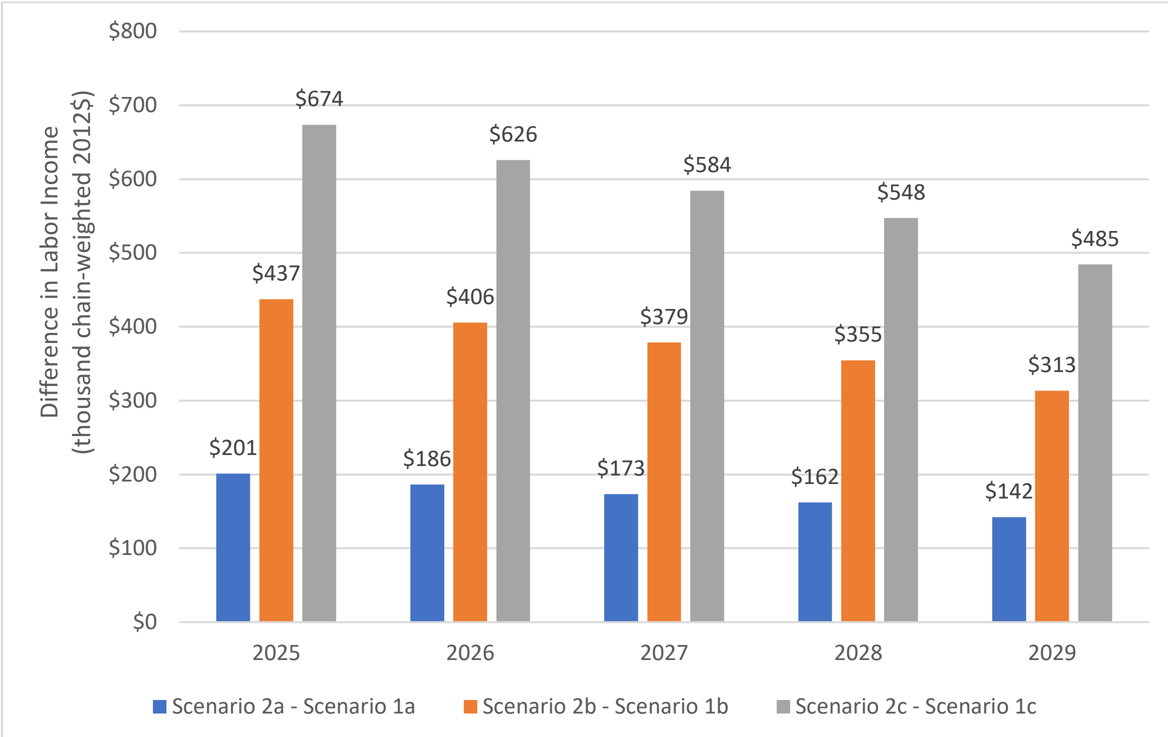


Exhibit ES-6. Results of the opportunity cost calculations performed, as measured by the difference in the potential amount of labor income generated annually (2025–2029)



Results suggested the potential opportunity cost of exporting available ethane (as measured by the difference in the number of jobs that could be created and the amount of labor income that could be generated) instead of using the resource domestically to manufacture ethylene derivatives (i.e., LDPE, LLDPE, and HDPE) is significant. In terms of potential labor income produced, it could be between $142,000–674,000 (chain-weighted in 2012 dollars). Additionally, in terms of jobs created (direct and indirect jobs combined), the number could be between 1,350–7,439 total.

Additional benefits might be realized under the scenario where the increased domestic production of ethylene derivatives was not only used by domestic industries to reduce their reliance on imports, but also to meet increased export demand for these products from the United States. Quantifying these additional benefits within the structure of the model framework used is non-trivial. An application could be explored wherein increased export demand of ethylene derivatives occurred, but the scenario would need to be assessed within its own context and could not be combined with current scenarios given model constraints.

What is the impact of progressive import tariffs (such as those imposed by China where value-added goods are tariffed at higher rates than the raw materials used to make them are tariffed) on ethane, ethylene, and polyethylene?

Typically, when countries impose higher tariffs on higher value-added goods than on raw materials or feedstock products, it is to encourage the development of these industries within their own borders. China is the world's second largest producer of ethylene, producing 18 million metric tons in 2018 (27). Despite the high growth rate of ethylene production in China, the country remains a net importer of this product. In 2019, China imported 2.51 million metric tons of ethylene in total, valued at $2.4 billion (28). It is economically viable for China to both import U.S. ethylene produced from ethane and to import ethane to use as a feedstock to produce ethylene domestically. Ethylene produced in China is primarily made from naphtha, gas oil, and coal, whereas ethylene produced in the United States and in the Middle East is primarily produced from ethane. The latter has lower per unit investment costs and allows for a higher ethylene yield fraction (29).

China is also a major importer of polyethylene. It is forecast to be responsible for 55–60 percent of all global net polyethylene imports over the next decade (30). China imports polyethylene from a variety of countries including the United States, Saudi Arabia, Iran, Singapore, Qatar, the United Arab Emirates, South Korea, Russia, India, Thailand, and Taiwan.

Over the last 10–15 years, China has significantly reduced its dependence on U.S. exports of HDPE and LLDPE as imports from the Middle East and Southeast Asia have increased in importance or held steady. China's imports of HDPE from the United States in 2007 accounted for eight percent of China's total HDPE imports; in 2017, that figure dropped to five percent. The same trend can be seen in China's LLDPE imports, with U.S. market share dropping from 11 percent in 2007 to seven percent in 2017. In comparison, HDPE imports from Iran to China increased from 0.5 percent in 2007 to 17 percent in 2017 (31).

China has imposed and adjusted additional tariffs on polyethylene imported from the United States multiple times since the onset of the 'trade war' in 2018. U.S. polyethylene exports to China have decreased significantly due to the hikes in tariffs that reached 25–30 percent for some derivative products.

The COVID-19 pandemic caused polyethylene production, export, and demand to shift globally. Initial COVID-19 lockdowns in the United States in March 2020 caused domestic polyethylene demand to decrease significantly. In China, the gradual lifting of COVID-19 restrictions in March and April 2020 resulted in increased demand for polyethylene imports, and China responded by offering waivers on the additional 'trade war' tariffs imposed on U.S. polyethylene, among other chemicals. The exemptions brought the tariffs imposed on Chinese imports of U.S. HDPE and LLDPE down to 6.5 percent and allowed the United States to successfully compete against polyethylene produced in the Middle East and increase its exports of polyethylene to China (32).

China is actively working to increase self-sufficiency across the petrochemical industry, including the ethylene value chain, to bolster security of supply and add economic value. China's push toward petrochemical self-sufficiency and the gains that have been made can be seen in the reduction of its chemicals trade balance. From 2007 to 2017, China reduced its chemicals trade deficit from $42.6 billion to $23.5 billion (33).

Could these strategies by other countries result in capital flight from the United States to other countries where U.S. raw materials will be upgraded to higher value-added goods and sold back to America?

Differential tariffs on raw materials or feedstock versus final products are imposed to incentivize the development of a sector domestically, i.e., to attract foreign companies to invest in domestic productive capacity. Globalization has allowed for increased specialization, where different parts of the production process occur in different locations and are subsequently assembled in the home country (or elsewhere) and shipped directly to market. U.S. manufacturing operations moving abroad to take advantage of cheap labor or to be closer to their final market is well-documented; however, in recent years, several factors have led to a slowdown or reversal in this trend.

Manufacturing's total share of U.S. gross domestic product (GDP) has remained mostly stable since the 1940s, ranging approximately 11–13 percent while manufacturing's share of total employment declined from approximately 30 percent in 1950 to 8.51 percent in 2019 (34) (35). Several studies analyzed this trend and found a robust link between a sharp decline in U.S. manufacturing employment and the United States granting Permanent Normal Trade Relations (PNTR) to China (36) (37). The PNTR came into effect in 2001 when China joined the World Trade Organization (WTO). The PNTR permanently set U.S. tariffs on Chinese imports at Normal Trade Relations levels, thereby significantly reducing the risk of tariff changes on U.S. companies producing in China. The PNTR thereby incentivized U.S. companies to shift operations to China by reducing the risk on sunk cost with offshore operations (36). However, Chinese producers were incentivized to invest in the United States, increasing competition for U.S. manufacturers (36). The PNTR encouraged further specialization in the industry with U.S. investments being more closely aligned with the U.S. manufacturing sector's comparative advantage such as the use of skill-intensive production technologies that are less labor intensive (36).

3. Reshoring Trends

Reshoring—the return of U.S. businesses (that previously moved operations offshore) to the domestic territory—has gained increasing attention in recent years and is driven by a variety of factors. Labor costs in host countries have risen over the years, and new digital technologies related to information, communication, and automation have made production processes less reliant on cheap labor. Reshoring has contributed to a slight recovery in U.S. manufacturing jobs in recent years. After dropping to a record low of 11.45 million in 2010, manufacturing employment has been increasing through 2020 to 11.5 million, despite a slight decrease in 2020 due to the global COVID-19 pandemic (38).

Globally flows of Foreign Direct Investment (FDI) have stagnated in recent years due to reduced flows from advanced economies to developing economies (particularly Asia). However, flows of FDI among advanced economies such as the United States and Europe, that are concentrated in manufacturing sub-sectors have increased by about 32 percent. Most notable is the 60 percent increase in FDI flows in chemical product manufacturing from 2016 to 2017 (39).

Factors driving firms to reshore include increasing long-term labor costs, exchange rate fluctuations, shipping delays, supply chain flexibility, greater proximity to end markets, skilled labor, research and development, changes in tax policies, and increasing political risk in host countries (39). For the chemicals manufacturing industry specifically, reshoring of manufacturing plants is anticipated to provide continued growth. Disruptions to supply chains have also accelerated reshoring, as manufacturers are incentivized to bring production closer to U.S. demand centers. In particular, chemicals manufacturing reshoring was kickstarted by the aftermath of the Fukushima earthquake, which caused massive supply chain disruptions for critical petrochemicals, and the COVID-19 pandemic, which further disrupted supply chains and provided additional incentive for manufacturers to close the distance between their production and demand centers.

According to a June 2021 survey of the National Association of Chemical Distributors, approximately 85 percent of 84 distributors reported at least one item as out-of-stock, compared to 47 percent in March (40). Plastics production has experienced severe shortages for plastic raw materials while demand for plastics has continued to surge. As ethane is a feedstock for plastics production that is relatively low cost and plentiful in the United States, reshoring has economic advantages (41). The price of many plastics feedstocks has increased substantially, including a 70 percent increase in the price of polyvinylchloride, a 170 percent increase in the price of epoxy resins, and a 43 percent increase in the price of ethylene. Major supply chain issues in China and the rest of the world imply that scaling up domestic production of petrochemicals will significantly lessen the impact of these disruptions (42). Additionally, the U.S. chemical industry domestically benefits from a cost-advantage as it primarily relies on relatively low-cost, gas-based feedstocks such as ethane while its competition often relies on higher cost naphtha (43).

The Biden-Harris Administration has been addressing the challenges facing the manufacturing sector through policies designed to improve U.S. competitiveness against China and other competitors. Several legislative changes such as the Strategic Competition Act of 2021, the Endless Frontier Act, and the CHIPS for America Act, all part of the Innovation and Competition Act of 2021, were passed by the U.S. Senate in early June 2021. When signed into law, these bills would allocate approximately $200 billion in new spending, increase Federal financial support for strategic sectors, and emphasize an increase in resources committed to research and development and capital-intensive manufacturing (44).

Have other countries enacted policies around use versus exporting purity ethane?

Specific governmental policies requiring the domestic use versus export of ethane were not found during the development of this report. However, ethane-producing countries, like Saudi Arabia, do not export a significant amount of domestically produced ethane, and instead crack the feedstock into ethylene and ethylene derivatives for export. In 2019, exports of polymers of ethylene accounted for 3.83 percent of Saudi Arabia's total annual exports (45). The decision to domestically crack ethane rather than export was likely based on the limited export market for ethane and the strength of Saudi Arabia's domestic petrochemical industry. Alternatively, other top petrochemical producing countries, like Norway, have experienced declines in their production of ethane, leading to increased demand for imports from the United States (46). The province of Alberta, Canada, has an extensive, and aggressive, policy of promoting ethane use for petrochemical manufacturing. Recently propane use has also received government subsidy. Outside of Canada, however, there is little evidence indicating foreign government involvement in encouraging the domestic use of ethane over export, presumably because the financial benefit of exporting verses upgrading is market dependent.

Large net consumers of ethylene, such as China, have taken a broad approach to investing both in steam cracking facilities using mixed-feedstocks[8] and those designed to specifically process ethane feedstocks, primarily imported from the United States, into higher-value ethylene and ethylene derivatives (47). While importers of U.S. ethane also seek to produce ethylene locally rather than importing, spot prices of ethylene from the United States are lower than for ethylene produced in other countries. The U.S. ethylene 4-year average (2017–2020) spot-price ranges 38–77 percent less than average spot prices in Europe, Japan, South Korea, and Southeast Asia (48). Between 2017–2020, ethane comprised 78 percent of the feedstock for U.S. ethylene (16). The comparatively low U.S. ethylene spot prices are likely due to the favorable feedstock margin on ethane to ethylene in the United States compared to feedstock margins globally (16). U.S. domestic steam crackers, with access to nearby ethane extraction, or ethane-pipeline infrastructure, can maintain a wider profit margin on their ethylene production than their global counterparts.

4. Environmental and Community Considerations for Ethane Development

This report includes a section focused on the environmental impacts of ethane development that occurs after the resource arrives at a petrochemical manufacturing facility as well as when it is transported, stored, and distributed via pipeline systems leading up to customer delivery (including export of ethane feedstock or finished product, e.g., ethylene). This report does not address the environmental implications of upstream oil and natural gas development. However, DOE and the Environmental Protection Agency (EPA) have previously published reports on these topics.[9]

[8] Mixed feedstock can include a combination of ethane, propane, butanes, naphtha, and gas oil.

[9] These reports include the 2011 report by the Secretary of Energy Advisory Board's Shale Gas Production Subcommittee, available at https://www.energy.gov/sites/prod/files/90day_Report_Second_11.18.11.pdf; DOE's 2014 *Addendum to Environmental Review Documents Concerning Exports of Natural Gas from the United States,* available at https://www.energy.gov/sites/prod/files/2014/08/f18/Addendum.pdf; and EPA's 2016 report *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources,* available at https://www.epa.gov/hfstudy.

Producing ethylene from ethane produced in the natural gas value chain rather than from crude oil or coal-based petrochemical feedstocks results in lower CO_2 emissions per unit of production, which is becoming a factor in why producers in Europe are moving toward ethane-based production (44) (45). However, ethane-fed steam crackers are still a source of hazardous air pollutants (HAPs) which can cause community harm through reduced air quality. Further domestic investment in upgrading ethane to higher-value compounds, namely ethylene, should consider both the potential economic value and the local and national environmental impacts. Large steam crackers and petrochemical complexes have a direct impact on communities that extend beyond emissions and environmental impacts, including local job and supplier development, as well as regional economic stimulus.

The primary air polluting emissions, the key contaminants of concern associated with petrochemical plant operations, are SO_2, NO_2, volatile organic compounds (VOC), and CO_2. Section IX of this report provides a description of each of these pollutants and their negative effects on human health. Additionally, technologies already implemented, and new technologies under development that could further reduce harmful emissions, are described herein. Examples of technologies with impact include the following:

- Dry sorbent injection (DSI) and wet scrubbers are two promising technologies that have the potential to substantially to reduce SO_2 emissions.
- Flameless oxidation, which decomposes NO_2 into less harmful products allows petrochemical operators to substantially reduce NO_2 emissions.
- Carbon capture technologies provide opportunities to reduce CO_2 emissions; this technology can be implemented for new steam cracker plants and retrofitted in existing plants.
- To reduce emissions from steam crackers, industry is also considering changing the production process of ethylene. The three main technologies considered are electric ethylene furnaces, producing ethylene from CO_2, and using catalytic routes to produce ethylene.
- Some companies undertake efforts to create electric furnaces that are partially powered by renewable energy sources.

Lastly, stakeholders (including environmental organizations and members of local communities) have suggested several opportunities for both legislative and regulatory changes that could improve local environmental conditions for communities near petrochemical facilities. These include:

- Modifications to current industrial flaring regulations
- Updating and expanding emissions reporting requirements
- Increased funding for environmental oversight and enforcement

Relevant issues associated with each of these opportunity areas identified by stakeholders are explored in detail in the body of the report. In addition, key issues and trends tied to emissions monitoring, non-environmental impacts to local communities, and plant safety are also detailed in this study.

U.S. Ethane: Market Issues & Opportunities

Table of Contents

I. Legislative Language

Congress in the explanatory statement to the Energy and Water Development and Related Agencies Appropriations Act, 2021, part of the Consolidated Appropriations Act, 2021 (Pub. L. 116-260), stated, "The Secretary of Energy, in consultation with the heads of other relevant federal departments or agencies and stakeholders, as appropriate, is encouraged to conduct not later than one year after enactment of this Act a study assessing the long-term trends related to the domestic production and consumption of ethane, the export of ethane, and the opportunities for and economic benefit of investments for further domestic use."[10] Congress instructed that the study should include an examination of the following questions:

- What is the potential value (direct investment, direct and indirect job creation, tax generation, etc.) of domestic manufacturing growth based on available domestic ethane supply?
- Given demonstrated historical investment in ethane-based domestic manufacturing, and assuming it will continue given sufficient projected ethane supply, what is the opportunity cost of exporting available ethane supply in support of foreign manufacturing?
- What is the impact of progressive import tariffs (such as those imposed by China where value-added goods are tariffed at higher rates than the raw materials used to make them are tariffed) on ethane, ethylene, and polyethylene?
- Could these strategies by other countries result in capital flight from the United States to other countries where U.S. raw materials will be upgraded to higher value-added goods and sold back to America?
- Have other countries enacted policies around use versus exporting purity ethane?"

DOE's Approach to Addressing Questions

The objective of this Department of Energy (DOE) study is to assess the long-term trends related to the domestic production and consumption of ethane, the export of ethane, and the opportunities for and economic benefit of investments for further domestic ethane use. Both public and private information sources were leveraged to answer the preceding questions. Information sources included, but were not limited to, data on imports and exports of ethane, ethylene, and ethylene derivatives from the U.S. Census Bureau; the U.S. Energy Information Administration (EIA)'s Short-Term Energy Outlook (STEO) and Annual Energy Outlook (AEO); Bloomberg; Ethylene Derivatives Market Data from IHS Markit; Petrochemicals Market Estimates & Forecast Grand View Research; and EIA and U.S. Environmental Protection Agency (EPA) public databases. Across the datasets, forecast periods vary and are identified in the text and charts. The forecast period for AEO2021 is 2021–2050; the forecast period for the Ethylene

[10] 166 Cong. Rec. H7879, H8363 (Dec. 21, 2020).

Derivatives Market Data from IHS Markit is 2020–2035[11]; and the forecast period for the Petrochemicals Market Estimates & Forecast Grand View Research data is 2020–2028.

The report begins with an overview of ethane and ethylene uses, markets, and demands to provide a general introduction to the issues of primary concern. The overview is followed by an analysis of ethane's contribution to the U.S. economy and an economic assessment of the opportunity cost of exporting U.S. ethane. The report also includes a discussion of the impact of tariff regimes on the U.S. ethane and ethylene derivative industry, as well as a review of federal and state regulations impacting the industry. For comparative consideration, regulatory and policy frameworks in key foreign petrochemical producing and consuming countries are discussed followed by a review of health, safety, and environmental impacts of ethane-fed steam crackers.

II. Overview of Ethane, Ethylene, and Natural Gas Liquids

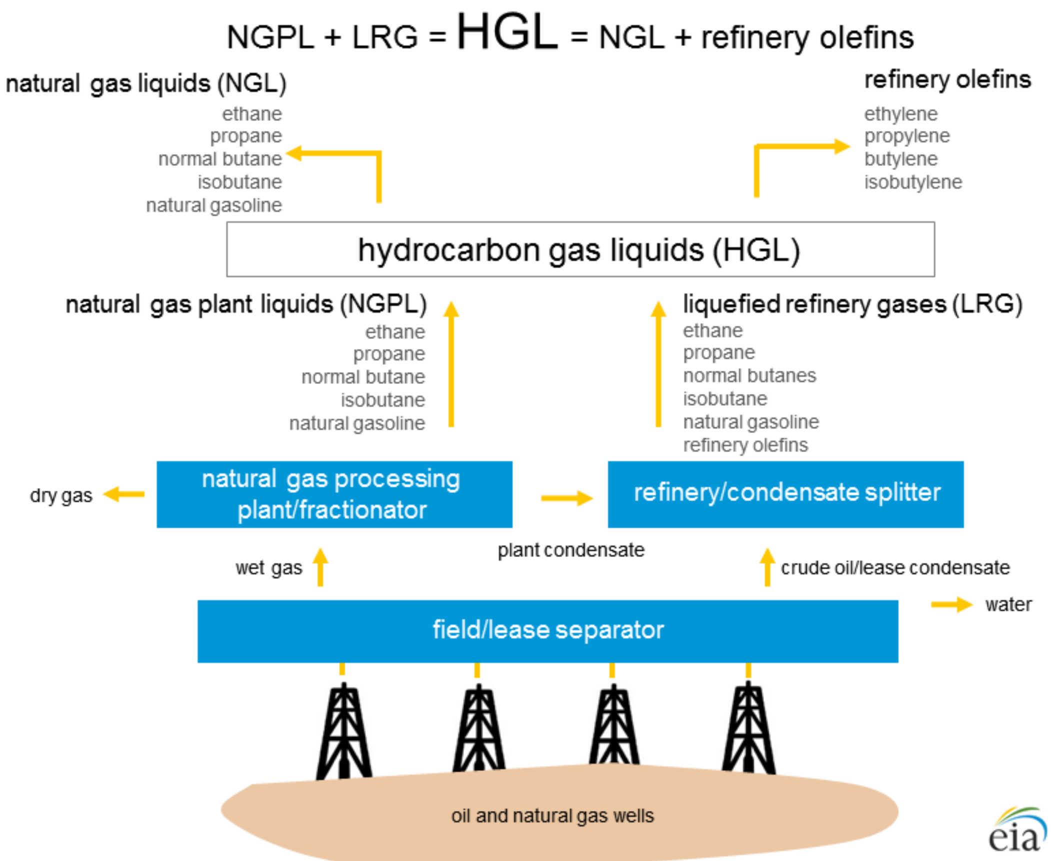
Ethane is a colorless, odorless hydrocarbon (compound of hydrogen and carbon) gas liquid (HGL) used to produce ethylene, which is then used by the petrochemical industry to produce a range of intermediate products, most of which are converted into plastics. Ethane consumption in the United States has increased over the past several years due to increased supply availability and lower cost relative to other petrochemical feedstocks like propane and naphtha, a crude oil derivative. Ethane can also be used directly as a fuel for power generation, either on its own or when blended with natural gas (49).

Ethane can be produced with either wet natural gas or crude oil/condensates (Exhibit II-1). Processing crude oil and plant condensate through refining and condensate splitting produces liquefied refinery gas (LRG), which is a mix of output molecules including ethane, propane, and butanes, in addition to unsaturated hydrocarbon compounds called olefins, which include ethylene and propylene. Natural gas processing separates dry gas (methane), commonly called "natural gas," from heavier compounds found in wet natural gas, called natural gas plant liquids (NGPLs), which include ethane, propane, and butanes. HGL is used to refer to both NGPL and LRG and does not distinguish between the processes by which the liquids were removed. The term natural gas liquid (NGL) is used to specifically distinguish ethane, normal butane, isobutane, propane, and natural gasoline (pentanes plus) from olefins. Data used throughout the report will refer to NGLs, NPGLs, LRGs, and HGLs depending on the source of the information. Therefore, it is important to note most U.S. ethane is found in NGPLs. In 2020, approximately 0.4 percent of U.S. ethane was produced at refineries, while over 99 percent of

[11] With the exception of data on ethylene dichloride, which has a forecast period of 2021–2035.

U.S. ethane was produced at natural gas processing plants (50). This report will focus primarily on U.S. ethane produced from the NGPL production pathway.

Exhibit II-1. Sources, production, and types of HGLs (51)

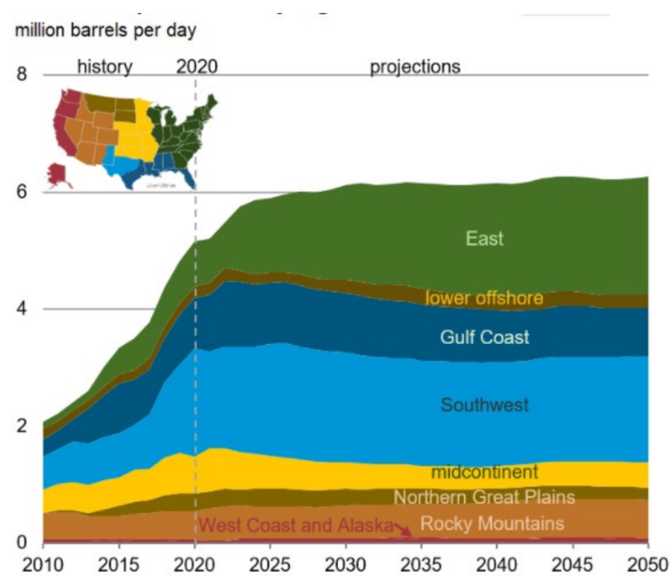


Despite lower levels of natural gas production in 2020 versus 2019, high ethane prices relative to natural gas resulted in ethane production growth of 182,000 barrels per day (b/d), or 9.9 percent, in 2020 (11). Natural gas processing plant operators have some discretion in determining the quantities of ethane to recover from raw natural gas. Therefore, ethane production levels generally respond to price signals and are broken into two processes, ethane rejection and ethane recovery. Ethane rejection occurs when ethane prices are low relative to dry natural gas prices, and natural gas processing plant operators choose to leave ethane in processed natural gas (provided the processed natural gas still meets pipeline specifications after the ethane is rejected) and sell it into the natural gas market at its heating value. When ethane prices are higher than natural gas prices, "natural gas processing plant operators may choose to recover the ethane and other NGPLs and sell them at their market value into the petrochemical sector" (12).

From EIA Natural Gas Weekly Update March 10, 2021 (11)**:**
[In 2020] ethane prices averaged 43 percent, higher than dry natural gas prices, leading to higher rates of recovery. The consistent premium in ethane prices relative to natural gas prices was due to continuing growth in ethane demand for petrochemical feedstock. [P]etrochemical industry capacity to consume ethane as a feedstock grew by 270,000 b/d as a result of new petrochemical cracking capacity that came online in late 2019 and throughout 2020. Although the petrochemical industry was also affected by the COVID-19 pandemic and associated declines in industrial activity, as well as multiple hurricanes that made landfall along the Gulf Coast, year-over-year domestic demand for ethane as a feedstock grew 165,000 b/d (10.7 percent). Meanwhile, exports of ethane stayed relatively flat, growing 4,000 b/d.

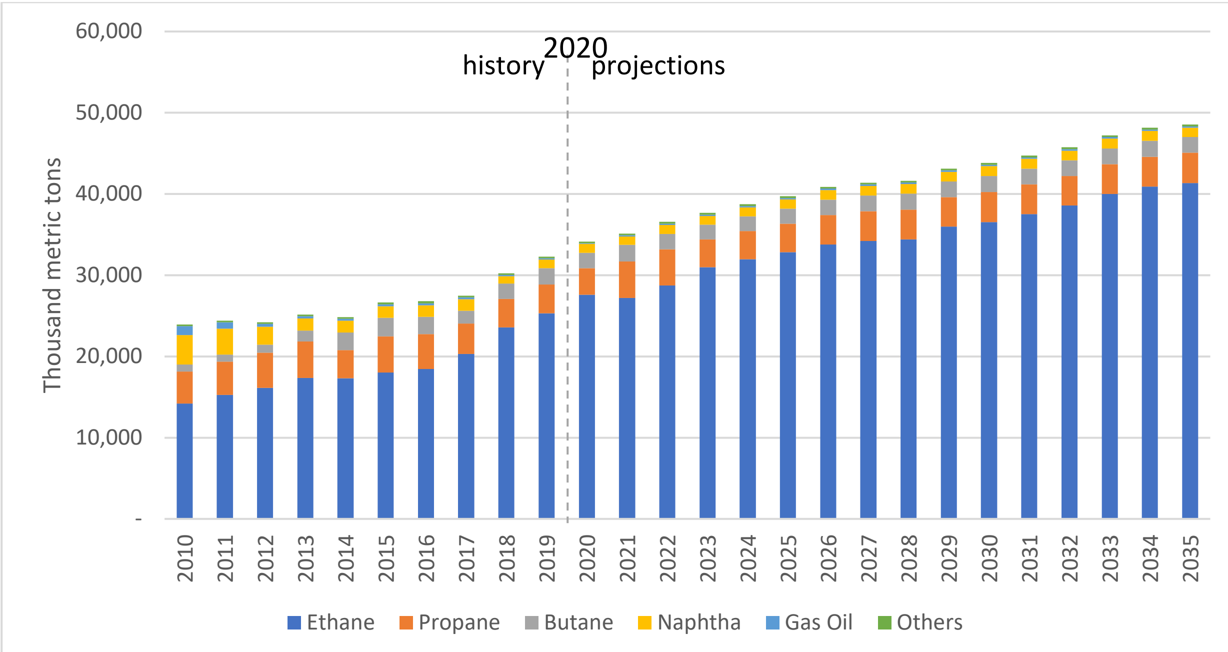
AEO[2021] projects demand for ethane to continue growing into the future. Petrochemical projects currently under construction are expected to add an additional 230,000 b/d of domestic demand. Ethane exports are also expected to increase as overseas petrochemical plants designed to consume ethane imported from the United States are completed. Rising demand and continuing growth in U.S. natural gas production are projected to increase U.S. ethane production by 750,000 b/d, reaching 2.76 million b/d by 2050 [Exhibit II-2]. Production of other NGPLs is projected to peak in 2031 and remain relatively flat through the remainder of the projection as production of natural gas gradually shifts into areas where the share of NGPLs in the raw natural gas is lower.

Exhibit II-2. U.S. NGPL production by region (11)



Ethane consumption for ethylene production in the United States has increased in response to increases in available supply and lower costs compared to other petrochemical feedstocks including naphtha and propane (52). While ethylene can be derived from other feedstocks including naphtha, gas oil, propane, and butane, in the United States, about 78 percent of the ethylene produced in 2019 originated from ethane feedstock (16). The United States benefits from the higher feedstock margins on U.S.-produced ethane; however, other countries continue to rely more heavily on other feedstocks for ethylene production due to greater local resource availability or accessibility of other lower-margin feedstocks. Exhibit II-3 provides detailed information on the amount of domestically produced ethylene sourced from different feedstocks between 2010 and 2020 (16).

Exhibit II-3. Domestic ethylene feedstocks 2010–2035 (16)

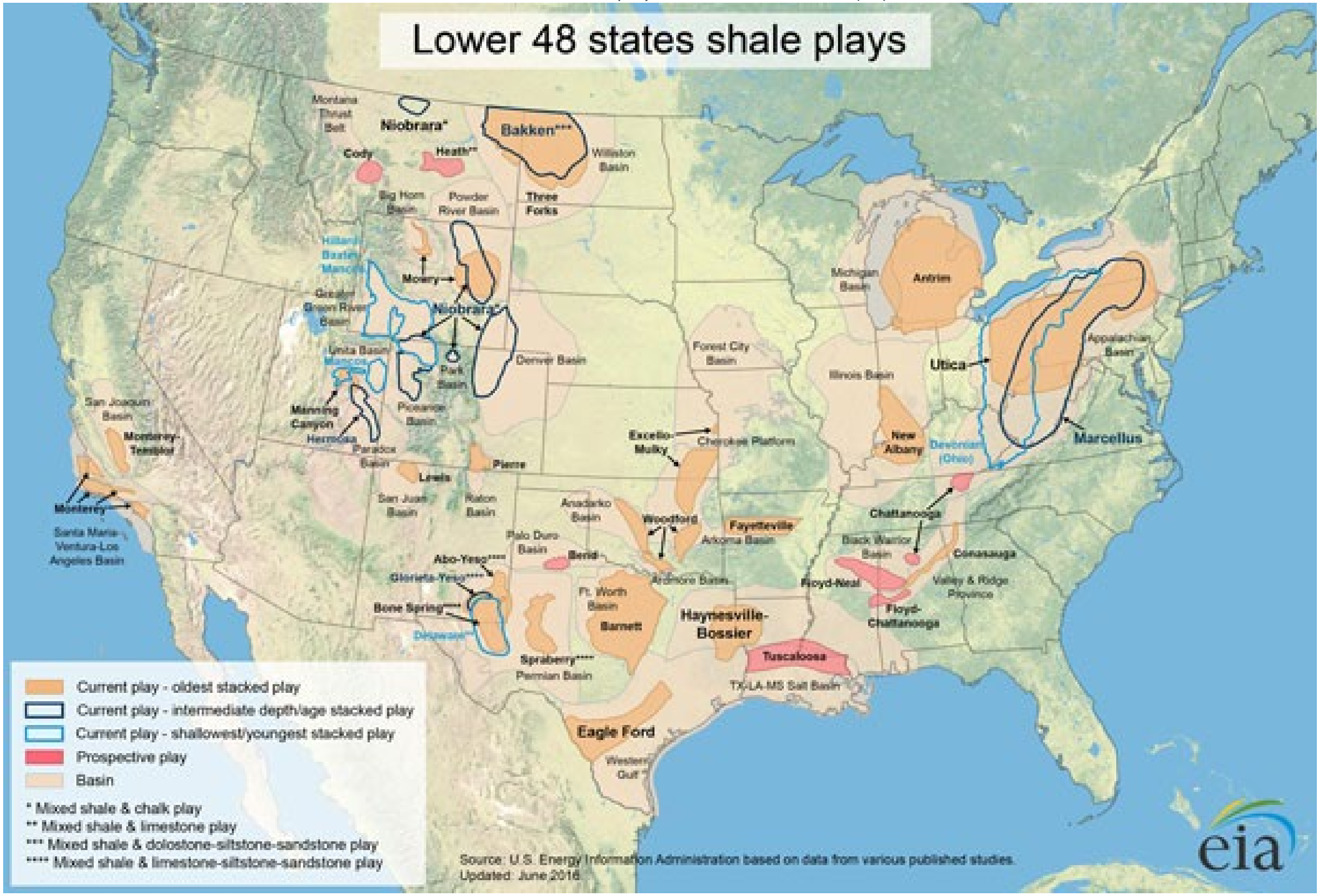


The following section introduces the basics of ethane and the ethylene value chain as well as critical considerations affecting the development of U.S. petrochemical production.

1. Natural Gas Liquids and America's Resource Endowment

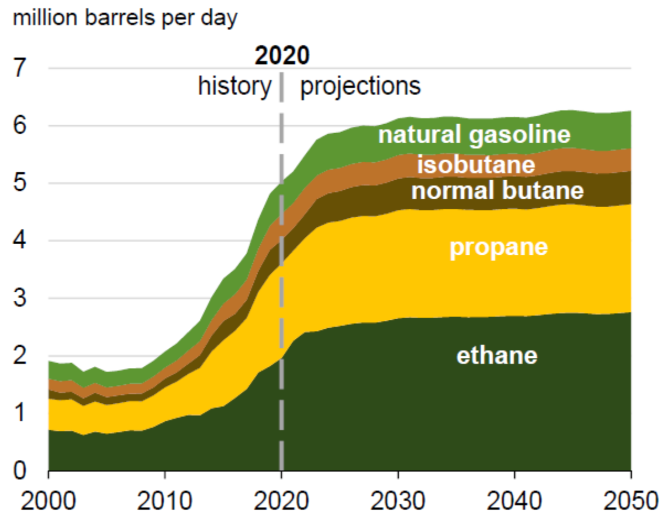
In the early 2000s, oil and gas producers in the United States began using horizontal drilling and hydraulic fracturing techniques to unlock hydrocarbon resources in low permeability U.S. shale formations, leading to an increase in oil and natural gas production rich in NGLs. Shale resources, or plays, with significant natural gas availability have been found in 30 of the 48 lower U.S. states (Exhibit II-4). Although many states produce natural gas, natural gas production is concentrated among just a few states, particularly Texas and Pennsylvania, which account for 45 percent of natural gas production (53) (54).

Exhibit II-4. U.S. shale plays in the lower 48 states (55)



U.S. Shale Plays

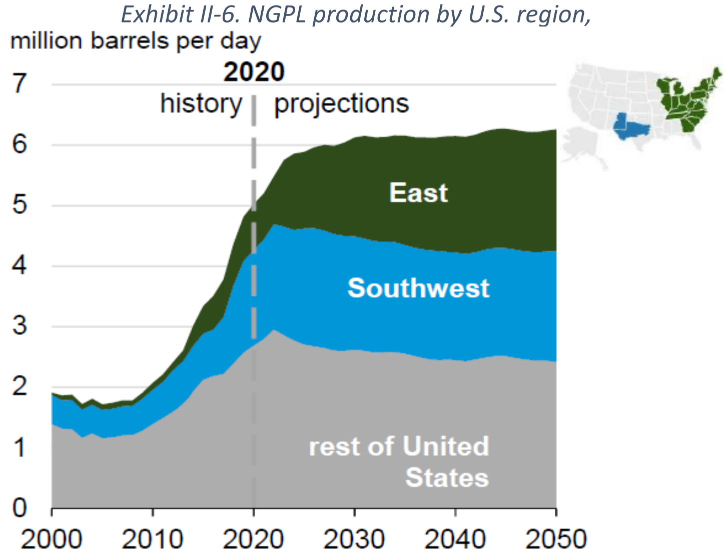
Exhibit II-5. U.S. NGPL production by type, AEO2021 reference case (13)



AEO2021 indicates U.S. NGPL production more than doubled between 2010 and 2020 with projected growth of approximately 20 percent between 2020 and 2050 (Exhibit II-5) (13). The main driver of growth in total U.S. natural gas production and the main source of total U.S. dry natural gas production is the continued development of the Marcellus and Utica plays in the East. 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 shale plays that extend over wide areas and have large amounts of undeveloped resources (such as in the Marcellus, Utica, and Haynesville) (49).

The reference case in AEO2021 projects NGPL production will increase approximately 20 percent between 2020 and 2050. Most NGPL production growth in the reference case occurs before 2025, when producers focus on NGL-rich plays, where NGLs-to-gas ratios are highest, and increased demand spurs higher ethane recovery (13).[12]
Ethane is forecast to comprise over 40 percent of annual NGPL production in the United States from 2021 to 2050, continuing a trend of high rates of recovery (12). 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

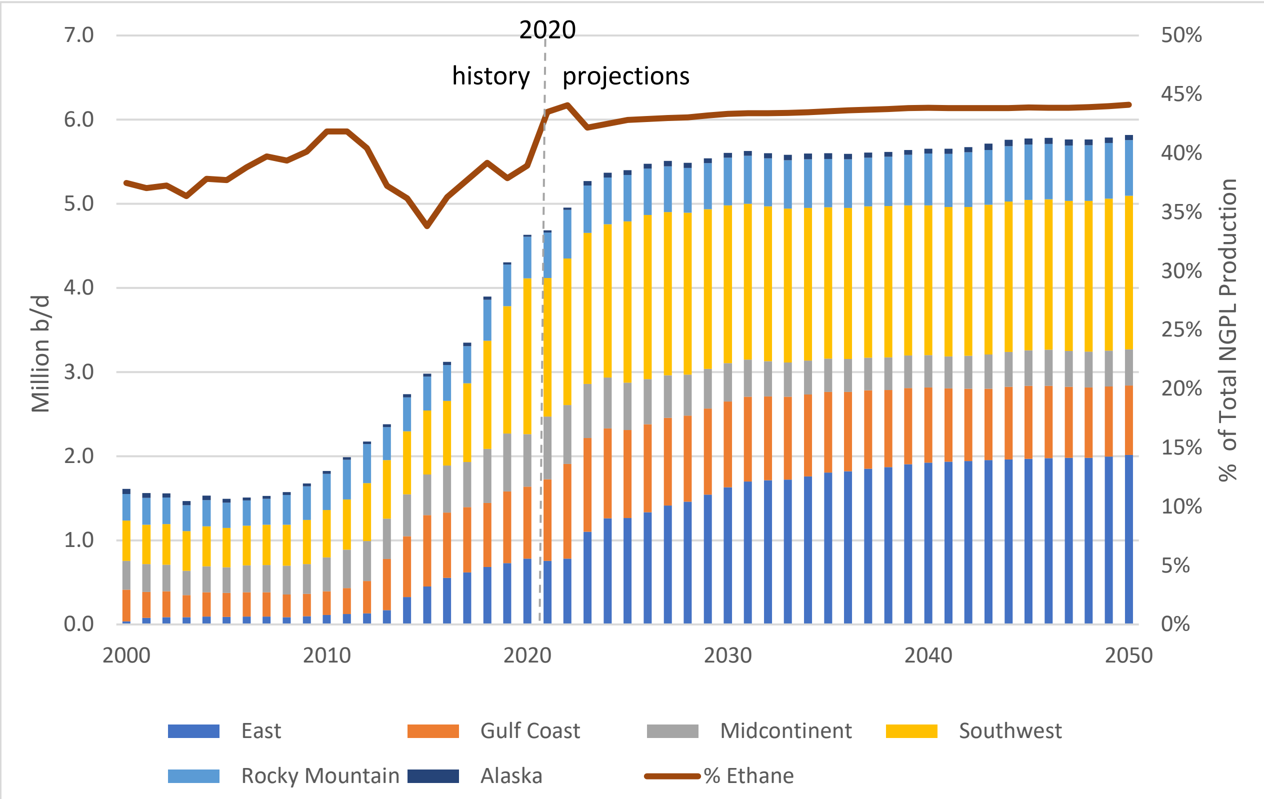
Exhibit II-6. NGPL production by U.S. region,



[12] NGL is used specifically to be inclusive of NGLs processed both through natural gas processing and refinery/condensate splitting as NGLs produced from shale resources may be processed through either track. However, NGPL is specifically called out as the data referenced refers exclusively to NGLs produced through natural gas processing plants/ fractionators (i.e., NPGLs). See Exhibit II-1 for further clarification.

natural gas and crude oil resources in those regions (Exhibit II-6). By 2050, the East and Southwest regions are projected to account for more than 60 percent of total U.S. NGPL production (Exhibit II-7) (56). NGPL output in the East 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 areas with more dry gas, the rate of growth in NGPL production will slow relative to the rate of natural gas production growth.

Exhibit II-7. AEO2021 NGPL production (history and projections) (12)



Shale plays produce natural gas composed of a mixture of several hydrocarbons, the composition of which varies significantly across plays and even within the same play. The hydrocarbon mixture includes methane (the primary component), nitrogen (N), carbon dioxide (CO_2), and NGLs (ethane, propane, butane, isobutane, and pentanes). Methane gas (known in the marketplace as natural gas) is largely used for electric power generation, heating, and industrial feedstock. Pentanes plus (natural gasoline) has a five-carbon or longer chain, is heavier than the purity molecule components, and is used in motor gasoline and industrial applications (Exhibit II-8). Propane is used in residential, commercial, and transportation sectors as fuel for space heating, cooking, and transportation, and it is employed as a petrochemical feedstock. Butanes are blended in motor gasoline and used as feedstocks for the petrochemical industry. Ethane is primarily used as a petrochemical feedstock specifically for ethylene production (Exhibit II-8).

Exhibit II-8. NGLs, uses, products, and consumers (57) (58)

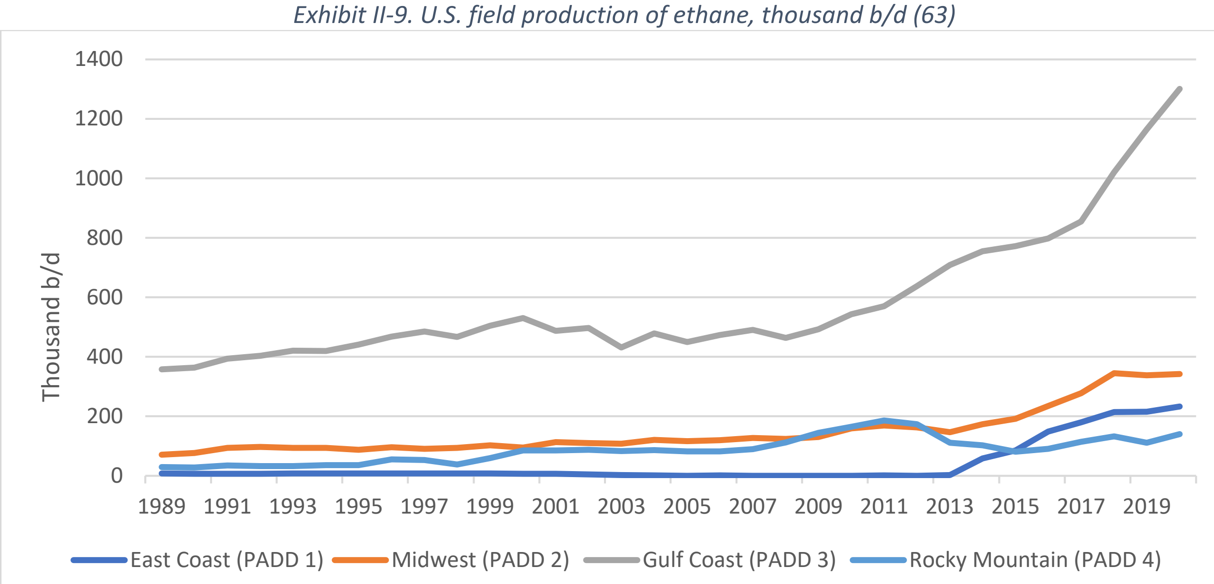
NGL	Chemical Formula	Uses	End-Use Products	End-Use Sectors	2020 U.S. Field Production (Thousand Barrels)
Ethane	C_2H_6	Petrochemical feedstock for ethylene production; power generation	Plastics; anti-freeze; detergents	Industrial	737,847
Propane	C_3H_8	Fuel for space heating, water heating, cooking, drying, and transportation; petrochemical feedstock	Fuel for heating, cooking, and drying; plastics	Industrial (includes manufacturing and agriculture), residential, commercial, and transportation	615,754
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	326,665
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	213,628
Total 2020 U.S. Field Production of NGLs (Thousand Barrels)					1,893,894

NGLs are sold either as purity molecules or as mixtures (e.g., ethane propane [E/P]), depending on the economics of production, transportation, storage, and distribution. Comparatively heavier molecules, such as butane, are liquified at lower pressure and higher temperatures, causing the heavier molecules to be mostly removed from the natural gas mix, prior to natural gas transfer through pipelines, when NGLs are present. Ethane, butanes, and propane have higher net heating values than methane and may need to be removed from piped natural gas to meet pipeline specifications, which restricts heat content to meet safety and operational requirements. Ethane is also a heavier molecule than methane, with a higher net heating value. Historically, ethane has more frequently been rejected (not removed from the natural gas mix) than recovered, compared to butane and propane, due to the economics of recovery, storage, and sales.

There are safety standards governing the upper limit of rejected ethane that can be placed into a given pipeline system. Ethane that is rejected is left in the natural gas stream to be sold and subsequently consumed as natural gas to fuel power generation and manufacturing facility operations, respectively. Ethane rejected into the natural gas stream is also consumed by residential and commercial users for heating purposes. Pipeline systems that transport natural gas specify and enforce gas quality specifications that limit the amount of heat content allowable for gas shippers. Specifically, allowable heating value percentages are governed by the Wobbe Index, a tool that specifies the threshold up to which natural gas can be safely used as fuel for residential and industrial purposes. Per IHS Markit, most U.S. interstate and intrastate natural gas pipeline systems provide shippers with gross heating value gas specifications within the 950–1,100 British thermal units (Btu)/standard cubic foot range (59).

The composition of NGPLs in shale plays varies. EIA projects shale plays in the eastern region of the continental U.S. will produce NGPLs with up to 49 percent ethane content by 2050, compared to 42–47 percent ethane content in the Southwest, Midcontinent, and Gulf Coast regions and 25 percent in the Rocky Mountain region (Exhibit II-6) (60). While eastern shale plays, particularly the Appalachian Utica play, are rich in ethane and other NGLs, the U.S. Gulf Coast has historically produced the majority of U.S. ethane (Exhibit II-9) (61). The Gulf Coast's high level of ethane production, along with supportive state policies and existing petrochemical processing, transportation, distribution, and storage infrastructure, has led to significant regional investments on the Gulf Coast in steam crackers and ethane export terminals. Producers have begun to make similar investments in the Appalachian region, including the Shell Chemical Appalachia PA petrochemicals complex, with a projected annual production of 1.6 million metric tons (62).

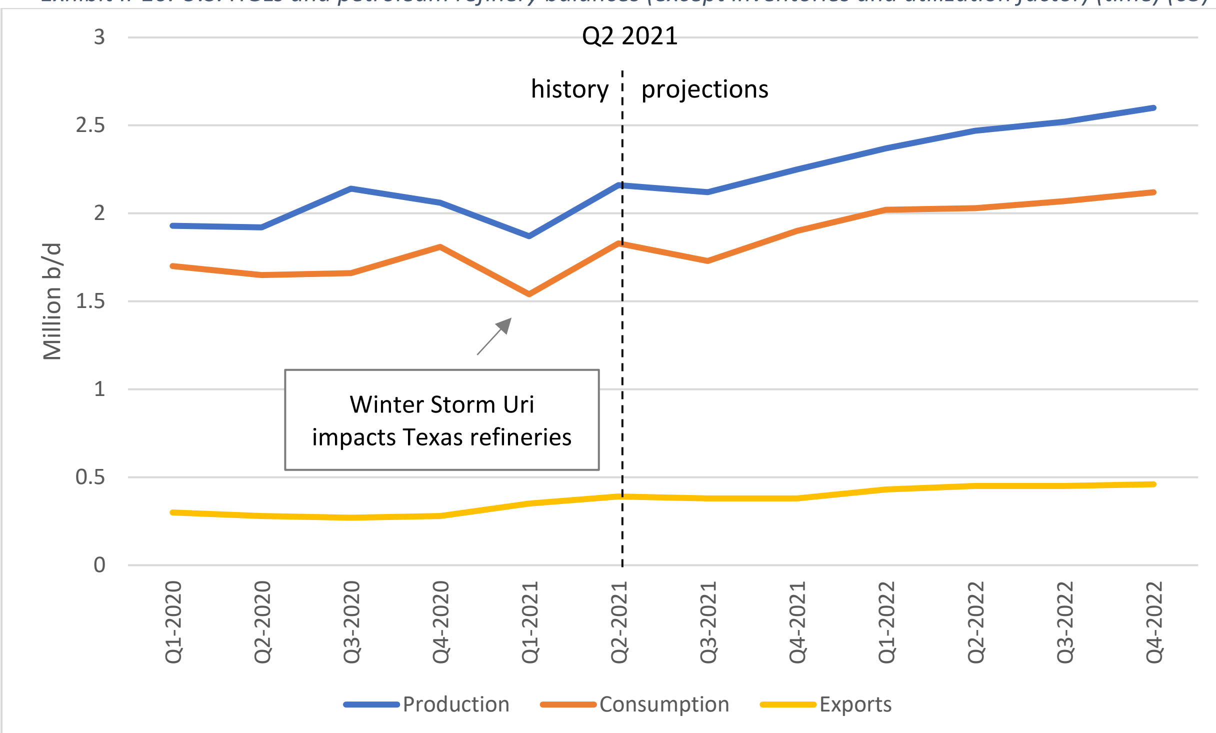
Exhibit II-9. U.S. field production of ethane, thousand b/d (63)



Note: West Coast (Petroleum Administration for Defense District [PADD] 5) production levels are negligible and not included; data is from the Natural Gas Plant Field Production table within the Petroleum & Other Liquids Database (61)

AEO2021 projects U.S. ethane production from NGPLs to grow seven percent between 2021 and 2022, and increase by an annual average growth rate of 0.5 percent from 2022 through 2050 to an estimated 2.76 million b/d by 2050 (12). Based on EIA reported ethane production values, U.S. ethane production grew by five percent between 2019 and 2021, indicating continued demand growth during the COVID-19 pandemic (12). The largest monthly decline in ethane production to date occurred during the extreme cold winter weather event of 2021 (Winter Storm Uri) in the Gulf Coast region, resulting in mass power outages at local petrochemical plants. The storm resulted in a drop of 654,000 b/d of ethane being produced in January 2021 to a total of 1.21 million b/d in February 2021, resulting in a Q1-2021 decline of 1.54 million b/d (Exhibit II-10) (64).

Exhibit II-10. U.S. HGLs and petroleum refinery balances (except inventories and utilization factor) (time) (65)



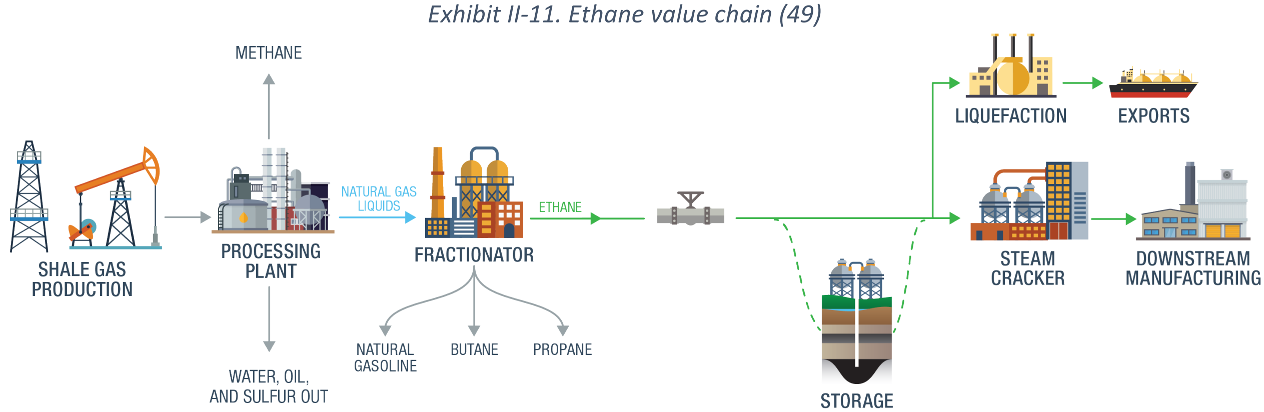
2. *Domestic Ethane*

While net exports of ethane accounted for approximately 14 percent of overall U.S. production in 2020, (65) only five states—Texas, Louisiana , Illinois, Iowa , and Kentucky —have ethane-fed steam crackers that consume ethane as a feedstock (66). Texas consumed about 707 million barrels (bbls) of HGLs in 2020—the highest level of any state—and accounted for more than 60 percent of total U.S. HGL consumption, almost all of which was in the industrial sector. Louisiana, the second-largest total HGL-consuming state, accounted for 158 million bbls in 2019, about 14 percent of total U.S. HGL consumption. The next largest HGL-consuming states are Illinois and Iowa, consuming 26 and 24 million bbls, respectively, in 2019 (67). Domestic demand for ethane has continued to rise due to efficiencies in converting ethane to ethylene.

3. *Ethane Value Chain*

A value chain represents the full sequence of events or activities a firm (i.e., a business unit or enterprise), or set of firms, performs to transform inputs into output products of value. Each event or activity performed is assumed to add value to the product for the end-consumer. Based on a firm's manufacturing process, a value chain can be used to identify opportunities for improvement, additional ways to add value to products (e.g., by using lower cost inputs) or gain a competitive market advantage. As a petrochemical feedstock, the value chain for ethane is complex. The ethane value chain is most commonly described by the stages of processing pure ethane, a base petrochemical primarily produced via natural gas processing, into derivative products (49). Exhibit II-11 provides an overview of the upstream, midstream, and downstream activities underpinning the value chain for ethane.

Exhibit II-11. Ethane value chain (49)



Following extraction from the wellhead, liquid components of the natural gas output are removed during processing, leaving a mixture of NGLs called Y-grade. Y-grade is then transported and fractionated at a fractionator to separate the component NGLs: ethane, propane, butane, and natural gasoline (pentanes). Depending on the makeup of the NGL input and market factors, fractionation operators produce either purity ethane—ethane that is at least 95 percent pure—or E/P, which ranges 78–82 percent ethane and 18–22 percent propane (68) (69). Unlike other petroleum fuels, purity ethane (ethane) has a low boiling point (approximately -128°F at normal pressure) requiring transportation modes to include higher pressures or cryogenic capabilities (68). Additionally, storage wells for liquid ethane require significantly higher pressurization, i.e., 543 pounds per square inch, compared to other NGLs, such as liquid propane, which requires pressures greater than 122 pounds per square inch at 70°F (70). Due to the difficulties in storing purity ethane, producers (particularly in the Conway hub in Kansas) produce primarily E/P mixes for storage or processing through E/P mix splitters attached to steam crackers, or transport excess ethane by pipelines to NGL hubs for storage or steam cracking (69).

When used to manufacture downstream products, ethane is piped into a steam cracker that uses steam to crack ethane into ethylene. New steam crackers (post-2017) in the United States are not designed to process E/P, and the industry has set a preference of using ethane for ethylene production. However, some steam crackers are capable of processing mixed feedstocks based on cost effectiveness of the feedstock (69). Ethylene can be developed into different derivative compounds, which in turn can be used to manufacture several products including food packaging, plastic bags and bottles, textiles, anti-freeze, rubber products, resins, foam insulation, and vinyl for pipes, siding, and medical devices (71).

Based on the description of the ethane value chain provided above, the industrial manufacturing sectors listed in Exhibit II-12 were identified as those highly likely to be engaged in at least one segment of the value chain for ethane. Industrial manufacturing sectors are aggregated following the 2017 North American Industrial Classification System (NAICS) using both 3- and 4-digit codes. Descriptions are available directly from the 2017 NAICS manual (72).

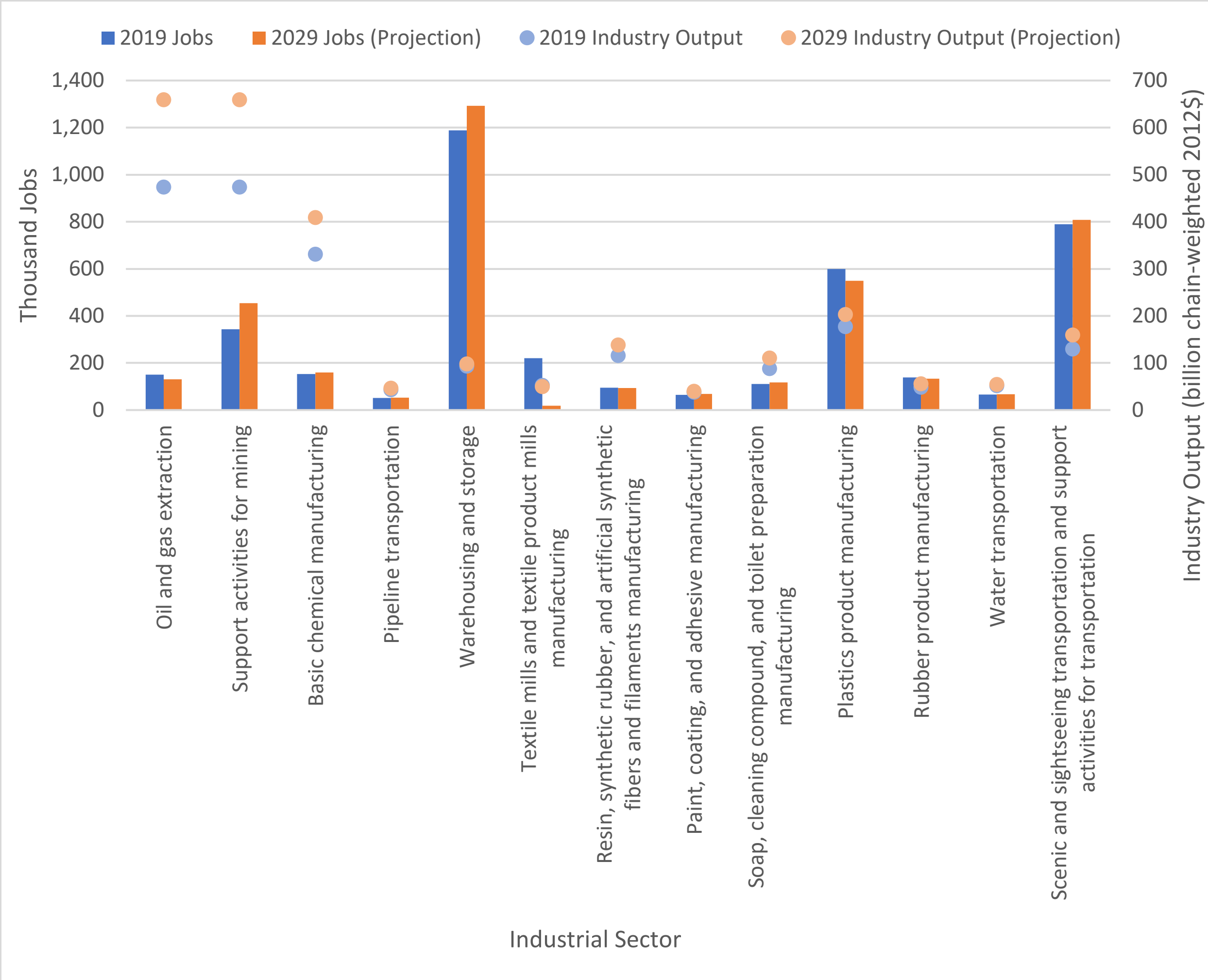
Exhibit II-12. Industrial manufacturing sectors highly likely to be engaged in the ethane value chain by segment (72) (49)

Value Chain Segment	Industrial Sectors	2017 NAICS Codes	Description
Natural Gas Production and Natural Gas Processing	Oil and Gas Extraction	211	Comprises establishments primarily engaged in the operation and/or development of oil and gas field properties. Such activities may include exploration for crude petroleum and natural gas; drilling, completing, and equipping wells; operating separators, emulsion breakers, desilting equipment, and field gathering lines for crude petroleum and natural gas; and all other activities in the preparation of oil and gas up to the point of shipment from the producing property. This subsector includes the production of natural gas, sulfur recovery from natural gas, and recovery of hydrocarbon liquids.
	Support Activities for Mining	213	Comprises establishments primarily engaged in providing support services, required for mining and quarrying, and for the extraction of oil and/or gas.
Fractionator	Basic Chemical Manufacturing	3251	Comprises establishments primarily engaged in manufacturing chemicals using basic processes, such as thermal cracking and distillation. Chemicals manufactured by this industry group are usually separate chemical elements or separate chemically defined compounds. Includes industries engaged in petrochemical manufacturing.
Pipeline Transportation	Pipeline Transportation	486	Comprises establishments primarily engaged in the transportation of products, such as crude oil, natural gas, refined petroleum products, and slurry.
Storage	Warehousing and Storage	493	Comprises establishments primarily engaged in operating warehousing and storage facilities.
Downstream Manufacturin g	Textile Mills and Textile Product Mills Manufacturing	313 314	Comprises establishments that transform a basic fiber (natural or synthetic) into a product, such as yarn or fabric that is further manufactured into usable items, such as apparel, sheets, towels, and textile bags for individual or industrial consumption. Also comprises establishments that make non-apparel textile products.

Value Chain Segment	Industrial Sectors	2017 NAICS Codes	Description
	Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Manufacturing	3252	Comprises establishments primarily engaged in one of the following: 1) manufacturing synthetic resins, plastics materials, and non-vulcanizable elastomers and mixing and blending resins on a custom basis; 2) manufacturing non-customized synthetic resins; 3) manufacturing synthetic rubber; 4) manufacturing cellulosic (e.g., rayon, acetate) and non-cellulosic (e.g., nylon, polyolefin, polyester) fibers and filaments in the form of monofilament, filament yarn, staple, or tow; or 5) manufacturing and texturizing cellulosic and non-cellulosic fibers and filaments.
	Paint, Coating, and Adhesive Manufacturing	3255	Comprises establishments primarily engaged in one or more of the following: 1) mixing pigments, solvents, and binders into paints and other coatings; 2) manufacturing allied paint products; and 3) manufacturing adhesives, glues, and caulking compounds.
	Soap, Cleaning Compound, and Toilet Preparation Manufacturing	3256	Comprises establishments primarily engaged in 1) manufacturing and packaging soaps, detergents, polishes, surface active agents, textile and leather finishing agents, and other sanitation goods or 2) preparing, blending, compounding, and packaging toilet preparations.
	Plastics Product Manufacturing	3261	Comprises establishments primarily engaged in processing new or recycled plastics resins into intermediate or final products including but not limited to plastic bags, plastic packaging, plastic pipes, laminated plastics, foams, plastic bottles, plastic siding, floor covering, plastic trashcans, plumbing fixtures, and other plastic building materials.
	Rubber Product Manufacturing	3262	Comprises establishments primarily engaged in processing natural, synthetic, or reclaimed rubber materials into intermediate or final products including but not limited to rubber tubing, tires, and other rubber automobile parts (e.g., hoses and belts).
Export	Water Transportation	483	Comprises establishments primarily engaged in water transportation of passengers and cargo using watercraft, such as ships, barges, and boats. Includes deep sea, coastal, Great Lakes, and inland transportation.
	Scenic and Sightseeing Transportation and Support Activities for Transportation	488	Comprises establishments who provide services in support of transportation. Support activities are for all forms of transportation including port and harbor operations.

Employment and total industrial output associated with the industrial manufacturing sectors in Exhibit II-12 are outlined in Exhibit II-13. Employment (thousand jobs) and total industrial output (billion chain-weighted 2012 dollars [2012$]) values provided are based on reported data from the Bureau of Labor Statistics (BLS) and representative of the industrial manufacturing sector as a whole. As such, they should not be interpreted as employment or total industrial output associated with the value chain for ethane alone, but rather as industries who are highly likely to be engaged in the value chain for ethane. Data includes information for the year 2019 and projections for the year 2029.

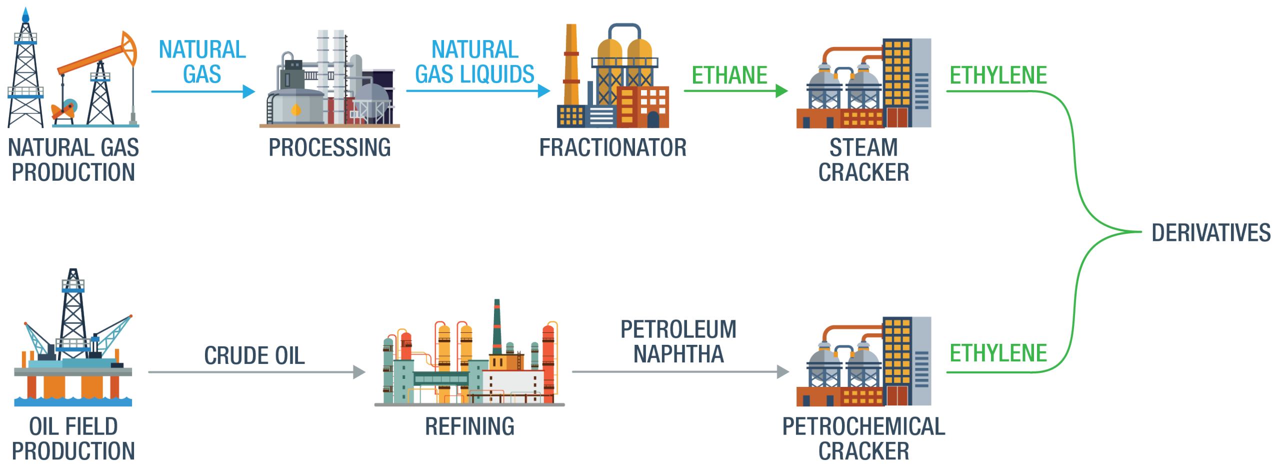
Exhibit II-13. Employment by industrial output by industrial manufacturing sector highly likely to be engaged in the ethane value chain by segment (73)



A. *Ethylene Demand and End-Uses*

U.S. demand for ethylene is forecast to grow 51 percent between 2019 and 2035 (16), with the greatest domestic demand for polyethylene, followed by ethylene dichloride (EDC) and ethylene oxide. U.S. domestic ethylene production capacity is forecast to increase nearly 50 percent (16) by 2035. The market currently values ethane due to the high yield ratio of ethane to ethylene. Yield of ethylene from petrochemical cracking of naphtha, a crude oil derivative, ranges 29–34 percent, whereas cracking ethane yields 80–84 percent (15). The production process for naphtha to ethylene and ethane to ethylene follow the pathways shown in Exhibit II-14. Due to the high yield for ethylene from ethane and the significant growth in U.S. production of ethane, ethane-cracking is a more cost effective and efficient method for producing ethylene feedstock, domestically and globally.

Exhibit II-14. Ethylene production pathways (49)

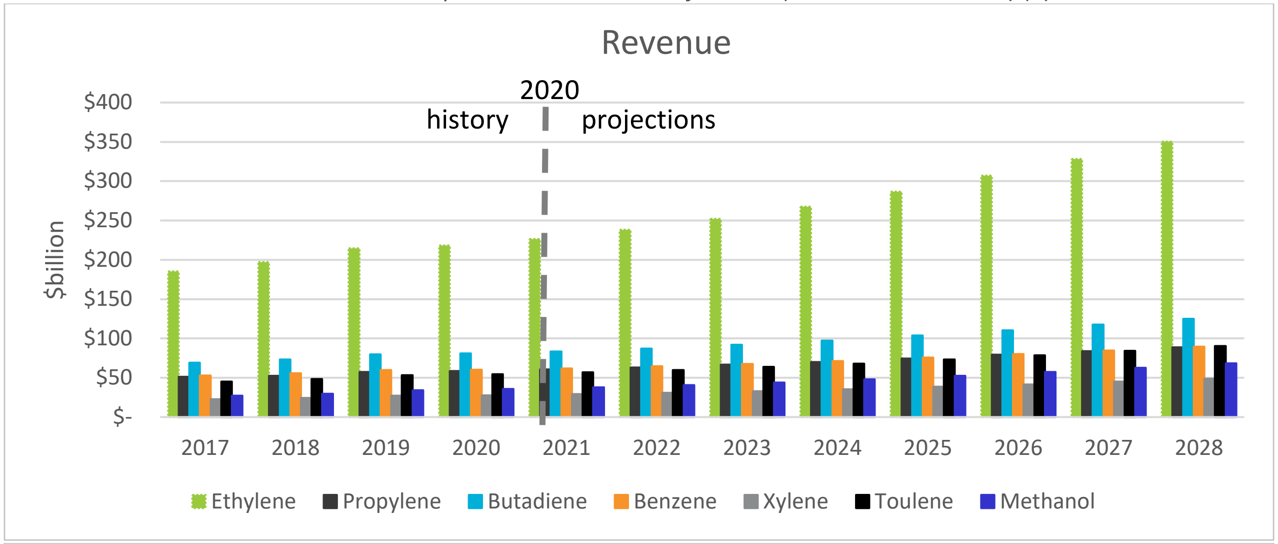


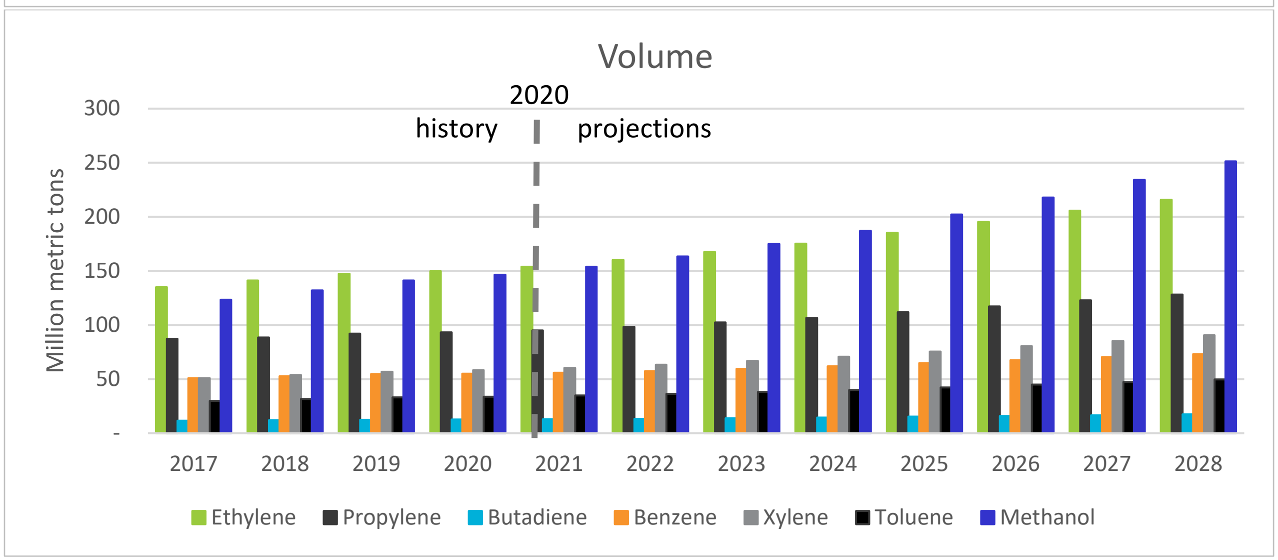
Global market demand for ethylene currently exceeds other top petrochemicals, both by volume and revenue, and is expected to grow 40 percent by volume and 60 percent by revenue by 2035 (Exhibit II-15) (9). In response to growing demand for ethylene, countries with significant oil reserves including Saudi Arabia and Qatar continue to invest in producing ethylene from locally derived ethane and mixed-feedstocks[13] to meet global ethylene demand (74). Large net consumers of ethylene, such as China, have taken a broader approach, investing both in steam cracking facilities using mixed-feedstocks and those designed to specifically process ethane feedstocks, which will be imported from the United States, into higher-value ethylene and ethylene derivatives (47). The preference for ethane-derived-ethylene has also driven investment in a new European steam cracker (75).

Spot prices for ethylene from the United States are lower than for ethylene produced in other countries. The U.S. ethylene 4-year average (2017–2020) spot price was 38–77 percent less than average spot prices in Europe, Japan, South Korea, and Southeast Asia (48). The freight differential is likely the primary cause of increased ethylene spot prices in countries reliant on U.S. ethane feedstock (i.e., a high percentage of countries which utilize ethane as their feedstock). For ethylene producing countries with a mixed feedstock, the cause is likely the use of feedstocks with lower conversions factors to ethylene. U.S. domestic steam crackers, with access to nearby ethane extraction and gas processing, or ethane-pipeline infrastructure, can maintain a wider profit margin with their ethylene production than their global counterparts.

[13] Mixed feedstock can include a combination of ethane, propane, butanes, naphtha, and gas oil.

Exhibit II-15. Global petrochemical market forecast (revenue and volume) (9)

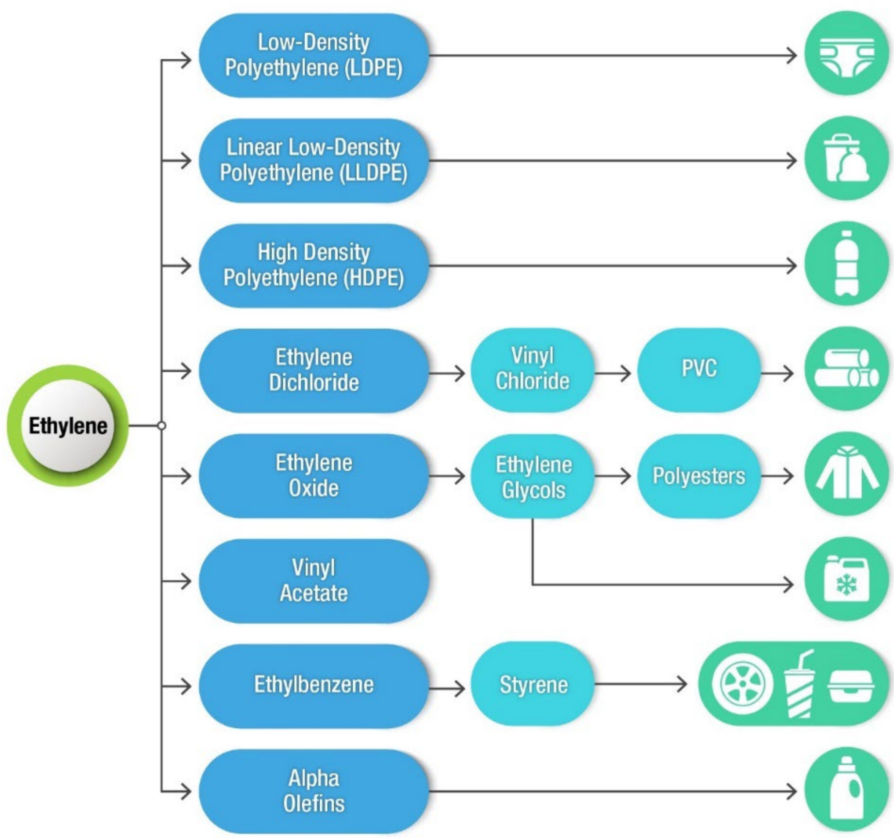




B. *Ethylene Derivatives Demand and End-Uses*

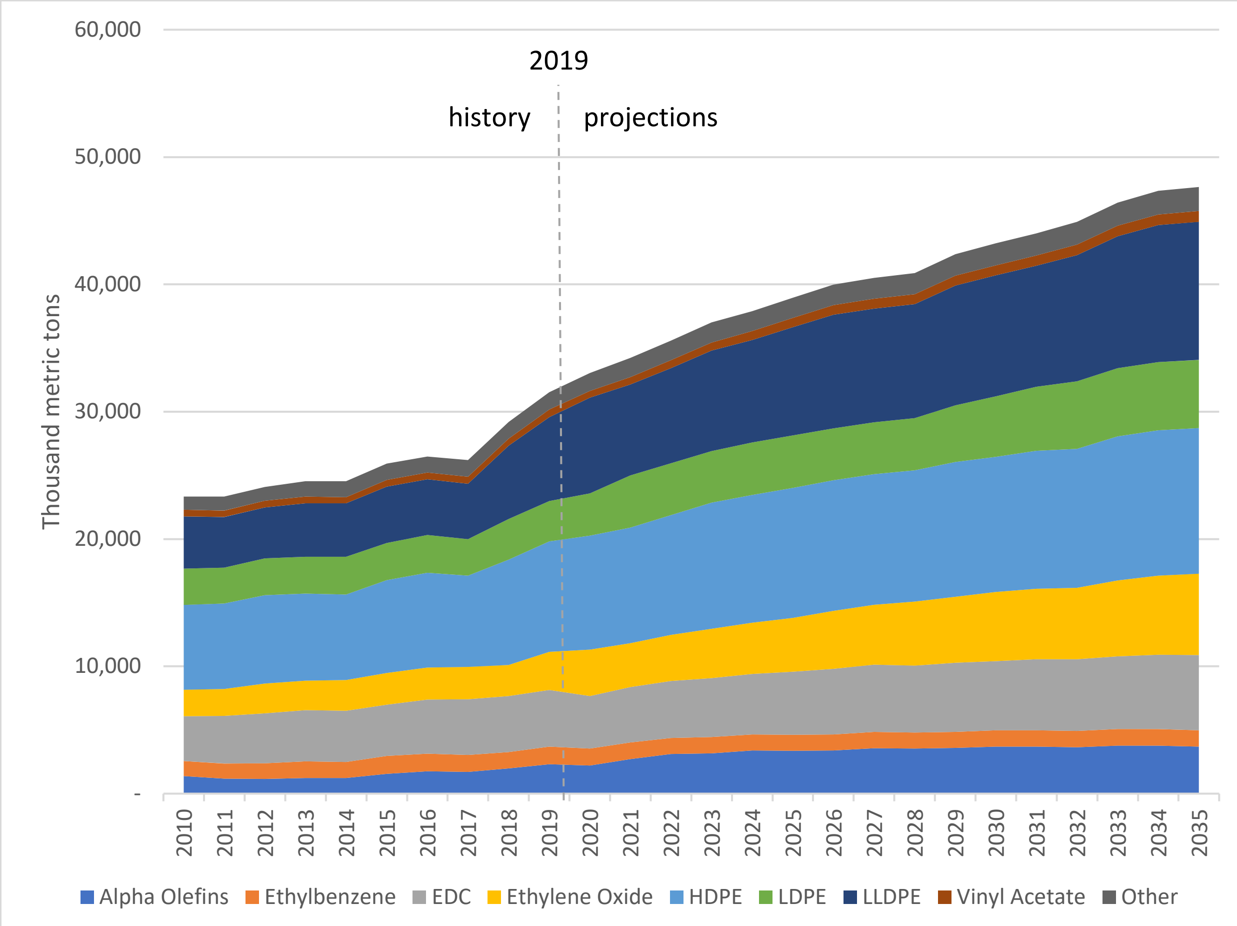
Ethylene can be used to produce a wide variety of derivatives for industrial and consumer use. Key derivatives include polyethylene, EDC, ethylene oxide, vinyl acetate, ethylbenzene/styrene, and alpha olefins. This report provides a demand analysis of the highest demand ethylene derivatives: polyethylene and EDC. Polyethylene is the most widely used ethylene derivative and the primary petrochemical used to make plastics for consumer goods. It is broken into three categories of densities: low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), and high-density polyethylene (HDPE). EDC is used to produce polyvinylchloride (PVC), which is used globally in construction. Exhibit II-16 provides an overview of the full ethylene value chain and output products.

Exhibit II-16. Ethylene derivatives and uses (76)



Ethylene demand for different derivatives is illustrated in Exhibit II-17.

Exhibit II-17. U.S. ethylene derivative demand and forecast (16)



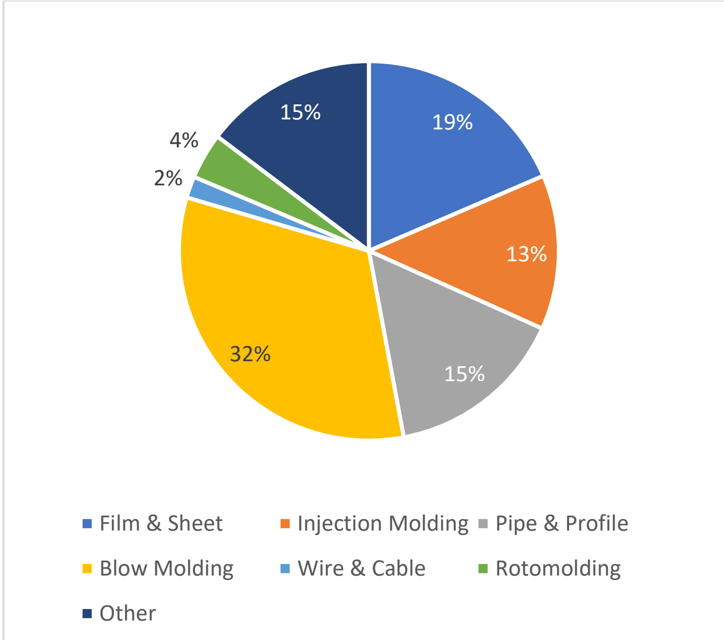
High-Density Polyethylene

U.S. domestic demand for HDPE is forecast to increase 35 percent (16) from 2019[14] to 2035. HDPE is used globally to make bottles for consumer and commercial cleaning materials, pipes, and toys. In the United States, HDPE demand is highest for blow molding,[15] film and sheet plastics, injection molding, and pipes (Exhibit II-18).

[14] Due to the novel coronavirus pandemic of 2020–2021, the base year for analysis is 2019.

[15] Blow molding is a process of molding plastics with hollow centers, primarily for containers and bottles.

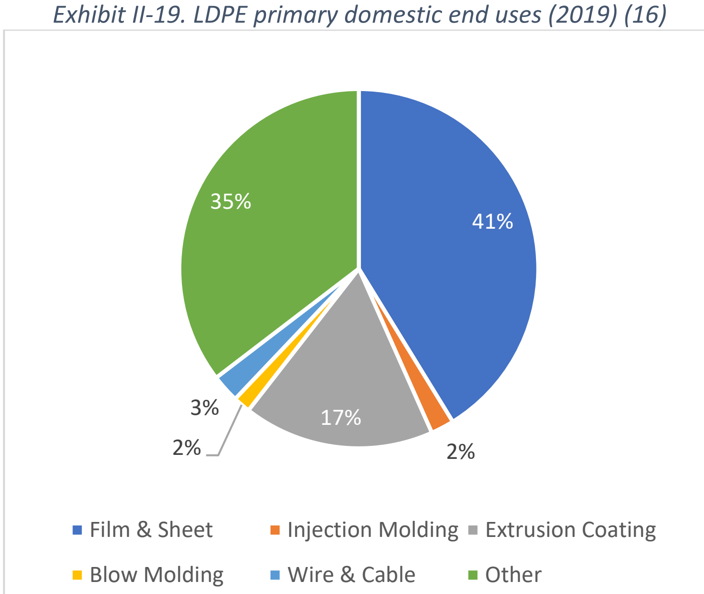
Exhibit II-18. HDPE primary domestic end uses (2019) (16)



Low-Density Polyethylene

U.S. domestic demand for LDPE is forecast to increase 27 percent (16) from 2019[16] to 2035. LDPE is used in consumer materials including film-wrap and grocery bags, to medical equipment including prosthetics. Domestically, LDPE is primarily consumed for film and sheets and extrusion coating (lamination) (Exhibit II-19).

Exhibit II-19. LDPE primary domestic end uses (2019) (16)

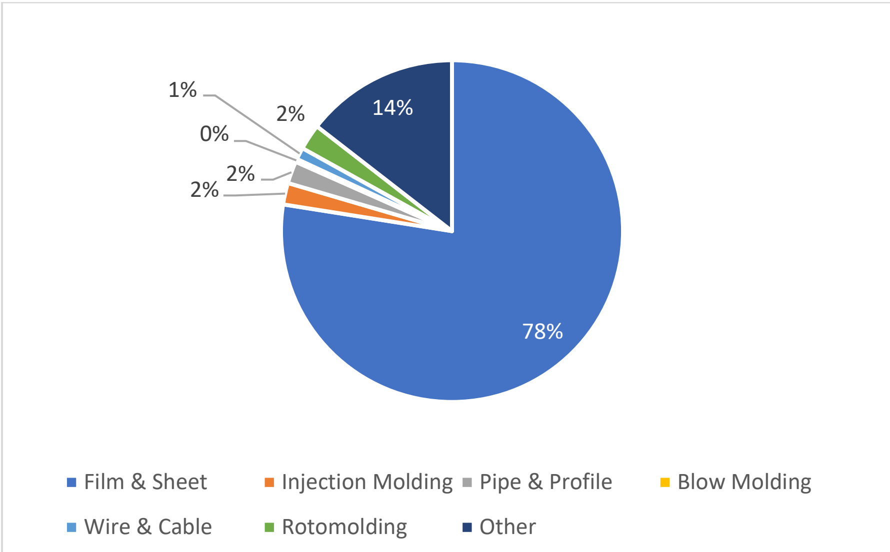


[16] Due to the novel coronavirus pandemic of 2020–2021, the base year for analysis is 2019.

Linear Low-Density Polyethylene

U.S. domestic demand for LLDPE is forecast to increase 34 percent (16) from 2019[17] to 2035. In 2019, more than three-fourths of LLDPE in the United States was consumed for the manufacture of film and sheets (Exhibit II-20).

Exhibit II-20. LLDPE primary domestic end uses (2019) (16)



Ethylene Dichloride

U.S. domestic demand for EDC is forecast to increase 39 percent (16) from 2019[18] to 2035. In 2019, over 98 percent of EDC was used for vinyl chloride (16).

4. International Market for U.S. Ethane

U.S. exports of purity ethane (ethane) have grown steadily since the United States began exporting ethane by way of the Mariner West pipeline to Canada in January 2013 (77). While exports of ethane only account for approximately 20 percent of overall U.S. production (as shown in Exhibit II-10), domestic demand for ethane has continued to rise due to the efficient conversion rate of ethane to ethylene and low natural gas prices. In addition, countries with domestic production of ethane, or agreements with other international suppliers of ethane, are selecting to additionally contract with U.S. ethane suppliers. IHS Markit identified three types of countries making the switch to importing U.S. ethane: "Those [countries] currently cracking domestically produced ethane, thus having potential to diversify supply or crack more ethane. [Countries with] non-ethane crackers that could potentially be re-configured to use ethane as a feedstock. And countries that are short in ethylene and willing to invest in greenfield projects to use ethane as a new feedstock" (78).

[17] Due to the novel coronavirus pandemic of 2020–2021, the base year for analysis is 2019.

[18] Due to the novel coronavirus pandemic of 2020-2021, the base year for analysis is 2019.

Foreign private enterprises, in countries and regions with emissions reductions targets like Belgium and other European Union members, are turning away from crude oil-based feedstocks and towards U.S. ethane feedstocks to reduce their petrochemical industry emissions. INEOS Belgium is in the application phase for Project One, "Europe's most environmentally friendly [ethane] steam cracker," a facility estimated to produce half as many CO_2 emissions than a naphtha-based cracker (75). Project One plans to have a 1.45 million metric ton annual ethylene nameplate capacity, and intends to use U.S. ethane as the plant's primary feedstock (79).

> At this time, INEOS' emissions reduction predictions cannot be confirmed. However, a 2013 study in the *Applied Petrochemical Research* journal reported an approximate 15 percent reduction in life cycle GHG emissions (kilograms of CO_2-equivalent) per 400,000 metric tons of ethylene produced from ethane feedstock compared to the equivalent ethylene tonnage from naphtha feedstock (233).

By volume, the largest importers of U.S. ethane in 2020 were Canada, India, United Kingdom, Norway, and China (Exhibit II-21). Ethane demand is mainly driven by demand for ethylene and its derivatives, given that the primary use of ethane is as a feedstock for ethylene. Over the last decade, consumption of ethylene in China and the "Other Asia Pacific" region (Australia, India, Indonesia, Malaysia, Singapore, and Thailand)[19] grew most rapidly, followed by the "Middle East & Africa" region and North America[20] (Exhibit II-22).

[19] The data used for this analysis from Nexant ChemSystems defines an "East Asia" region as Japan, South Korea, and Taiwan. The "Other Asia Pacific" region is defined as Australia, India, Indonesia, Malaysia, Singapore, and Thailand.

[20] The data used for this analysis from Nexant ChemSystems does not disaggregate "North America" by Canada and the United States for ethylene; based on market volume forecasts from Grand View Research Petrochemicals Market Estimates & Forecast 2017–2028, the U.S. comprised over 80 percent of 2019 North American ethylene market volume (9).

Exhibit II-21. U.S. ethane export recipients, by country, 2014–2020 (80)

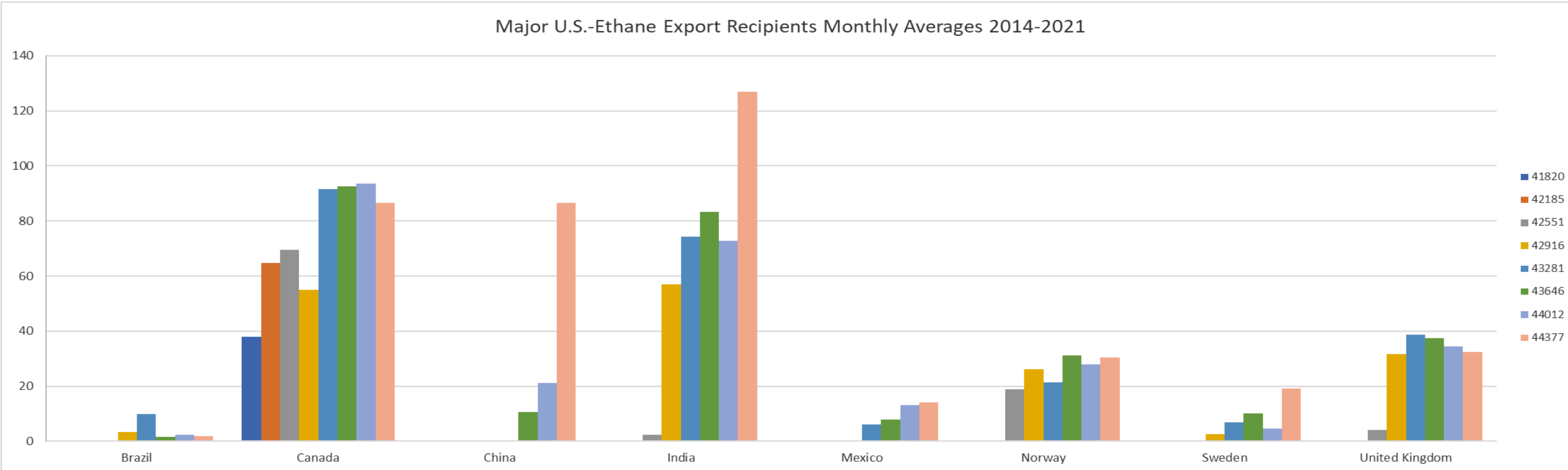
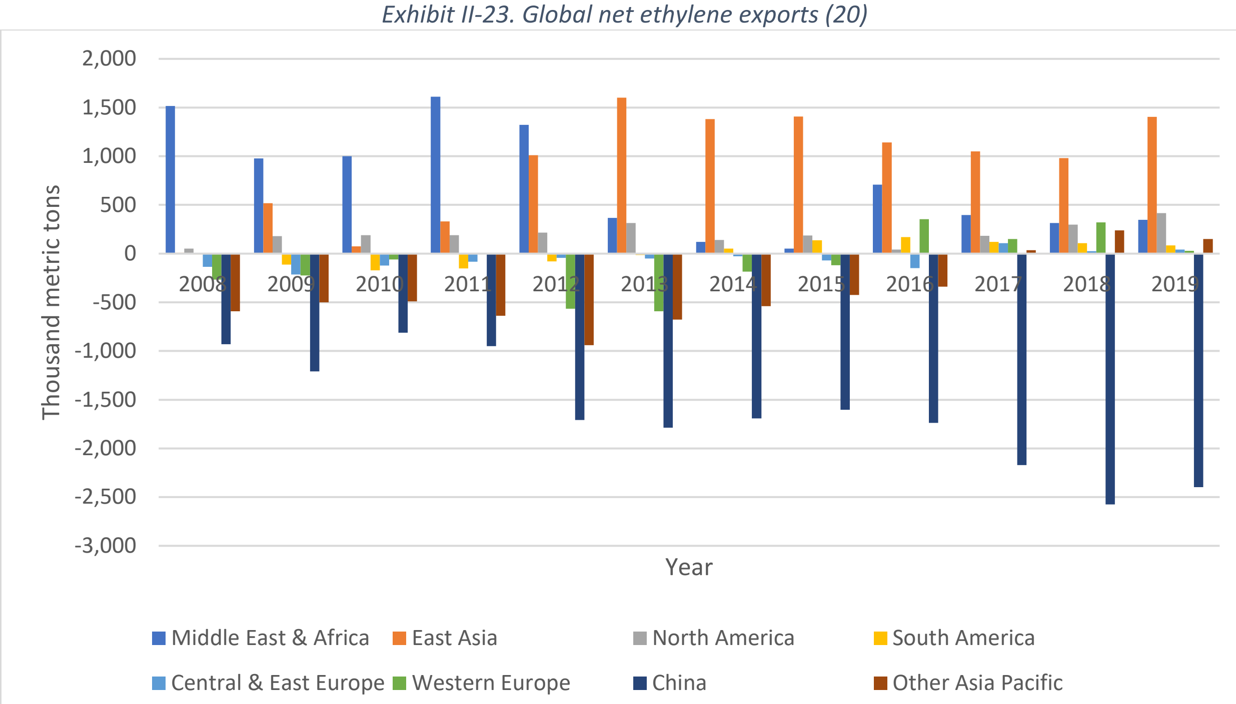


Exhibit II-22. Annual average rate of change in ethylene consumption and production by region 2010–2019 (20)

Region	Avg. Annual Change Domestic Consumption	Avg. Annual Change Domestic Production
China	6%	8%
Other Asia Pacific	6%	7%
Middle East & Africa	5%	7%
North America	3%	3%
Central & East Europe	2%	2%
South America	-1%	1%
Western Europe	-1%	0%

The growth in Chinese domestic ethylene production (Exhibit II-22) and continued negative net ethylene exports (Exhibit II-23) indicate Chinese domestic consumption exceeds its domestic production capabilities. East Asia (Japan, South Korea, and Taiwan), the Middle East and North Africa are net ethylene exporters. In addition, North American net ethylene exports increased over 50 percent between 2017 and 2019 (20).[21]

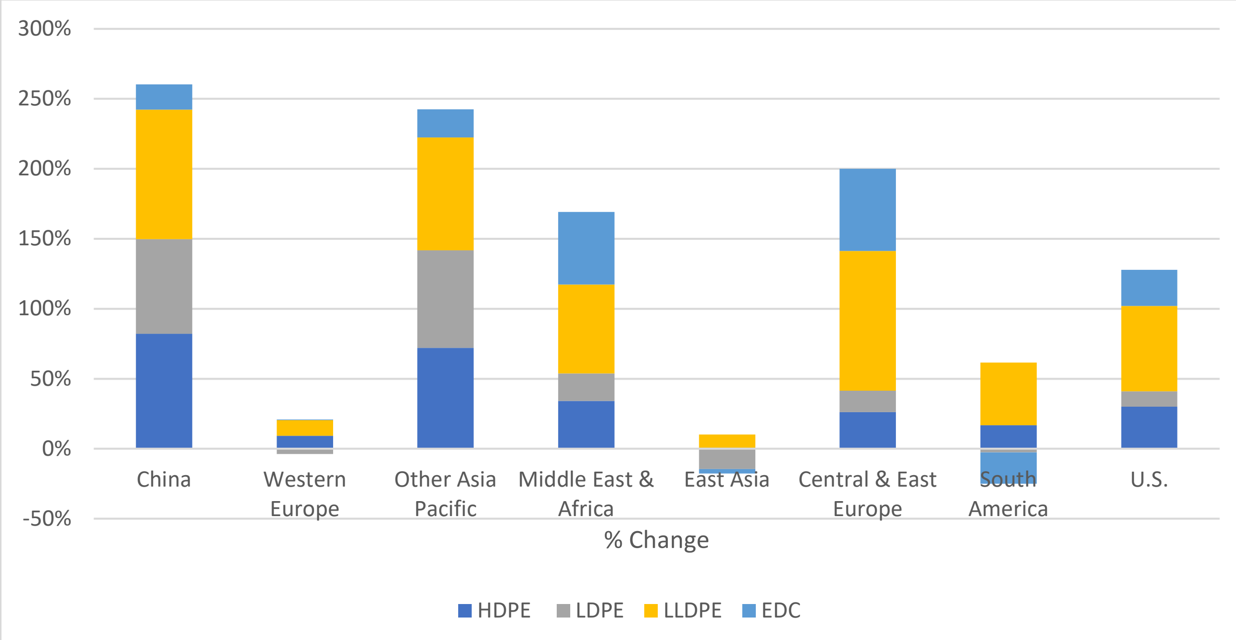
Exhibit II-23. Global net ethylene exports (20)



Over the past decade, global demand among ethylene derivatives has increased the most for LLDPE and HDPE. China and "Other Asia Pacific" region countries saw the greatest overall demand increase for total combined ethylene derivatives (Exhibit II-24).

[21] In 2016, North America reportedly had an 11-year low in net ethylene exports; the value may be an error in the data set—a 3-year growth rate as opposed to a 4-year growth rate is reported to prevent an overestimate.

Exhibit II-24. Average annual percent change in top ethylene derivative demand (2010–2019) (20) (16)



Note: U.S. demand data is from HIS Markit Ethylene Derivatives Market Data report 2021. All other data is from the Bloomberg Terminal.

III. Ethane's Contribution to the U.S. Economy

To estimate ethane's contribution to the U.S. economy, information is provided on ethane development and trends related to NGLs production, investment in production and logistics infrastructure related to produce and deliver ethane, investment in the U.S. petrochemical industry associated with increased ethane availability, and trends in interstate commerce and international trade. Opportunities for investment, job creation, and economic growth are described herein.

1. Investment in U.S. Petrochemical Industry Associated with Ethane Availability

Ethane in the United States is primarily used by the petrochemical industry as a feedstock in the production of ethylene. Consumption of ethane for ethylene production in the United States is projected to grow by 800,000 b/d between 2020 and 2030 (16). Domestically produced ethane is projected to supply all of the ethane demand for ethylene production, and most of the domestically sourced ethane is projected to be supplied via natural gas processing (16). The capacity to produce ethylene in the United States is also projected to increase, growing on average by 13.6 percent from 2020 to 2023 and then leveling off over the forecast period of 2025–2035 (16).[22] In 2019, the capacity to produce ethylene in the United States was estimated to be equal to approximately 36.3 million metric tons while actual ethylene production was estimated to be equal to 31.4 million metric tons (16) (17). A map of

[22] The year 2035 is the last year for which projected values for ethane demand for ethylene production are provided by the data resource used.

established sites with steam crackers and planned crackers in the United States between 2013 and 2022 is provided in Exhibit III-1 (81).[23]

Exhibit III-1. Map of established sites with ethylene crackers (steam crackers) and planned ethylene crackers (1)

EIA projects three new steam crackers will be operational in 2022 (1): Gulf Coast Growth Ventures (which came online in January 2022), Baystar, and Shell Chemical Appalachia (1). Both Baystar and Gulf Coast Growth Ventures are located in Texas, while Shell Chemical Appalachia will be located in Pennsylvania (1). These crackers are represented by the red triangles in Exhibit III-1. Together, the three planned steam crackers are projected to increase U.S. capacity to produce ethylene to approximately 43.5 million metric tons per year (1). More information on each planned cracker is provided below.

Shell Chemical Appalachia, Pennsylvania: Shell made the final investment decision on the Pennsylvania Petrochemical Complex in mid-2016 and began significant construction soon after in November 2017. The plant is expected to come online in 2022, will use ethane from shale gas extracted from the Marcellus and Utica basins, and shall feature an ethane-fed steam cracker with a polyethylene derivatives unit. Shell estimates the plant will produce 1.6 million metric tons of polyethylene per year (62), and hopes that the plant will have a competitive advantage over Gulf Coast ethylene and polyethylene producers due to the low-cost, local ethane feedstock as well as the plant's relative proximity to 70 percent of North America's

[23] The STEO prepared by the EIA in 2016, suggested in 2017 there would be five new ethylene cracker plants in the United States (234). The parent company and location of the five new plants and their respective capacity for ethylene production (in parenthesis) include: Dow Chemical Company in Freeport, TX (1,500 thousand metric tons per year), OxyChem/Mexichem JV in Ingleside, TX (544 thousand metric tons per year), Chevron Phillips Chemical in Baytown, TX (1,500 thousand metric tons per year), ExxonMobil Chemical Company in Baytown, TX (1,500 thousand metric tons per year), and Formosa Plastics Corp. USA in Point Comfort, TX (1,043 thousand metric tons per year) (234). A list of ethane fed crackers at established cracker sites is provided in Appendix B: U.S. Ethane Crackers.

polyethylene customers, providing a shortened supply chain and reduced transportation and other relevant logistical costs (62).

Baystar, Texas: French petroleum refining company, Total S.A. (Total), and Austrian chemicals company, Borealis, entered a joint venture, Bayport Polymers LLC (Baystar), to build a 625,000-metric ton per year polyethylene production unit in Pasadena, Texas. The Pasadena production unit will be supplied by Baystar's one million metric tons per year ethane-fed steam cracker in Port Arthur, Texas, (82) that will become operational in 2022. The Baystar steam cracker will also service an existing 400,000 metric tons per year in demand from the joint venture's polyethylene plant located near the Houston Ship Channel (83).

Gulf Coast Growth Ventures, Texas: ExxonMobil and Saudi Arabian chemical manufacturing company, SABIC, entered into a joint venture, Gulf Coast Growth Ventures, to construct a plastics manufacturing plant in San Patricio County, Texas. The facility, which came online on January 20, 2022, includes 1.8 million metric tons of ethane-fed steam cracker capacity. ExxonMobil has announced that this is the "world's largest steam cracker" (84). Ethylene from the cracker will feed three derivative units. One will be a monoethylene glycol unit, which is used in producing latex paints, automotive coolants and anti-freeze, and various forms of plastics. The plant's two polyethylene units will provide polyethylene for use in film, packaging, bottles and containers, and various sized pipes (85).

2. *Potential Job Creation from Ethane Development*

According to the EIA, in response to greater ethane feedstock availability and resultant lower domestic ethane prices, the petrochemical manufacturing sector as a whole has expanded the production capacity of several ethylene cracker plants and also built new petrochemical crackers that use ethylene as a feedstock. These expansions have generated nearly $200.4 billion dollars in new investment (86). An analysis performed by the American Chemistry Council (ACC) suggests these new investment dollars could generate nearly $292 billion per year in new chemical and plastics industry output and support 786,000 jobs by 2025, including 79,000 direct chemical industry jobs, 352,000 indirect jobs, and 355,000 induced jobs (87).

Like other construction projects, the introduction of a new steam cracker facility is likely to generate and support additional employment in the construction industry. A list and description of construction jobs likely to be required during the construction phase of a steam cracker are provided in Exhibit III-2. The list is based on reported information from BLS (88).[24]

[24] Note: Construction occupations are described by the BLS as construction and extraction occupations (88).

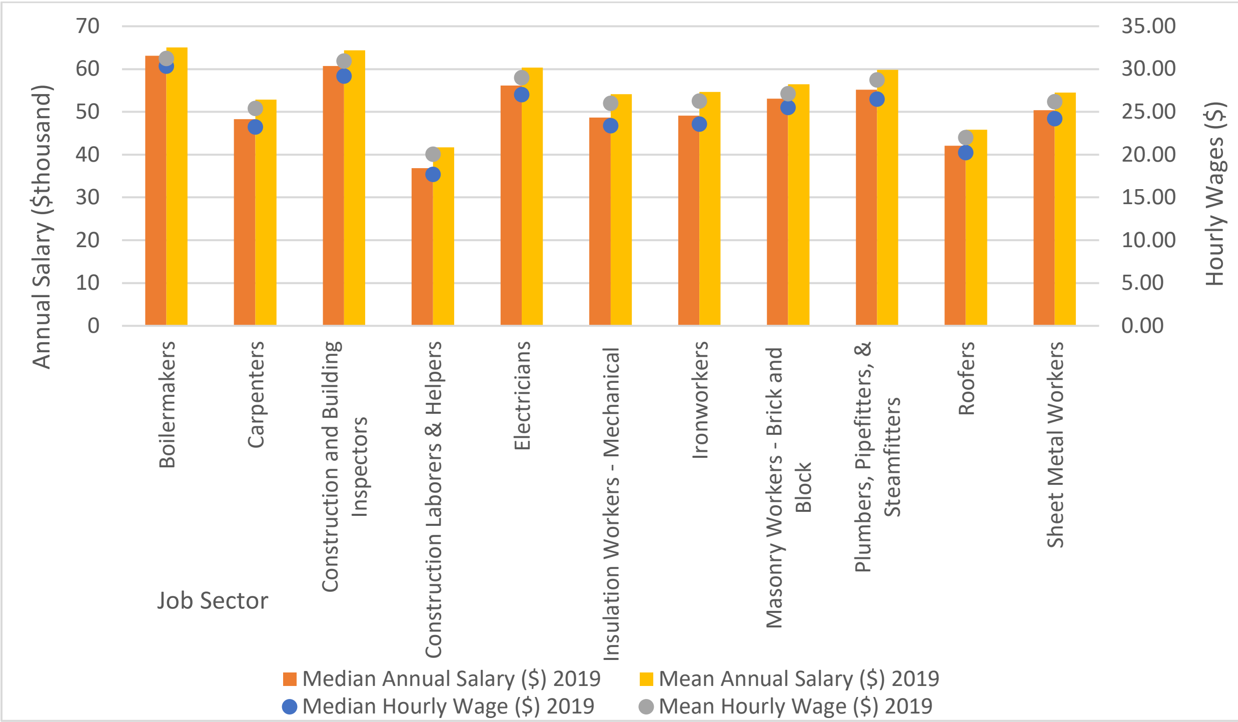
Exhibit III-2. List of construction jobs likely to be required during the construction phase of a new steam cracker (88)

Occupation	Job Summary
Boilermakers	Assemble, install, maintain, and repair boilers, closed vats, and other large vessels or containers that hold liquids and gases
Carpenters	Construct, repair, and install building frameworks and structures made from wood and other materials
Construction and Building Inspectors	Ensure that construction meets building codes and ordinances, zoning regulations, and contract specifications
Construction Laborers & Helpers	Perform many tasks that require physical labor on construction sites
Electricians	Install, maintain, and repair electrical power, communications, lighting, and control systems
Insulation Workers	Install and replace the materials used to insulate buildings or mechanical systems
Ironworkers	Install structural and reinforcing iron and steel to form and support buildings, bridges, and roads
Masonry Workers	Use bricks, concrete and concrete blocks, and natural and manmade stones to build structures
Plumbers, Pipefitters, & Steamfitters	Install and repair piping fixtures and systems
Roofers	Replace, repair, and install the roofs of buildings
Sheet Metal Workers	Fabricate or install products that are made from thin metal sheets

The entry-level educational requirement (i.e., typical level of education that most workers need to enter these occupations) for the employment opportunities listed in Exhibit III-2 is a high-school diploma or equivalent, and some additional on-the-job training in the form of an apprenticeship. The median and mean pay reported in 2019 by BLS for the occupations listed in Exhibit III-2 are provided in Exhibit III-3.[25] Median and average wage data are from the BLS Occupational Employment and Wage Statistics survey (89). Data are provided for the median average wage rate ($ earned per hour) and annual salary (wages earned per year) for each occupation.

[25] Median pay is the wage at which half of the workers in the occupation earned more than that amount, and the other half earned less.

Exhibit III-3. Median and mean pay per hour and per year by those employed in construction and extraction occupations



3. Potential Jobs Supported by and Created from Ethane Availability

To provide more information on the potential value of domestic manufacturing growth in response to increased ethane availability, an analysis was performed to estimate the potential number of jobs supported in industries identified as likely to be involved in ethane value chain. The analysis relied on values reported by the BLS in 2019 for employment (number of wage and salary workers) and output by industry (millions of chain-weighted 2012 dollars [2012$]) (90).[26] Data are representative of the U.S. as a whole, and a summary of the data and corresponding result by industry are outlined in Exhibit III-4.

[26] Additional data on employment by industry was collected from the 2019 SAEMP25N table generated by the BEA, which include estimated values for the number of full-time and part-time employees including wage and salary workers, as well as proprietor employees (239). A ratio of the number of employees from the 2019 SAEMP25N per million dollars in industry output for the same industries was estimated to examine whether a difference in potential the number jobs supported was realized if proprietary employees were also considered. The only industries for which differences were realized included 1) Oil and Gas Extraction, and 2) Warehousing and storage. For those industries, the ratio of the number of per million dollars in industry output generated was estimated to be equal to 1.32 and 14.3, respectively.

Exhibit III-4. Summary of national data from BLS on employment and output by industry used to estimate potential jobs supported

Value Chain Segment	Industrial Sectors	2017 NAICS Codes	Industry Output 2019 (M chained-weighted 2012$)	Employment 2019 (K)	Ratio of Employment to Output
Natural Gas Production and Natural Gas Processing	Oil and Gas Extraction	211	474,300	150	0.32
	Support Activities for Mining	213	82,300	343	4.17
Fractionator	Basic Chemical Manufacturing	3251	331,500	153	0.46
Pipeline Transportation	Pipeline Transportation	486	43,800	51	1.17
Storage	Warehousing and Storage	493	93,800	1,188	12.66
Downstream Manufacturing	Textile Mills and Textile Product Mills Manufacturing	313 314	52,800	222	4.20
	Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Manufacturing	3252	116,000	95	0.82
	Paint, Coating, and Adhesive Manufacturing	3255	38,000	65	1.72
	Soap, Cleaning Compound, and Toilet Preparation Manufacturing	3256	88,500	110	1.25
	Plastics Product Manufacturing	3261	177,300	599	3.38
	Rubber Product Manufacturing	3262	48,500	137	2.84
Export	Water Transportation	483	51,800	65	1.27
	Scenic and Sightseeing Transportation and Support Activities for Transportation	488	130,300	790	6.06

Results outlined in Exhibit III-4 suggest nationally, for every million dollars in output generated by industries involved in the ethane value chain, the following number of wage and salary employees will be supported for each industry:

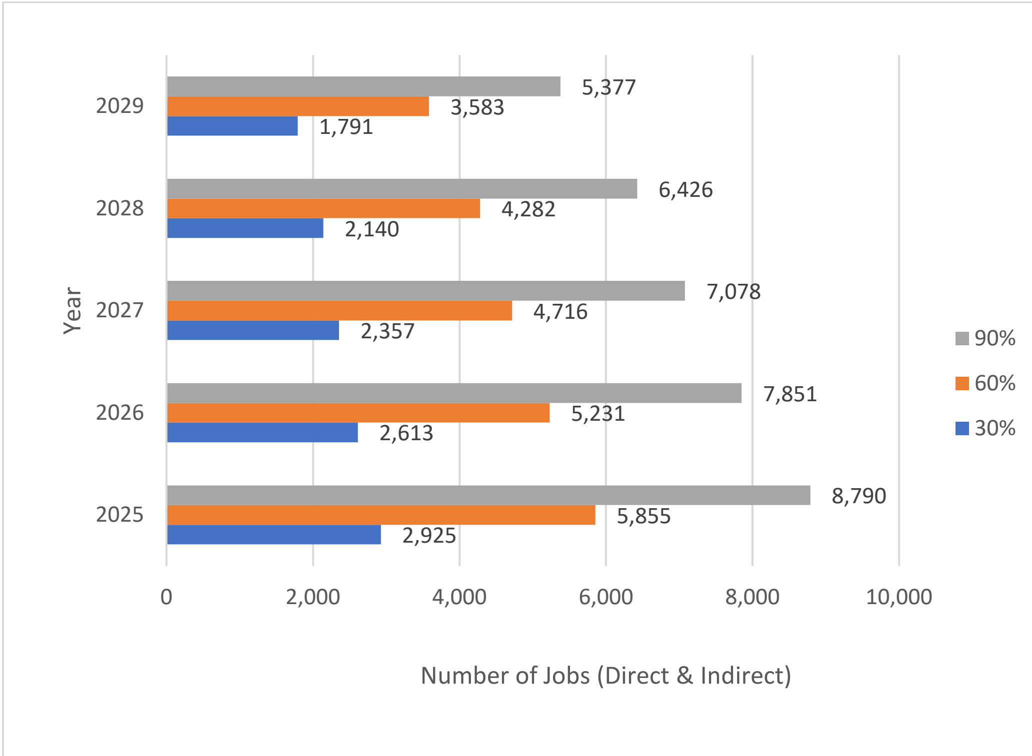
- Oil and gas extraction: <1 job per million U.S. dollars ($M) in industry output
- Support activities for mining: 4 jobs per $M in industry output
- Basic chemicals manufacturing: <1 job per $M in industry output
- Pipeline transportation: 1 job per $M in industry output

- Warehousing and storage: 13 jobs per $M in industry output
- Textile mills and textile product mills manufacturing: 4 jobs per $M in industry output
- Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Manufacturing: 1 job per $M in industry output
- Paint, Coating, and Adhesive Manufacturing: 2 jobs per $M in industry output
- Soap, Cleaning Compound, and Toilet Preparation Manufacturing: 1 job per $M in industry output
- Plastics Product Manufacturing: 3 jobs per $M in industry output
- Rubber Products Manufacturing: 3 jobs per $M in industry output
- Water transportation: 1 job per $M in industry output
- Scenic and Sightseeing Transportation and Support Activities for Transportation: 6 jobs per $M in industry output[27]

Direct and indirect jobs created in response to domestic manufacturing growth based on available domestic ethane supply were estimated using projected IO accounts produced by the BLS following the assumption that domestic ethane production would increase and be used to supply ethylene derivatives which would be used by downstream industries. Ethylene derivates supplied by domestic ethane resources were assumed to substitute for 30, 60, or 90 percent of projected imports of ethylene derivatives between 2025 and 2029. Results suggested approximately 1,700 to 8,800 new jobs (direct and indirect jobs) could be created depending on what percentage of projected imports were replaced and in which year. Results are included in Exhibit III-5 and should not be considered cumulatively.

[27] Jobs are rounded to the nearest whole number.

Exhibit III-5. Potential number of jobs created in response to domestic ethane growth under the assumption that ethane would be used to supply ethylene derivates that would substitute for projected imports



Industries that would gain jobs included, but were not limited to, industries that engaged in the manufacturing of the derivatives, which includes those who manufacture resin, synthetic rubber, artificial synthetic fibers and filaments, and chemicals, and wholesale trade industries.

4. Ethylene Derivatives Production

In addition to ethylene, the capacity to produce ethylene derivatives including LDPE, LLDPE, HDPE, and EDC in the United States is projected to increase over the forecast period of 2020–2050 (16). Similarly, domestic demand for all four ethylene derivatives is projected to increase over the forecast period of 2020–2050 (16). Most of the domestic demand for LDPE, LLDPE, and HDPE is for use in the production of film and sheet products, while most of the demand for EDC is for use in the production of vinyl chloride, which is used to make PVC plastic products including pipe, cable coatings, and packaging materials (16).

Available supply of ethylene derivatives LDPE, LLDPE, and HDPE is projected to consist of both domestic production and imports, while domestic supply of EDC is projected to consist of only domestic production (16). In 2019, imports of LDPE, LLDPE, and HDPE represented approximately 10, 18, and 12 percent of available domestic supply of the three derivatives, respectively (16). Imports of the three derivatives are projected to continue to occur throughout the forecast period of 2020–2035, representing, on average, approximately five, 13, and nine percent of available domestic supply, respectively.

5. Investment in Production and Logistics Infrastructure

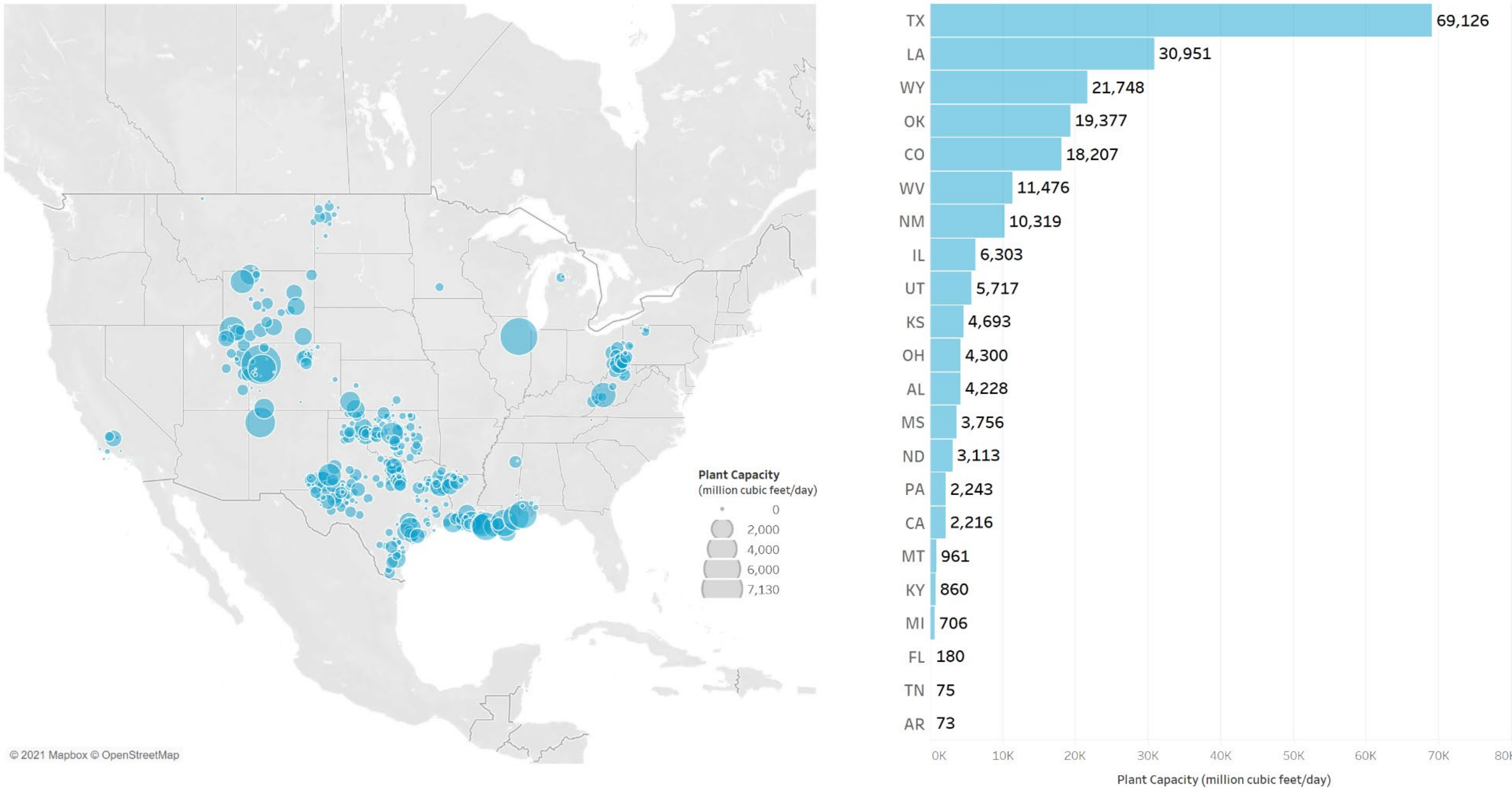
A. Natural Gas Processing Plants and Fractionators

EIA estimates that between 2014 and 2017[28] natural gas processing capacity and processing throughput increased by about five percent on a net basis in the lower 48 states, even as the number of individual plants declined (91). Natural gas processing plant utilization rates stayed constant at 66 percent from 2014 to 2017, but several states experienced significant changes, largely reflecting changes in natural gas production across regions. Processing plants are midstream facilities that separate NGPLs from natural gas. Some natural gas processing plants remove water and other contaminants from the raw natural gas stream and separate NGPL streams into component products. As of the end of 2017, there were 510 active natural gas processing plants in the lower 48 states with a total processing capacity of 80.8 billion cubic feet (bcf) per day (91). On average, these plants processed about 53.3 bcf per day, operating at about 66 percent of capacity. Plants operate at less than full capacity for many reasons including transportation constraints, varying production volumes and characteristics, and regional economics.

Regions with increased natural gas production, such as Texas (Permian, Eagle Ford), West Virginia (Marcellus, Utica), and North Dakota (Bakken) (Exhibit III-6), showed the largest increase in natural gas processing capacity and throughput between 2014 and 2017. In West Virginia, increases in the utilization of existing plants led to an increase in throughput from 2014 to 2017 that exceeded its increase in processing capacity. At the national level, utilization rates remained essentially flat between 2014 and 2017, although some states showed more significant changes. In the Bakken region—Montana and North Dakota—both utilization rates and capacity increased, alongside increases in natural gas production. Similarly, Ohio and West Virginia, in the Appalachian Basin in the Northeast, showed large increases in capacity and utilization. However, in states such as Texas and Oklahoma, processing capacity grew more than throughput, resulting in slightly lower utilization rates in those states. The lower utilization rate in Texas may be partly attributed to the state's natural gas production decline between 2014 and 2017 (91).

[28] EIA estimates and analysis in this section are based on responses from the EIA-757 Natural Gas Processing Plant Survey, which is collected every three years. As of the writing of this report, the 2017 survey data, released in 2019, is the most up-to-date EIA-757 data available.

Exhibit III-6. U.S. natural gas plant capacity (92)



B. Transportation, Storage, and Distribution Infrastructure

Pipelines

Most ethane in the continental United States is transported by pipeline. Most natural gas processing plants are also connected to HGL pipelines that ship a mixed HGL stream, referred to as Y-grade, to fractionation plants on the Gulf Coast (Exhibit III-7) for further processing into purity products (93). EIA's pipeline database indicates ethane and Y-grade pipelines comprised 23 percent of added capacity for new and expansion projects here in the U.S. between 2011 and 2022, and 33 percent of identified projects over the same timeframe (93). All 14 U.S. ethane pipelines started construction in 2014 or later, and three pipelines run from U.S. PADD 1 or PADD 2 to Alberta, Canada, or Ontario, Canada; the majority of lines end in PADD 3 (Exhibit III-8).

Exhibit III-7. High-vapor-pressure pipelines as of 2020 (94)

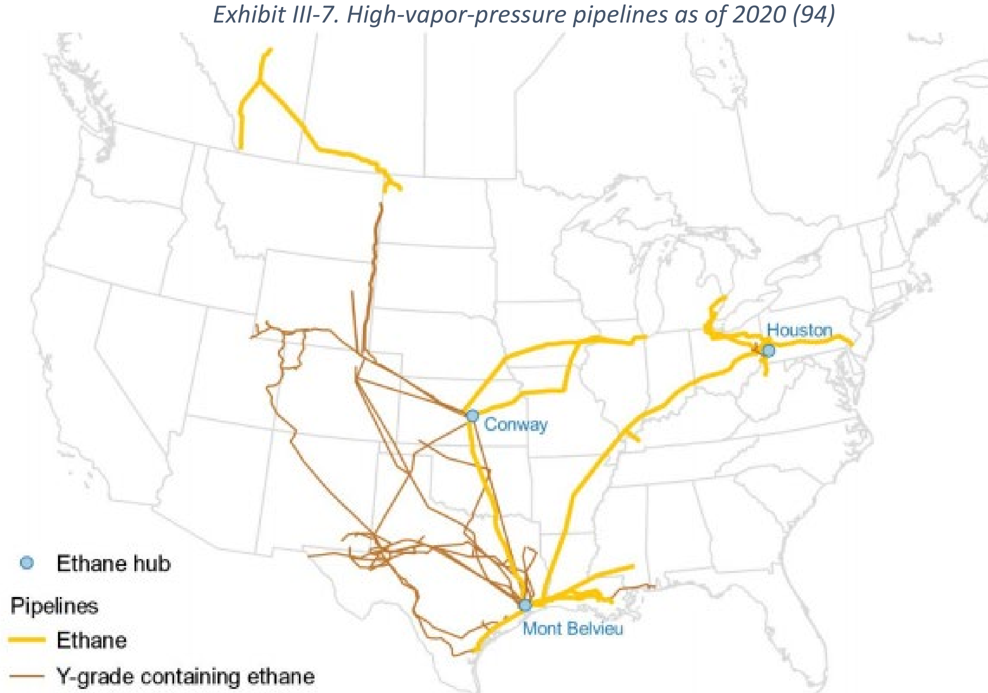
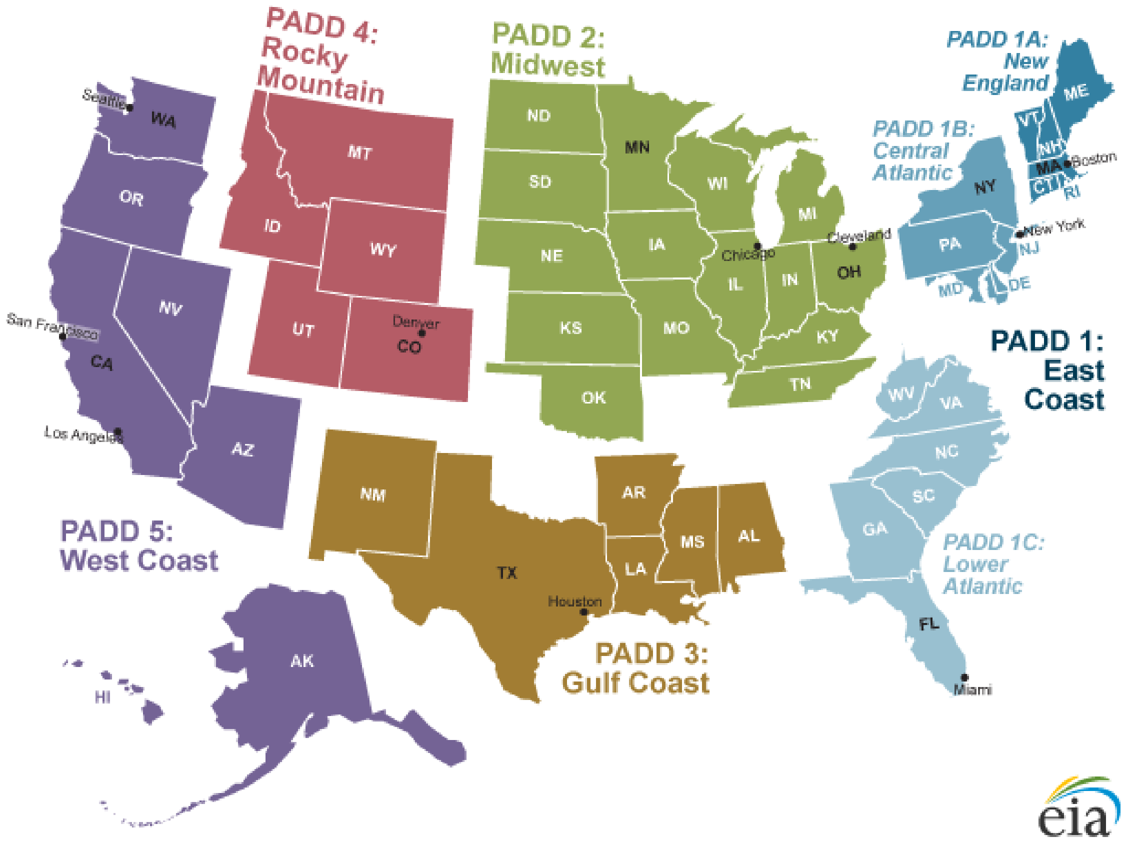


Exhibit III-8. U.S. Petroleum Administration for Defense Districts (95)



One-third of U.S. total ethane exports are delivered to Canada by way of the Vantage, Mariner West, and Utopia pipelines. Only the recently completed Shell Midstream Partners Falcon Ethane Pipeline Project, between PADD 1 and PADD 2, does not connect to either the U.S. Gulf Coast or Canada, indicating a growing demand for ethane in the Midwest and Central Atlantic. In response to the growth in Appalachian production of ethane, Enterprise Products Partners announced an expansion of the Appalachia-to-Texas Express Pipeline running from PADD 1 to PADD 3 to specifically move Appalachian ethane to the U.S. Gulf Coast PADD (Exhibit III-9) (96).

Exhibit III-9. U.S. liquid pipeline projects 2010–2021 (96)

Thousand Barrels/Day Capacity				
Product	Announced	Completed	Construction	% New Project[A]
All	10,975	39,792	2,042	44%
Ethane Only	45	1,580	120	64%
Y-grade, E/P	500	9,352	310	44%

[A] "New Project" refers to projects that are not add-ons/modifications to existing infrastructure.

In Q2-2021, the Baymark Pipeline, designed to specifically carry ethylene, began its expansion. Once completed, the Baymark pipeline expansion will originate in the Bayport area of southeast Harris County, Texas, and extend approximately 90 miles to Markham, Texas, in Matagorda County—and it is anticipated to have an added capacity of 100,000 b/d of ethylene (96).

Storage

A brief discussion on the role of storage

Excerpt on storage from the Ethane Storage and Distribution Hub in the United States. Report to Congress. November 2018 (89)

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 frequently 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… Today, the vast majority of NGLs storage is managed in underground salt caverns, and in the United States, they extend from Kansas to southern Texas and New Mexico.

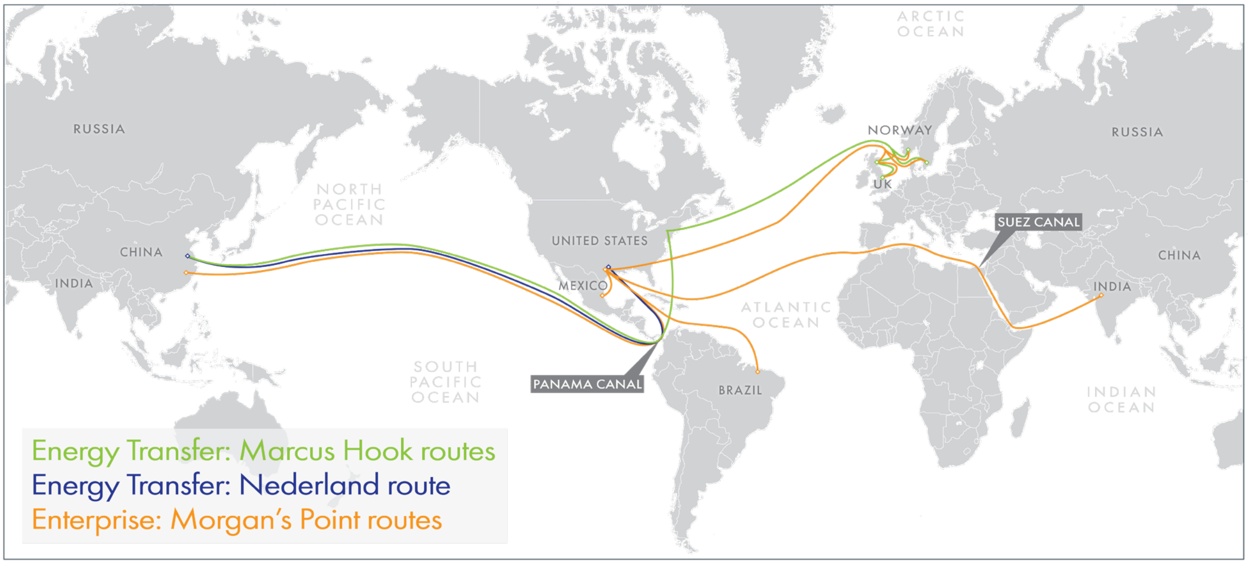
Storage is particularly important for ethane crackers that use furnaces and complex processing that are laborious to restart, particularly after a cold shutdown. Having ethane feedstock in storage helps ensure continuing operations, which is particularly critical for ethane crackers during supply interruptions. 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 size their ethane recovery units more appropriately, 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.

Marine Export Terminals and Cargo Vessels

Two-thirds of U.S. ethane exports are exported outside of North America from three U.S. marine terminals in Marcus Hook, Pennsylvania; Morgan's Point, on the Houston Ship Channel; and Nederland, Texas. (Exhibit III-10) (97).

Exhibit III-10. U.S. marine terminals (98)



The Marcus Hook Industrial Complex is operated by Energy Transfer and has on-site E/P splitters, ethane refrigerated storage, and two million bbls of storage in underground caverns (99). Ethane exports from Marcus Hook are estimated to have increased from 40 percent of the terminal's 70 million b/d capacity, to nearly 80 percent (100). Ethane from Marcus Hook is primarily exported to Norway, the United Kingdom, Sweden, and China.

Enterprise Products Partners opened the second U.S. ethane export terminal, Morgan's Point, in 2016. Morgan's Point is located on the Houston Ship Channel and, in addition to ethane, the terminal has been exporting ethylene since early 2020. The facility is connected to the Enterprise Products Partners' fractionation and NGL storage complex in Mont Belvieu, Texas. Mumbai-based Reliance Industries holds a long-term contract to transport ethane from Morgan's Point to Indian steam crackers, and it is the largest consumer of Morgan's Point ethane exports. Between 2018 and 2020, the terminal also exported ethane to the United Kingdom, China, Norway, Mexico, Brazil, Sweden, and Denmark (100).

The Nederland terminal has a 1.2 million bbl capacity ethane storage tank, an estimated 180,000 b/d ethane refrigeration facility, and is operated by the joint venture between Dallas-based Energy Transfer LP and Satellite Petrochemical, USA Corp (77). Satellite Petrochemical, USA Corp is a subsidiary of the Chinese acrylics manufacturer Zhejiang Satellite Petrochemical Co., which owns and operates the Satellite Petrochemical Lianyungang steam cracker in Jiangsu Province, China. In Q1-2021, the world's largest ethane carrier, the Seri Everest—a specialized ship class called a Very Large Ethane Carrier—departed from Nederland terminal, with U.S.-produced ethane, and traveled to the Lianyungang cracker (101). The joint venture for the Nederland terminal primarily services Satellite Petrochemical's Chinese steam cracker operations.

Rail

Most NGLs in the United States are transported by pipeline; however, a significant share of production in the Marcellus/Utica region moves by rail due to limited pipeline options (102). Shipments of ethane by rail require specifically designed tanks, as opposed to the pressurized vessels generally seen transporting what is commonly referred to as liquefied petroleum gas (LPG): propane, propylene, and butanes (103). Ethane requires either cryogenic temperatures or to be stored under very high pressure to remain in its liquid state. Ethane's vapor pressure exceeds the threshold for most high-pressure tank cars; therefore, transporters need to ensure hydrocarbon mixes transported via rail maintain a low-level of ethane.

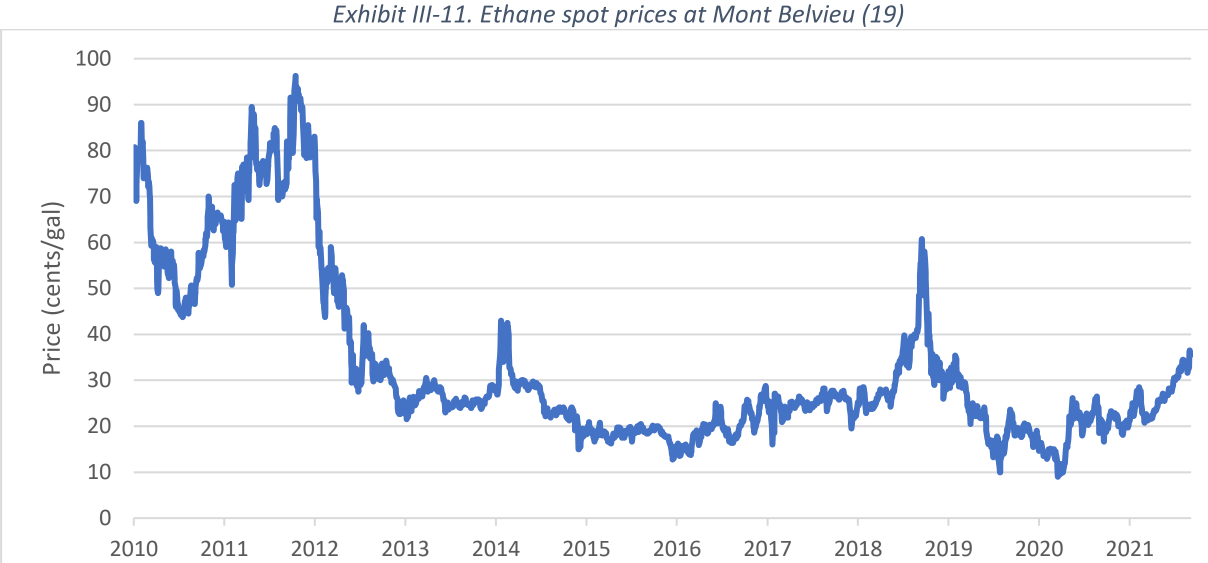
Ethylene and ethylene derivatives can be transported via rail, truck, and ship using pressurized general service tank cars with safety valves (104). The American Fuel & Petrochemical Manufacturers (AFPM) argues that refineries and petrochemical manufacturers experience "excessive freight rail rates" due to the lack of freight rail market competition in the United States. They have found the majority (over 75 percent) of their membership to be captive to a single railroad in their region to transport their produced ethylene and derivatives (105), (106). North American freight rail access is limited in the western and central regions, impacting shale plays including the Permian and Bakken (100).

6. Pricing Trends in Interstate Commerce and International Trade

A. Ethane Spot Market

Exhibit III-11 shows ethane spot prices at Mont Belvieu, Texas, from 2010 to 2021. Until 2008, ethane spot prices generally followed crude oil spot prices. Technological improvements in drilling and hydraulic fracturing techniques around 2010 enabled the United States to extract natural gas economically and efficiently from its vast endowment of shale gas resources. This led to an increased supply of ethane.

Exhibit III-11. Ethane spot prices at Mont Belvieu (19)



As ethane production gradually outgrew consumption and demand, ethane prices delinked from crude oil prices. Starting in mid-2012, ethane prices began to closely track natural gas prices. Ethane prices fell steeply from 2012 into 2013, and for the first six months of 2013, ethane prices averaged 27 cents per gallon, over 45 percent below the price in place for the first six months of 2012 (107).

In September 2012, the total volume of U.S. ethane in storage was 34.11 million bbls, up 59 percent from the previous year (108). Ethane supply outweighed demand. In 2012, steam cracker margins for E/P mix and propane were stronger than ethane cracking margins, making ethane the less economically preferred feedstock. Secondly, the spot price of ethane was higher than its fuel value, meaning that natural gas processors had more incentive to sell ethane to petrochemical producers than to reject it into the natural gas stream. This resulted in increased stock levels of ethane.

Limited downstream production capacity between 2012 and 2017 led to bottlenecks in processing ethane feedstock at steam crackers and suppressed domestic demand for ethane. Petrochemical production facilities take years to design, build and begin operations. Starting in 2017, ethane demand began to grow rapidly as new domestic petrochemical facilities were built and ethane export capacity was increased. Two new steam crackers on the U.S. Gulf Coast began operations in early 2018, increasing demand for domestic ethane as a feedstock. In addition, two ethane marine export terminals came online in 2016 at Marcus Hook, Pennsylvania, and Morgan's Point, Texas, increasing demand for U.S. ethane to be exported abroad. This combined increase in demand strained the capacity of existing infrastructure, driving ethane prices to peak in 2018 (109). Following that peak, as new infrastructure came online, ethane prices decreased from 2018 to 2020, reaching their lowest point in March 2020 at nine cents per gallon (19).

B. Ethylene Spot Market

Exhibit III-12 shows global ethylene prices from 2008 to 2021. Prices in all regions follow similar trends over time driven by overall economic outlook. Ethylene prices fell worldwide from 2008 to 2009 due to the global economic recession. Prices rose globally between 2009 and 2011, climbing to similar prices as those seen in 2008. From 2011 to 2014, global ethylene prices continued to rise while U.S. prices fell due to the economic advantage of low-cost ethane feedstock as a result of the increased production of natural gas from shale formations. Ethylene spot prices in the United States continue to be significantly lower than those found in the rest of the world. Conversely, Western Europe prices are consistently the highest. Prices in Japan and South Korea follow each other closely and sit between U.S. and Western Europe prices, respectively. Ethylene prices rose globally through 2020 due to production facility shutdowns, particularly in Europe, caused by the COVID-19 pandemic.

Exhibit III-12. International ethylene prices (20)

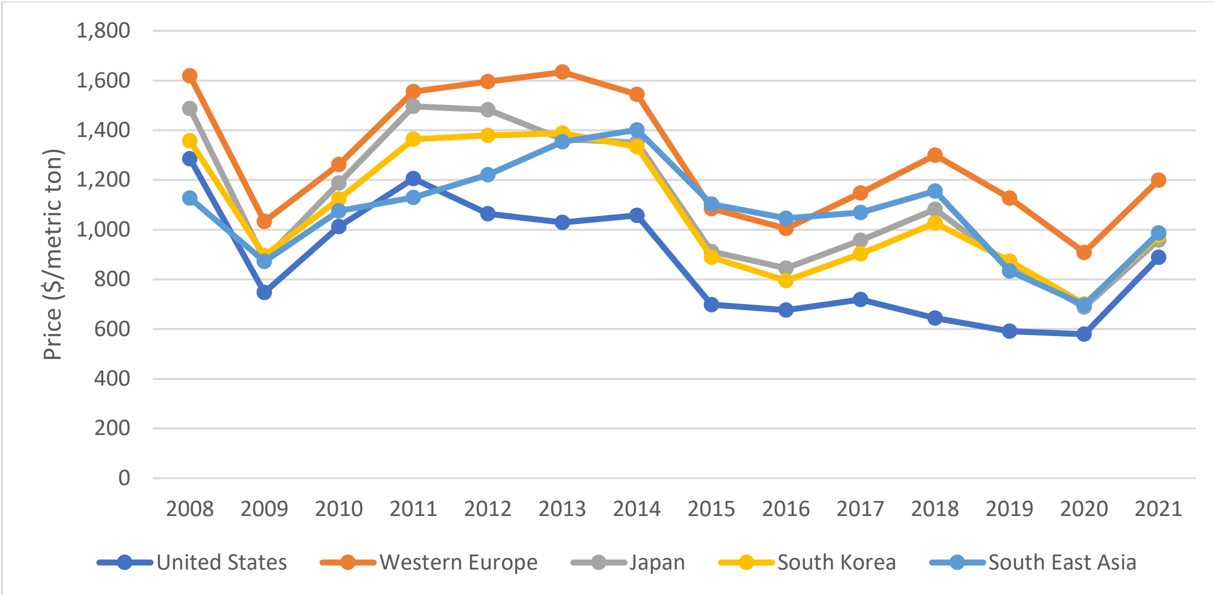
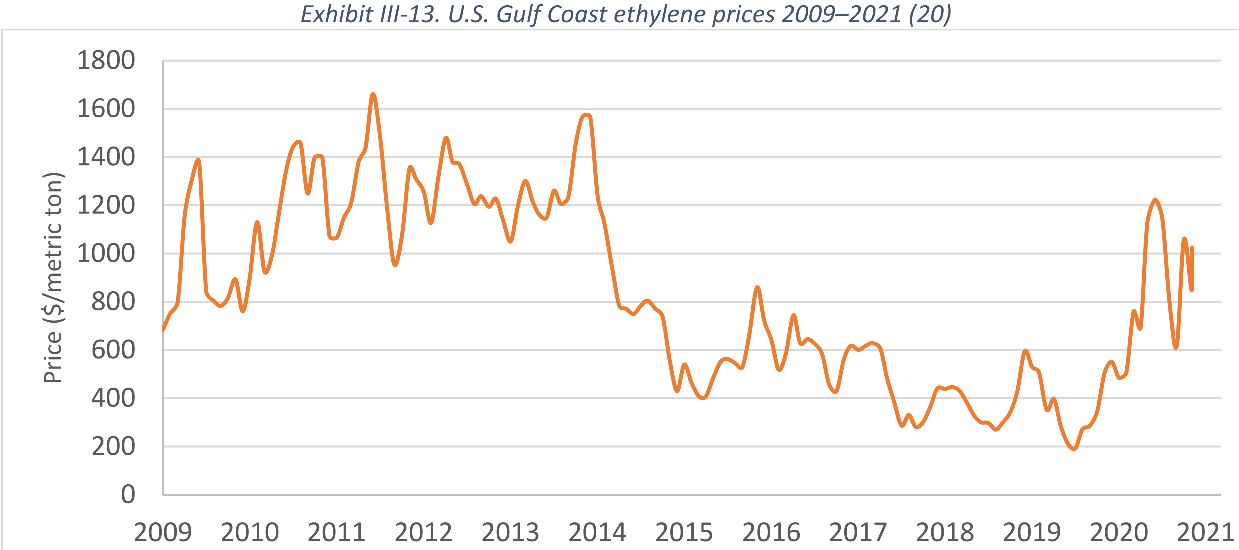


Exhibit III-13 shows U.S. Gulf Coast ethylene prices from 2009 through 2021. The most noticeable trend is the steep drop in price around 2014 resulting from the increased production of natural gas from shale formations. Increased supply of low-cost ethane drove the subsequent production of new steam crackers. This increased ethylene capacity led to the decrease in ethylene prices, and ethylene prices continued to decrease through mid-2019 until the COVID-19 pandemic subsequently caused prices to rise throughout 2020. In February 2021, severe winter storms resulted in the shutdown of steam crackers along the U.S. Gulf Coast. Diminished ethylene capacity combined with strong consumption and demand of ethylene derivatives resulted in the largest month-on-month increase in ethylene spot prices since October 2005 (110).

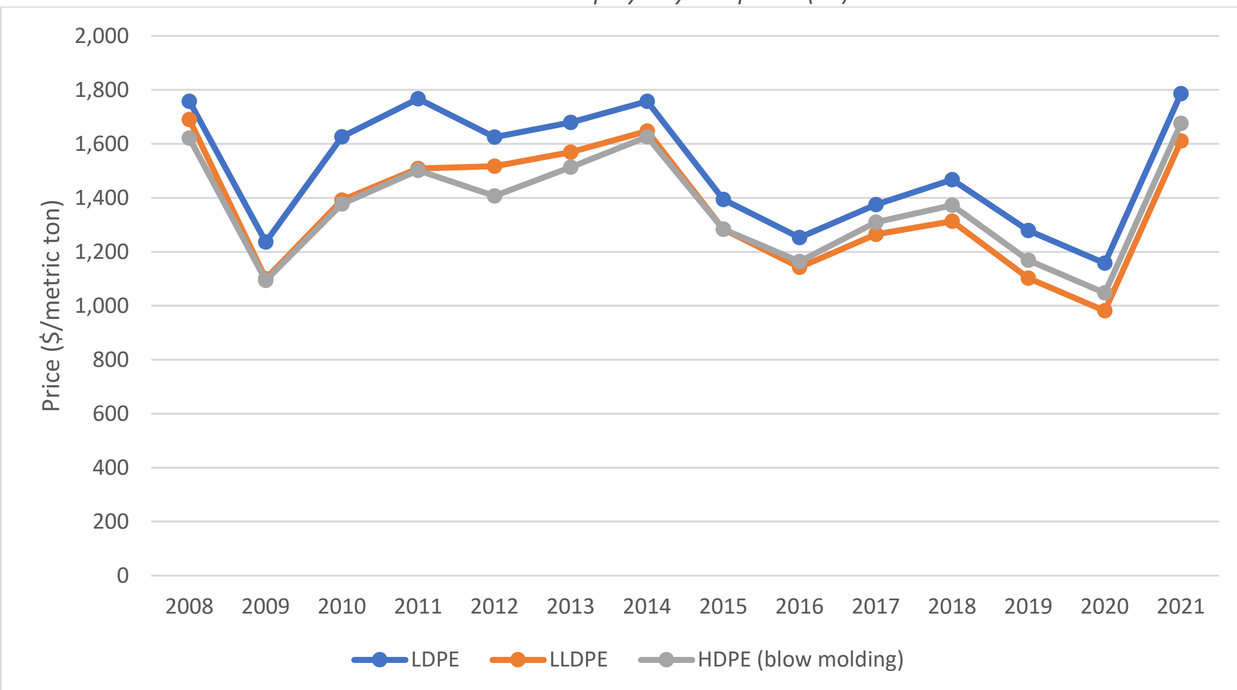
Exhibit III-13. U.S. Gulf Coast ethylene prices 2009–2021 (20)



C. Polyethylene Spot Market

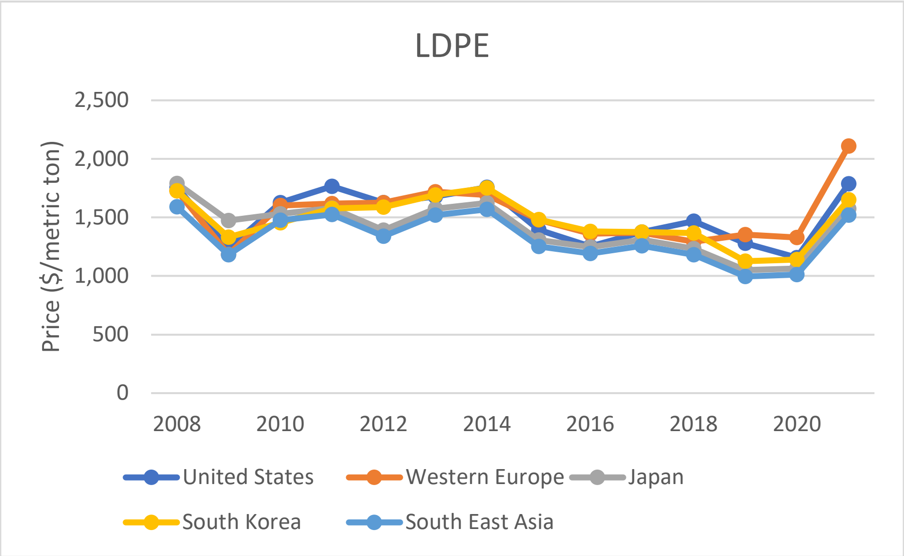
Exhibit III-14 shows U.S. prices for LDPE, LLDPE, and HDPE from 2008 to 2021. All prices of ethylene derivatives fell in 2008 due to the global economic crash. Prices rose between 2009 and 2014 when all other prices decreased. Prices rose steeply in 2020 due to the COVID-19 pandemic, which increased demand for polyethylene to create products like face masks, hygiene products, and food packaging (111).

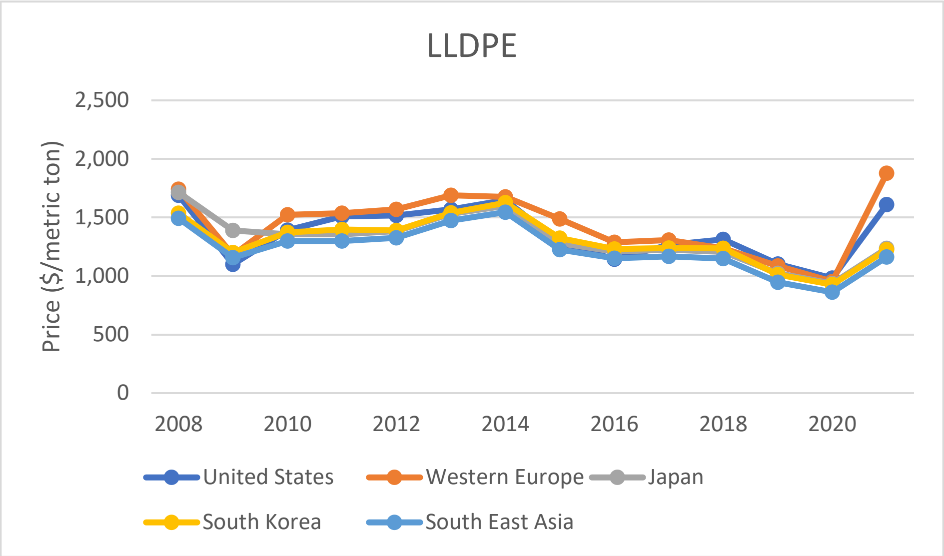
Exhibit III-14. U.S. polyethylene prices (20)

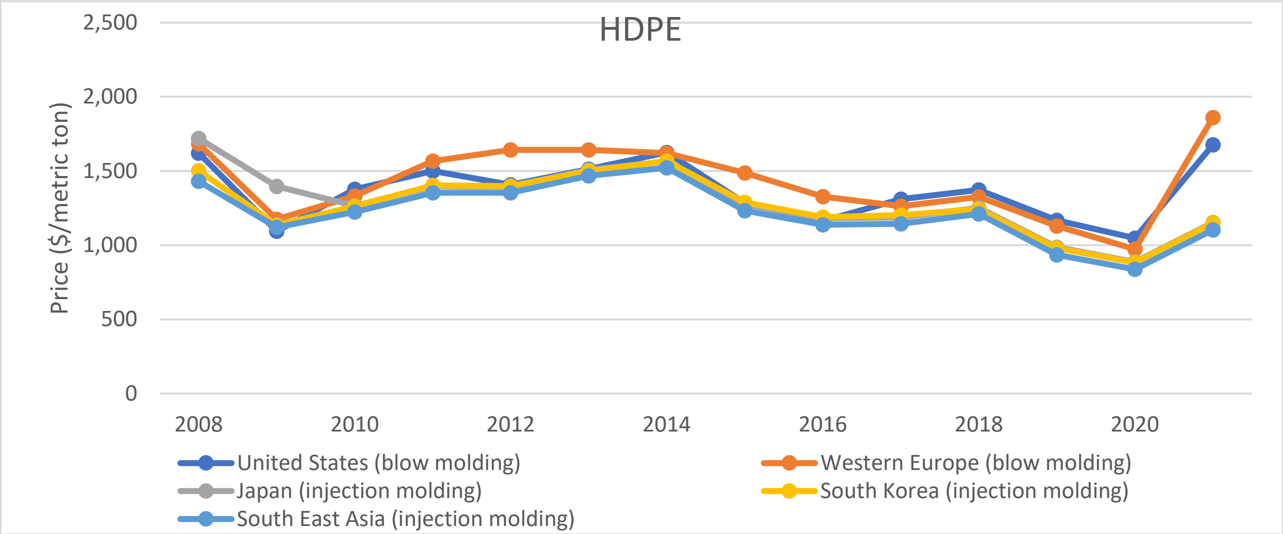


Spot prices for polyethylene (LDPE, LLDPE, and HDPE) across the globe follow each other closely and follow the same general economic trends over time (Exhibit III-15). Prices were lowest in Southeast Asia and highest in Western Europe, with Japan, Korea, and the United States falling in between. Prices everywhere crashed in 2009 with the global economic recession and rose dramatically in 2020 due to the COVID-19 pandemic. LLDPE and HDPE prices in Western Europe and the United States rose more significantly due to COVID-19 than did prices in Asia.

Exhibit III-15. International price trends for polyethylene 2008–2021 (20)







7. Opportunities for Tax Revenue and Job Creation from Increased Ethane Availability

A. Job Creation, Wages, and Other Tax Revenue Resources

Information on the potential opportunities for job creation and tax revenue sources are based on information reported in the literature by Dunn and Dunn (21)[29] and Clinton, Minutolo, and O'Roark (22),[30] respectively, who attempt to estimate the economic returns, including impacts to employment, wages, and local taxes, associated with steam cracker facilities in the United States.

Using 2001–2016 county-level data from Economic Modeling Specialists Inc. (21), the overall economic impact associated with the operation of a new steam cracker was estimated. Economic impacts considered included levels of and changes to employment and earnings within counties where at least one steam cracker was operational over the sample period (21). Results of a fixed effects regression model are considered, where the explanatory variables of interest are 1) an indicator variable for counties containing an operational steam cracker plant, 2) an indicator variable for counties who border counties with a cracker plant that do not contain one themselves, and 3) an interaction term consisting of an indicator variable for counties within an area with an operational steam cracker and a variable representing the percentage of total county employment in the petrochemical manufacturing (NAICS 325110) and plastics material and resin manufacturing (NAICS 325211) industries.

The coefficient estimates produced for the first indicator variable of interest suggested counties containing steam cracker plants have about 10.8 percent higher per capita employment than counties where steam crackers are not located (21). Similar results are observed for earnings. Specifically, results suggest per capita earnings, in counties where a steam cracker is located, are on average 12.8 percent more than per capita earnings in counties where steam crackers are not located (21).

[29] "Economic Impacts of Ethylene Cracker Facilities", published in the Pennsylvania Economic Review in 2019 by Washington and Jefferson College economics professors Dr. Robert Dunn and Dr. Leslie Dunn, originated as part of a grant from the Richard King Mellon Foundation through Washington and Jefferson College's Center for Energy Policy and Management (CEPM) (235). The Richard King Mellon Foundation is the largest foundation in Southwestern Pennsylvania, with a 2020 year-end endowment of $3.1 billion and grants and investments awards totaling $130 million. The Richard King Mellon Foundation describes itself as investing "in the competitive future and quality of life of Southwestern Pennsylvania, and in the protection, preservation and restoration of America's environmental heritage" (236). Washington and Jefferson College's CEPM was formed in 2012 during Southwestern Pennsylvania's shale gas boom and was designed to be a "center of excellence dedicated to fostering the development of energy policy that has a place for all energy sources and promotes economic growth while minimizing environmental impacts." The CEPM has trained more than 1,000 students, faculty, staff, citizens, and public officials through seminars and workshops on various energy production, conservation, transmission, and consumption knowledge. The CEPM "does not advocate for or against any particular policy" (237).

[30] "Updated Economic Impact Analysis: Petrochemical Facility in Beaver County, Pennsylvania" was conducted by Dr. Steven Clinton, Dr. Marcel C. Minutolo, and Dr. Brian O'Roark of the Robert Morris University (RMU) School of Business for Shell Chemical Appalachia, LLC. Dr. Steven Clinton is a Professor and Department Head of Marketing at RMU, Dr. Marcel C. Minutolo is a Professor of Strategic Management at RMU, and Dr. Brian O'Roark is a University Professor of Economics at RMU.

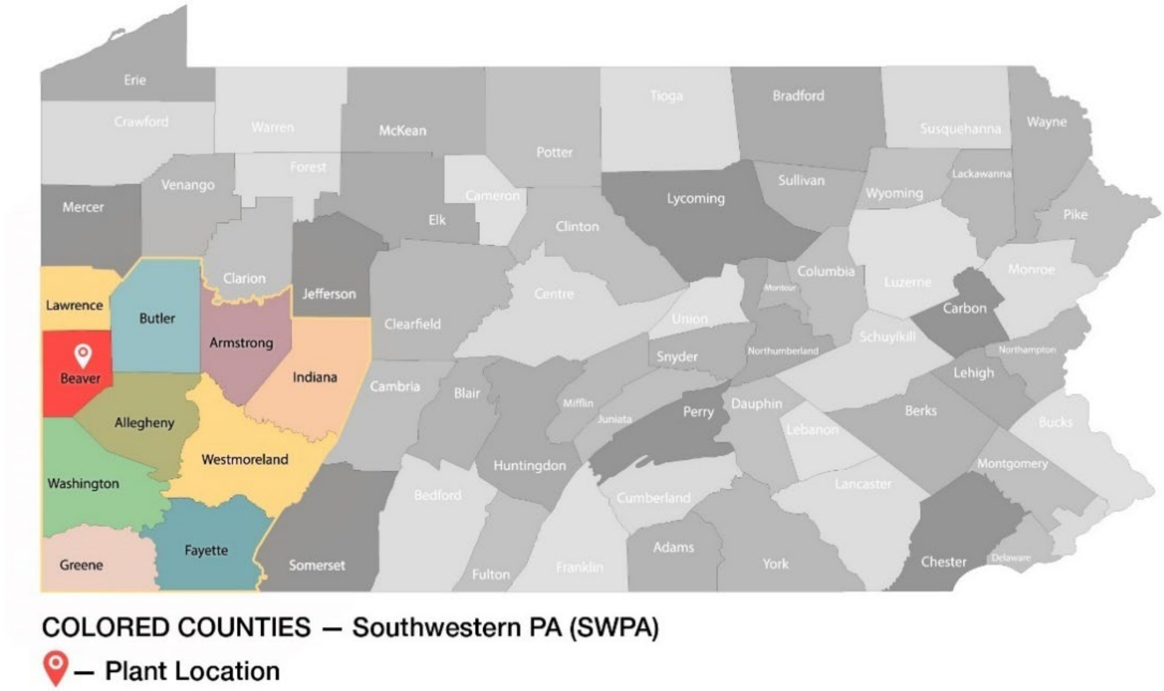
For bordering counties, net employment impacts are negative, while earnings impacts are positive (21). However, the net effects result in lower overall employment despite positive effects in certain sectors (21). Parameter estimates for the third explanatory variable of interest suggest increased employment in the petrochemical and plastics manufacturing industries in the counties with steam crackers does not lead to higher levels of employment for the county overall (21). Unlike employment, however, results suggest there is statistical evidence that earnings in counties where a steam cracker is present increase as employment in the petrochemical and plastics and resin manufacturing industries increase (21).

In terms of spillover to other industries, the presence of a cracker plant does not impact employment in manufacturing. However, manufacturing employment does increase as petrochemical and plastics employment increases inside a county. Additionally, there are positive impacts to manufacturing employment outside the petrochemical and plastics sectors, indicating positive spillovers to other types of manufacturing (21). The sectors that experience the largest negative impact from the presence of a cracker plant are finance, insurance, real estate, and information, which all experience reduced employment in counties with cracker plants. Additionally, wholesale and retail trade, transportation and warehousing, and education and health sector employment decrease as petrochemical and plastics manufacturing increase. This is evidence of certain sectors experiencing crowding out as wages increase with greater petrochemical and plastics employment (21).

Independent analysis commissioned by Gulf Coast Growth Ventures and Shell suggests nearly 6,000 construction jobs will be created to support building their new facilities (112) (23). Gulf Coast Growth Ventures estimates its new steam cracker will generate $22 billion in revenue for Texas during the construction phase (23). Additionally, the facility is projected to produce over 600 permanent jobs and the projected average annual salary of employees involved in the construction, operation, and maintenance of the facility is $90,000 per year (23).

A similar study (22) considered the impacts of a new Shell steam cracker plant currently being constructed in Beaver County, Pennsylvania, and expected to be completed and operational in 2022 (Exhibit III-16). This study sought to estimate the economic impacts this cracker plant would have on Southwestern (SW) Pennsylvania. In particular, the counties considered included Beaver, Lawrence, Butler, Armstrong, Indiana, Allegheny, Westmoreland, Washington, Fayette, and Greene. All bordering counties in Ohio and West Virginia were excluded from their analysis. As a case study, this research provides valuable insights into the potential economic and fiscal impacts of the construction of new steam cracker plants (22).

Exhibit III-16. Map of SWPA



The authors broke their study into two parts and three groups: economic impact and wage tax impact for 1) all of Pennsylvania, 2) SW Pennsylvania, and 3) Beaver County. All life-of-project estimates assume a 40-year total life of the plant, not including construction. The total time of construction is assumed to be 9.5 years, per estimates from Shell, from 2014 to mid-2022. The authors account for spillover and residual effects from the plant by incorporating direct effects from the plant, indirect effects, and induced effects through economic impact modeling. Unless otherwise indicated, all statistics listed account for direct, indirect, and induced effects (22).

Construction of the project resulted in an average annual employment increase of 3,947 jobs for PA resident workers, 2,252 of which were direct effects. This average annual employment increase accounted for 0.06 percent of the Pennsylvania average total annual employment from 2014 to 2021 (22). Total statewide labor income increases from plant construction were estimated at approximately $1.454 billion, or approximately $153.053 million per year. This accounts for approximately 0.022 percent of the average total annual labor income for Pennsylvania from 2014 to 2020 (22). Total value added for the construction phase came to an estimated $1.779 billion for Pennsylvania (22).

Ongoing operations are estimated to directly generate about 600 permanent jobs in PA at the plant. Accounting for all effects multipliers, operations are estimated to generate 11,197 new jobs statewide (Exhibit III-17). Total labor income from ongoing operations is estimated at $1.012 billion per year, or $22.384 billion over the life of the plant. Total annual value added for Pennsylvania from operations is estimated to be $3.695 billion, or $81.685 billion over the life of the plant (22).

Exhibit III-17. PA labor and value added (22)

PA		Employees	Labor (New Jobs)	Labor Income	Value Added
		Direct	Total	Total	Total
2014–2022	Construction	2,252	3,947	$1,454,486,617	$1,778,850,298
Annual	Operations	600	11,197	$1,012,469,516	$3,694,683,105
40 years	Operations	600	11,197	$22,384,414,397	$81,684,748,403

Construction of the plant was estimated to have resulted in an average annual employment increase of 3,171 jobs for SW Pennsylvania residents (Exhibit III-18), and 1,802 of these jobs were direct hires at the plant. Of the average annual employment in SW Pennsylvania as of 2019, this accounts for 0.25 percent (22). Total labor income for SW Pennsylvania during the construction phase is estimated at $1.873 billion, and total value added for SW Pennsylvania is estimated at $2.676 billion (22).

Exhibit III-18. SWPA labor and value added (22)

SWPA		Employees	Labor (New Jobs)	Labor Income	Value Added
		Direct	Total	Total	Total
2014–2022	Construction	1,802	3,171	$1,873,173,963	$2,676,124,205
Annual	Operations	540	10,127	$925,369,760	$3,280,676,985
40 years	Operations	540	10,127	$20,451,900,327	$72,541,057,771

Ongoing operations are estimated to generate 10,127 jobs for SW Pennsylvania residents, with 540 of these jobs being held directly at the plant. Of the annual average employment for SW Pennsylvania as of 2019, jobs generated from ongoing operations account for approximately 0.8 percent (22). In addition, ongoing operations are projected to generate $925 million annually in total labor income for SW Pennsylvania. Over the assumed 40-year operating life of the plant, the present discounted value of the total amount of labor income generated for SW Pennsylvania from ongoing operations is estimated at $20.45 billion. Annual value added for SW Pennsylvania from ongoing operations is estimated at $3.281 billion, or $72.541 billion over the plant's operating life (22).

Project construction is estimated to generate 856 new jobs in Beaver County, 605 of which will be held directly at the plant. This accounts for 1.07 percent of Beaver County's average annual employment as of 2019 (22). Total labor income for Beaver County is estimated to have risen by $514 million during project construction, while total value added attributable to project construction is estimated at $693 million (22).

Ongoing operations are estimated to generate 777–1,444 jobs for Beaver County residents, 240–450 of which will be held directly at the plant (Exhibit III-19). These job estimates account for 0.97–1.8 percent of Beaver County's average annual employment as of 2019 (22). Total annual labor income from ongoing operations for Beaver County is projected at $73–120 million, or $1.518–2.372 billion over the life of the plant. Total annual value added is projected at $260–846 million, or $10.288–16.685 billion over the life of the plant (22).

Exhibit III-19. Beaver County labor and value added, low and high range (22)

Beaver County		Employees	Labor (New Jobs)	Labor Income	Value Added
		Direct	Total	Total	Total
Low Range					
2014–2022	Construction	605	856	$513,781,733	$693,144,865
Annual	Operations	240	777	$73,372,898	$260,366,965
40 years	Operations	240	777	$1,518,907,523	$10,287,598,709
High Range					
2014–2022	Construction	605	856	$513,781,733	$693,144,865
Annual	Operations	450	1,444	$120,300,506	$846,255,117
40 years	Operations	450	1,444	$2,371,895,064	$16,685,119,689

In addition to positive economic impacts on a statewide, regional, and county level, the Beaver County steam cracker plant will also generate substantial tax revenue. Although there are many different sources of tax revenue generated by the plant, the authors focus on earned income tax as it provides the most substantial measurement of government revenue. A state income tax rate of 3.07 percent and local income tax rates of 1 percent are assumed. Although county-level income tax rates range 1–3 percent, 1 percent is used to avoid overestimation. These calculations also assume benefits are 34 percent of wages, so 75 percent of labor income would be taxed as wages and 25 percent would not be taxed (22). Project construction will generate an estimated $73.1 million in Pennsylvania state and local income taxes from construction labor (Exhibit III-20). Annually, state and local income taxes will generate an estimated $31 million from ongoing operations and $683 million in total over the life of the plant for Pennsylvania (22).

Exhibit III-20. PA state, local, and total income tax generation (22)

Pennsylvania		State	Local	Total
2014–2022	Construction	$55,158,985	$17,967,096	$73,126,082
Annual	Operations	$23,312,111	$7,593,521	$30,905,632
40 years	Operations	$515,401,141	$167,883,108	$683,284,249

Project construction will generate an estimated $57.1 million in state and local income taxes for SW Pennsylvania (Exhibit III-21). Ongoing operations will generate an estimated $28.2 million per year from state and local income taxes, and an estimated $624.3 million over the life of the project for SW Pennsylvania (22).

Exhibit III-21. SWPA state, local, and total income tax generation (22)

SWPA		State	Local	Total
2014–2022	Construction	$43,129,831	$14,048,805	$57,178,635
Annual	Operations	$21,306,639	$6,940,273	$28,246,912
40 years	Operations	$470,905,005	$153,389,252	$624,294,257

Construction of the plant will generate an estimated $15.7 million in state and local income tax revenue for Beaver County (Exhibit III-22). Annually, ongoing operations are estimated to generate $2.2–3.7 million in state and local income tax revenue, and an estimated $46.4–72.4 million over the life of the plant (22).

Exhibit III-22. Beaver County state, local, and total income tax generation (22)

Beaver County		State	Local	Total
Low Range				
2014–2022	Construction	$11,829,824	$3,853,363	$15,683,187
Annual	Operations	$1,689,411	$550,297	$2,239,708
40 years	Operations	$34,972,846	$11,391,806	$46,364,652
High Range				
2014–2022	Construction	$11,829,824	$3,853,363	$15,683,187
Annual	Operations	$2,769,919	$902,254	$3,672,173
40 years	Operations	$54,612,884	$17,789,213	$72,402,097

8. Petrochemical Manufacturing Plants: Economic Risks and Uncertainties

Several studies evaluating the economic benefits as well as the financial risks from construction and operation of petrochemical plants reach very divergent conclusions. The debate around the Shell cracker plant in Beaver County, Pennsylvania, provides a good example highlighting some of these differences.

A 2020 report from the Institute for Energy Economics and Financial Analysis (IEEFA) titled "Shell's Pennsylvania Petrochemical Complex: Financial Risks and a Weak Outlook" addresses the previously cited Royal Dutch Shell Petrochemical Complex under construction in Beaver County, PA.[31] The IEEFA's study concludes that the plant will likely be less profitable than expected and face an extended period of financial distress based on risks that were present before construction began and have been exacerbated by the coronavirus pandemic. These risks include a lower revenue than anticipated from the plant due to a steep decline in the price of plastics, an oversupply in the plastics market, higher levels of competition in the plastics

[31] "Shell's Pennsylvania Petrochemical Complex: Financial Risks and a Weak Outlook" (24) was conducted by Tom Sanzillo, director of finance at IEEFA, and Kathy Hipple, a financial analyst at IEEFA. The IEEFA's mission is to "examine issues related to energy markets, trends, and policies" and to "accelerate the transition to a diverse, sustainable and profitable energy economy." They are a non-profit that receives funding from global philanthropic organizations and individuals such as the Rockefeller Family Fund, Energy Foundation, Mertz-Gilmore Foundation, Rockefeller Brothers Fund, KR Foundation, Park Foundation, The Heinz Endowments, Charles and Helen Brown Foundation, Just Transition Fund, Wallace Global Fund, The 11th Hour Project/The Schmidt Family Foundation, Sequoia Climate Fund, and Climate Imperative.

market, unsustainably low ethane prices, and a predicted decline in the use of primary plastics in favor of recycled plastics (24).

The price of plastic today is 40 percent lower than the 2010–2013 period when the Shell petrochemical project was proposed, dropping from approximately $1/pound to $0.565/pound in December 2019. The Chicago Mercantile Exchange (CME) Group's forward price curves for HDPE are at $0.25/pound through 2021. These new prices were not accounted for in Shell's original revenue estimates (24).

The petrochemical buildout in the U.S. has oversupplied the market, with supply and demand imbalances predicted to last through 2026. As of 2010–2013, industry analysts predicted consistent growth and operating rates above 95 percent based on no new cracker capacity being added since 2005. As new capacity has been added in the U.S. and globally, plastics prices have remained depressed since 2019 as demand has not grown at a sufficient rate to support the new facilities. This has meant persistent supply and lower operating rates, both of which will impact Shell's Beaver County cracker plant's revenue negatively (24).

Shell also faces strong competition in a market that may already have depressed prices from oversupply. Shell will enter the market when margins are down for current producers and will also have to contend with companies that already dominate U.S. market share and have strong domestic market relationships such as Baystar, Chevron Phillips, Dow, and ExxonMobil. ICIS analysts are also projecting increased competition globally due to lower economic growth scenarios (24).

Shell has cited an abundant supply of ethane as crucial to its value proposition for Beaver County's cracker plant, but this abundant supply is not likely to last. Since 2015, more than 200 shale producers have filed for bankruptcy protection, representing nearly $130 billion in debt restructuring. Eleven of these producers were focused on the Appalachian region. Shell has written off almost $10 billion in shale assets since 2013. The eight largest publicly traded Appalachian-focused hydraulic-fracturing companies faced $29.4 billion in long-term debt as of 2019, with only a $10.5 billion market capitalization as of March 2020. These financial figures support evidence that the current supply of cheap natural gas, and subsequently ethane as a feedstock, is unsustainable. Shell could acquire more shale assets to protect this cheaper supply, but in doing so would increase its capital outlay and take on additional risks seen by other shale producers (24).

The last potential pressure on Shell's projected revenue is the growth of demand for recycled plastics. McKinsey and Company projects demand for plastics to climb long-term at a compound annual growth rate of 3–4 percent, with nearly 60 percent of plastics demand between 2020 and 2050 being supplied by recycled plastics and demand for virgin plastics flattening or declining (24).

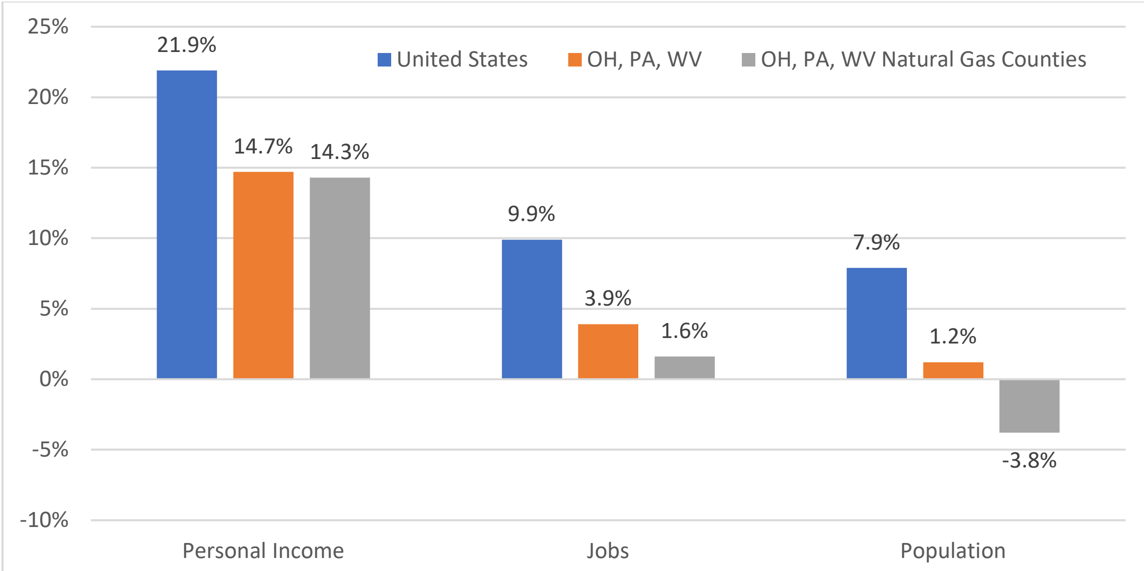
Another study from the Ohio River Valley Institute (ORVI) titled, "The Natural Gas Fracking Boom and Appalachia's Lost Economic Decade,"[32] emphasizes that despite increases in GDP in Appalachian natural gas counties in Ohio, Pennsylvania, and West Virginia, personal income, jobs, and population have not had the same beneficial effects (25).

Evidence cited from the Bureaus of Economic Analysis and Labor Statistics shows that for 22 counties in Ohio, Pennsylvania, and West Virginia that make up the Appalachian natural gas region, their collective contribution to U.S. GDP has risen by more than one third. These 22 counties accounted for $2.46 of every $1,000 of national GDP in 2008, climbing to $3.33 of every $1,000 of national GDP in 2019. The rate of GDP growth of these 22 counties was 61.1 percent from 2008 to 2019, more than triple the national average of 19.2 percent and more than quadruple the 14.1 percent average for Ohio, Pennsylvania, and West Virginia over the same period (25).

However, the rise in GDP contribution does not tell the whole story. Share of national personal income in these 22 counties fell by 6.3 percent from 2008 to 2019, from $2.62 to $2.46 for every $1,000 in national income. Share of national jobs fell from 2.62 to 2.46 for every 1,000 national jobs, a decline of 7.6 percent. And share of the nation's population also fell by 10.9 percent, from 3.26 to 2.9 for every 1,000 Americans. Exhibit III-23 shows a comparison of these economic results to the national average and the average across Ohio, Pennsylvania, and West Virginia (25).

[32] "The Natural Gas Fracking Boom and Appalachia's Lost Economic Decade" is a report published by ORVI in February 2021. ORVI is a non-profit think tank whose self-stated mission is to "support communities in the region working to advance a more prosperous, sustainable, and equitable Appalachia. The Institute produces data-driven research and proposes policies to improve the economic performance and standards of living for the greater Ohio River Valley, with a focus on shared prosperity, clean energy, and equitable democracy" (238). This report lists Sean O'Leary as the point of contact, a senior researcher at ORVI (25).

Exhibit III-23. Change in personal income, jobs, and population 2008–2019 (2019 dollars)



These results are at odds with predictions from industry studies such as those by the American Petroleum Institute (API) (113) and Kleinhenz and Associates (114). The API study projected the creation of nearly 44,000 new jobs in West Virginia and 212,000 in Pennsylvania because of the effects of increased Marcellus gas well production. The Kleinhenz and Associates study also projected the creation of an additional 200,000 jobs in Ohio. In fact, these studies even underestimated production from Marcellus gas wells, which produced 35 percent more than the highest predictions from the API study by 2019. As is evidenced in Exhibit III-23, this higher than predicted output did not translate to increased economic prosperity (25).

A letter co-authored by a group of economists, engineers, public policy analysts, and former policymakers (a group affiliated with academic institutions in the Appalachian region) and addressed to Governor Tom Wolf of Pennsylvania, Governor Mike DeWine of Ohio, and Governor Jim Justice of West Virginia, voiced additional concerns regarding prospective petrochemical manufacturing and projected economic and employment benefits tied to these activities (26).[33]

The letter expressed the signatories' collective belief that the predicted expansion and jobs boom touted as economic benefits of increasing the region's petrochemical and plastics manufacturing industries is unlikely to occur. They cite "the recent cancellation of the ASCENT ethane cracker in Wood County, West Virginia, the indefinite postponement of a final

[33] The authors of this letter include Ted Boettner, executive director of the West Virginia Center of Budget and Policy; University of Akron economics professor Amanda Weinstein; James Van Nostrand, professor at the West Virginia College of Law and director of the Center for Energy and Sustainable Development; Bethany College economics professor Wilfrid Csaplar Jr.; Nicholas Muller, professor of economics, engineering and public policy at Carnegie Mellon University; Mark Partridge, professor at chairman of Rural-Urban Policy at Ohio State University; and John Russo, founder and former director of the Center for Working Class Studies at Youngstown State University.

investment decision on the proposed Belmont County, Ohio cracker, the failure of the proposed Appalachian Storage Hub (ASH) to attract private investors, and the failure by China to follow through on an announced investment of $84 billion in the region" as compelling evidence of previously touted economic benefits as falling well short of optimistic industry projections (26).

In addition, the letter mentioned economic and technological barriers that may impede investment in and construction of more ethane cracker plants in Ohio and SW Pennsylvania. If the petrochemical manufacturing buildout begins to stall in the Appalachian region, it will subsequently prevent ancillary projects—including the buildout of ethane cracker plants and NGL storage facilities from moving forward. If these petrochemical manufacturing activities and associated projects fail to move forward, significant projected economic and jobs impacts will not be realized (26).

The letter to the governors also cited evidence that rapid growth and intense competition will create an oversupplied global marketplace. For example, U.S. ethylene and polyethylene production capacity has increased by 50 percent in recent years, and ethylene capacity in China is projected to rise rapidly over the next five years. This prediction echoes estimates put forth in the previously referenced IEEFA report on Shell's ethane cracker plant in Beaver County, Pennsylvania, and IHS Markit forecasts a plunge in global cracker utilization rates resulting from excess capacity and supply (115) (26).

It is also anticipated that, due to the lack of aromatics in ethane produced from the Marcellus-Utica shale play, inputs essential to plastics manufacturing, much of the ethylene and polyethylene produced will likely be shipped out of the country for manufacturing. Such an outcome will certainly undercut prospects for job growth, and partially remove the benefit of moving ethane production onshore (as a significant part of the plastics manufacturing process will still involve the global supply chain) (26).

9. Workforce Development and Apprenticeship Based Career Pathways

Building the skills and competencies of American workers as they relate to industries involved in the ethane value chain will be essential for ensuring the competitiveness of domestically sourced ethane, ethylene, and ethylene derivatives on the global market. Government-sponsored workforce training programs represent one means of providing the training and educational services needed for preparing both upcoming and incumbent members of the American workforce for careers in the value chain for ethane. Sponsored programs can be designed to provide either basic-level, general work skills or teach higher-level occupation-specific skills, based on industry needs (116).

In the United States, three main types of government-sponsored career and technical education training programs exist: 1) flagship Federal employment and training programs, which generally have larger budgets and participation rates; 2) specialized training programs wherein a unique service is provided to more narrowly defined populations; and 3) small-scale career and technical education training programs designed to serve particular segments of the population or based on identified workforce training needs for growing industrial segments (116).

While the returns to flagship and specialized career and technical education training programs have been examined in the literature—for example, see Blanco, Flores, and Flores-Lagunes (117)—evaluations of small-scale programs are often plagued with sample-size issues and/or other data constraints (116). As a result, estimating the returns to a government-sponsored, small-scale career and technical education training program is a non-trivial task. Returns ultimately depend on participation rates, the realization of employment opportunities from participating, and the wage differential of those who participate compared to those who do not (116).

Following human capital theory, individuals should participate in educational training programs so long as the present discounted value of the benefits associated with participating in the educational training program outweighs the costs, considering both the direct and indirect costs associated with participation. Under the assumptions of perfect foresight and information and assuming the costs associated with participating in the program are borne in time-period one, theoretically, individuals will be more likely to participate in training programs with lower direct costs, lower opportunity costs (i.e., lower indirect costs), and higher potential returns (116).

According to McCall, Smith, and Wunsch (116), however, imperfect information related to capital markets and their influence on the costs and benefits of participating in training programs frequently prevents individuals from participating. That is, individuals who are uncertain whether the returns to their participation, as measured by the difference in their wages prior to and after participating, will be enough to offset the costs of enrolling and participating in the program may be less likely to participate. Given government-sponsored career and technical education training programs are designed to have negligible to zero direct costs, they provide one means for eliminating some of the uncertainty related to potential returns.

Similar to career and technical education training programs, apprenticeship-based career training programs normally combine part-time formal education with on-the-job training and experience (118). Apprenticeship-based career training programs typically involve four parties—employers, trainees, educators, and government (118). Potential benefits of apprenticeship-based career training programs include but are not limited to a closer correspondence between skills taught and the requirements of production systems and better school-to-work transitions (118). Similar to career and technical education training programs, human capital theory can be leveraged to understand participation in and offerings of apprenticeship-based career training programs (118).

Based on a recent report by RAND Corporation, career training programs that aim to build the skills and competencies necessary to support robust employment in industries involved in the ethane value chain, specifically energy-sector employment in West Virginia (one state assumed to be heavily involved in the production of wet natural gas with high yields of ethane during processing), should be focused on the following:

1. Building basic knowledge, skills, and abilities related to reading and writing in English, listening, critical thinking, and mathematics;
2. Eliminating barriers and perceptions that inhibit students' access to educational and training opportunities; and
3. Building successful partnerships between academic institutions and employers (119).

Energy and advanced manufacturing jobs support millions of direct and indirect jobs in the U.S. economy. Having a trained, diverse, and versatile workforce is integral to filling these jobs, enabling the clean energy transition, and growing the U.S. economy. From the standpoint of ethane development, there are various workforce development initiatives and opportunities that DOE and DOE's Federal, state, and regional partners are pursuing to ensure success. One such activity is the NETL Regional Workforce Initiative (RWFI).

By working closely with local, state, and national governmental, non-governmental, and educational institutions, the RWFI endeavors to pinpoint the requisite skills needed as well as the training gaps that must be filled to prepare prospective job applicants for contributing to ethane development as well as clean energy and advanced manufacturing in the Appalachian region and beyond. In addition, the RWFI also strives to connect prospective stakeholders to clean energy and related economic development activities being advanced by NETL, other DOE national laboratories and programs, and other Federal and state government agencies focused on these workforce development and related opportunities. Lastly, the RWFI helps to catalyze research investments into enduring workforce and economic development opportunities for the Appalachian region and the nation (120).

Another workforce development initiative focused on advancing ethane development, advanced manufacturing, and the ongoing clean energy transition is the Tristate Energy and Advanced Manufacturing (TEAM) Consortium. The tristate region of Ohio, Pennsylvania, and West Virginia is experiencing economic growth tied directly to these industrial opportunities as well as indirectly by way of the various service industry jobs supporting these activities and the workforce beginning to take shape there.

Looking back to its origins, the TEAM Consortium was launched to help cultivate a properly trained, highly skilled, and well compensated workforce to support a range of industries across the region. The TEAM Consortium accomplishes its goals and objectives by connecting and uniting stakeholders from industry, higher education, and workforce and economic development organizations in partnerships that build new and increasingly accessible pathways to rewarding careers in energy and manufacturing across the region. TEAM partners also commit to promoting in-demand job opportunities, preparing prospective workers with the requisite knowledge and skills needed for success, and linking prospective employees to work-based learning (121).

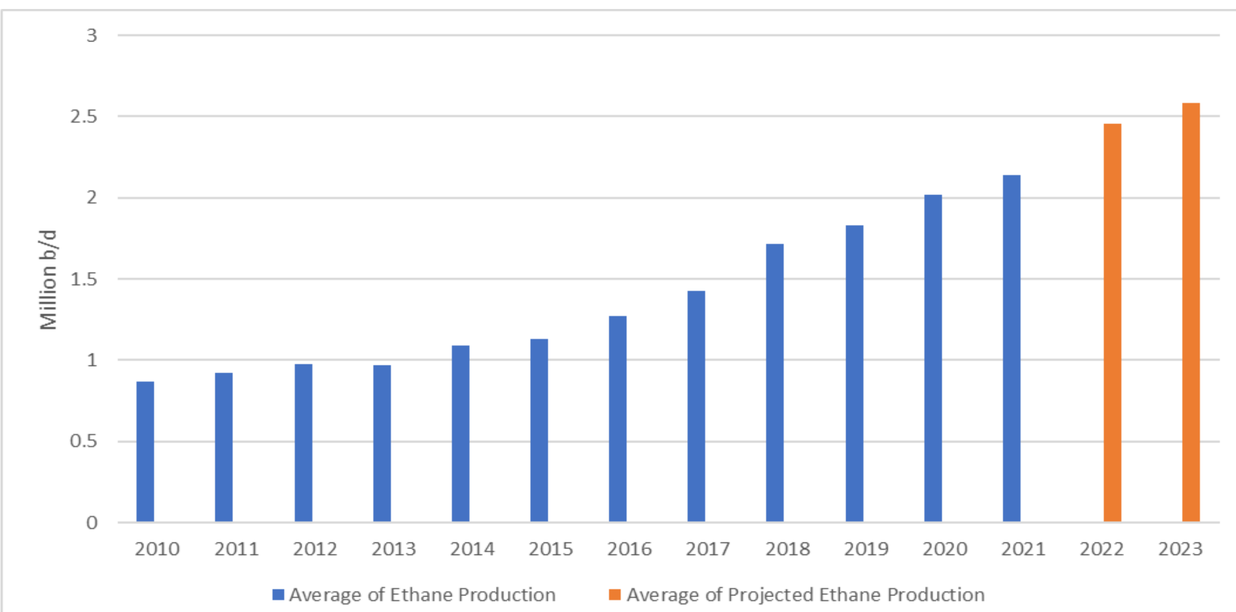
IV. Opportunity Cost of Exporting Ethane Relative to Domestic Use

To estimate the opportunity cost of exporting available ethane versus using domestically sourced ethane locally, this section begins with an overview of domestic ethane production and feedstock consumption. This section also provides a general overview of historical imports and exports of ethane, ethylene, and ethylene derivatives to and from the United States.

1. Ethane Production

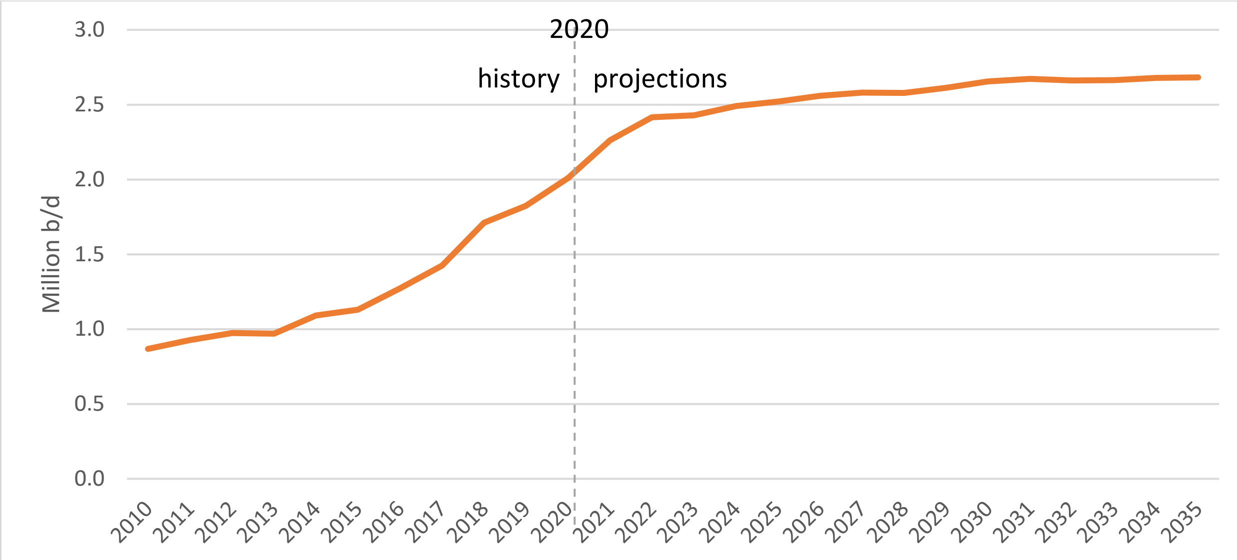
U.S. annual production and projected annual production of ethane, as measured in million b/d, is provided in Exhibit IV-1. Data reflected in the chart is based on reported estimates from the April 2022 STEO (4).

Exhibit IV-1. U.S. domestic ethane production and projected production (4)



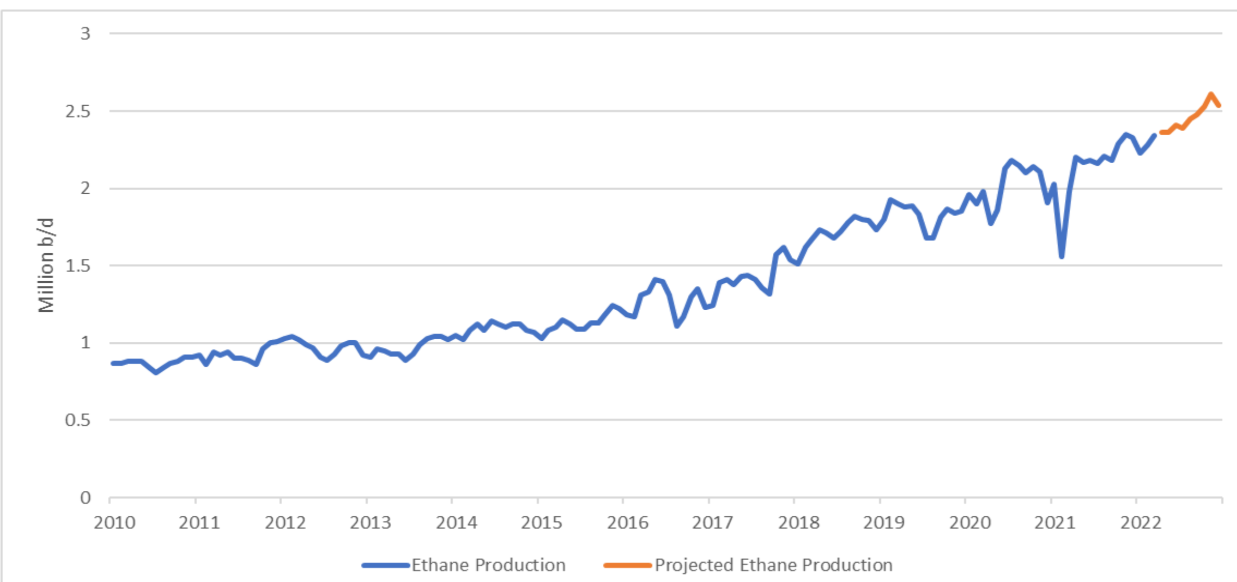
According to EIA, U.S. production of ethane is projected to increase to 2.68 million b/d by 2035, representing a 33 percent increase in ethane production levels from 2020 (Exhibit IV-2).

Exhibit IV-2. Projected U.S. ethane production through 2035 (12)



Annual U.S. ethane production levels, as described by Exhibit IV-1, have increased from year to year over the past decade (2010–2020) and are projected to continue to increase between 2020 and 2035. However, monthly domestic ethane production levels, specifically monthly ethane production from natural gas processing plants, have fluctuated. Exhibit IV-3 provides an overview of monthly ethane production as measured in million b/d between January 2010 and March 2022 and projected monthly production for April 2022 through December 2023 (4).

Exhibit IV-3. Monthly historical and projected ethane production from U.S. natural gas processing plants (4)



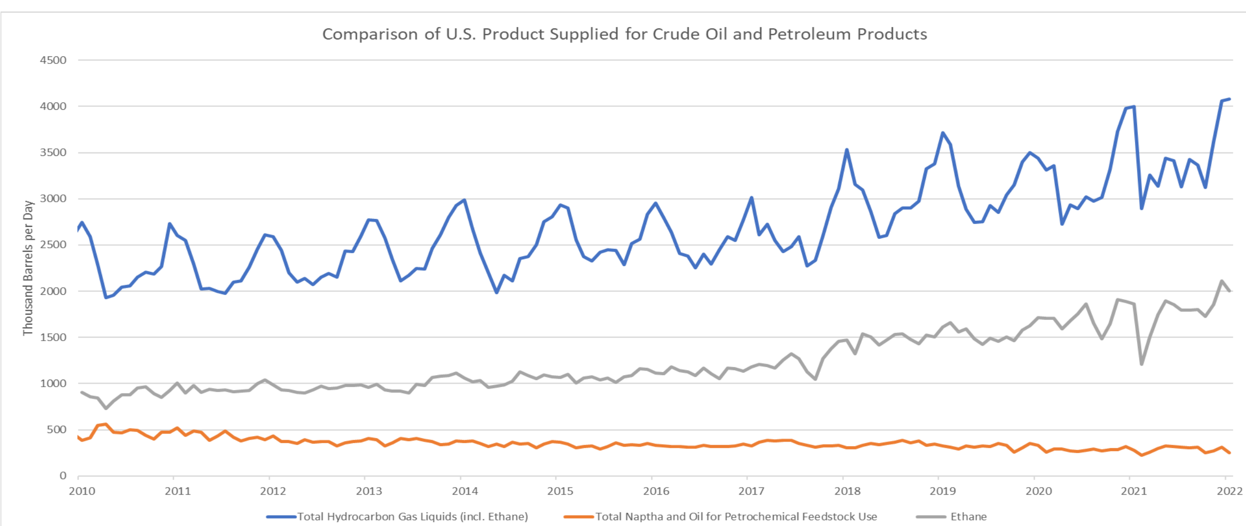
As shown in Exhibit IV-3, a sharp decrease in production occurred during February 2021, when an extreme cold weather event in the U.S. Gulf Coast region caused many petrochemical plants in the area to temporarily shut down, severely impacting demand for ethane. As a result, ethane production declined to its lowest level since October 2017 (64). U.S. ethane production, however, is projected to experience growth through the end of 2023, tapering off slightly in December of 2023 (122). Specifically, monthly ethane production is projected to increase by 230,000 b/d over the 22-month period of March 2021 through December 2023. On a monthly average, the projected production increase equates to approximately 10.5 k more b/d for each month (122).

U.S. ethane production has been increasing since January 2010 when an average of 870,000 b/d of ethane was produced in the United States (122). U.S. ethane production has been increasing since January 2010 when an average of 870,000 b/d of ethane was produced in the United States (120). Currently, monthly production (i.e., in March 2022) is estimated to be equal to an average of approximately 2.34 million b/d.

2. Feedstock Consumption

U.S. supply of total HGLs, including ethane, has risen from January 2010 levels of 2,747 K b/d to 4,081 K b/d in January 2022, while just U.S. ethane supplied has increased from January 2010 levels of 903,000 b/d to 2,006 K b/d in January 2022. However, U.S. consumption of naphtha and oil for petrochemical feedstock use has declined from January 2010 levels of 387,000 b/d to 252,000 b/d in January 2022 (122).

Exhibit IV-4. Comparison of Domestic Consumption of Crude Oil and Petroleum Products (122)



According to EIA, it is not possible for consumption of petrochemical feedstocks to become more efficient, as the chemical process cannot change, which means petrochemical feedstock consumption and petrochemical production should move in parallel (123). Therefore, a decrease in U.S. supply of naphtha and oil for petrochemical feedstock use is at odds with overall increases in petrochemical production both in the United States and globally. The likely reason for this is that more efficient petrochemical feedstocks such as ethane are being used, which is supported by research from the University of California's Energy Analysis Department. This study states "the choice for a particular feedstock, together with the processing conditions, determine the yield of ethylene, propylene, and other co-products in steam cracking" (124). Exhibit IV-5 shows yields of different feedstocks; ethane has a significantly better yield for high value chemicals, ethylene, and hydrogen. Combined with an increase in ethane production providing a greater supply of ethane and ethane cracker plants being built in the United States, the reason for a decline in naphtha and oil for petrochemical feedstock use while petrochemical production increases is likely due to an increased use of ethane as a feedstock.

Exhibit IV-5. Influence of feedstock on steam cracker field (pound per 10,000 pounds of feedstock) (124)

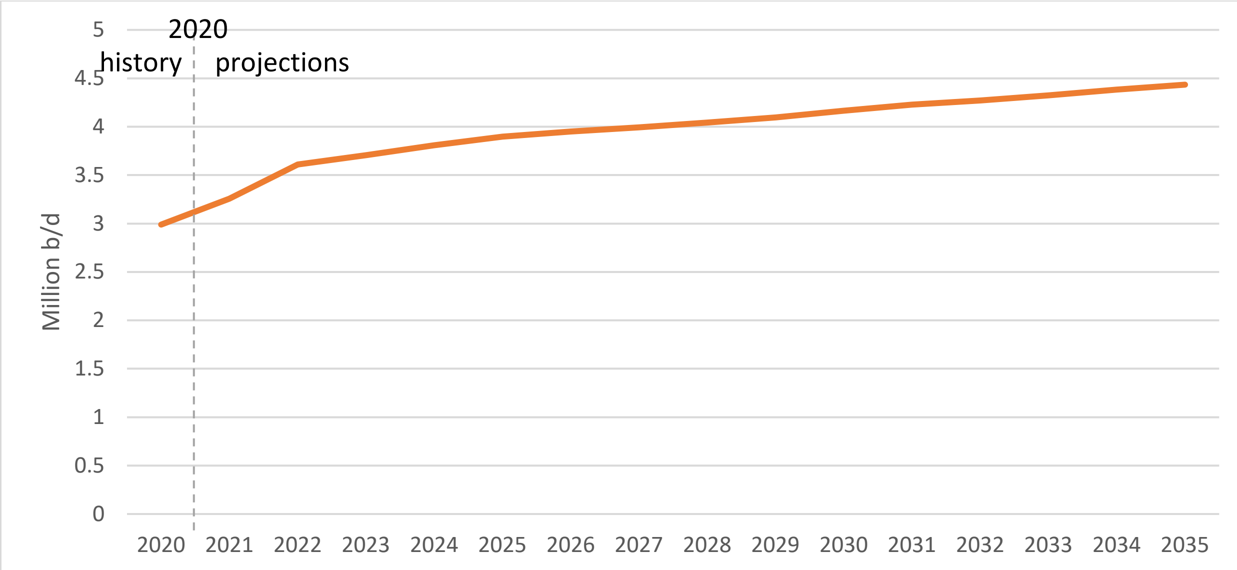
	Ethane	Propane	Butane	Naphtha	Gas Oil
High value chemicals	842	638	635	645	569
Ethylene	803	465	441	324	250
Propylene	16	125	151	168	144
Butadiene	23	48	44	50	50
Aromatics	0	0	0	104	124
Fuel grade products	157	362	365	355	431
Hydrogen	60	15	14	11	8
Methane	61	267	204	139	114
Others	32	75	151	200	304
Losses	5	5	5	5	5

3. Downstream Products

U.S. LPGs and other supply, from the AEO2021 reference case, includes ethane, natural gasoline, and refinery olefins.[34] LPG supply is predicted to grow from a 2022 level of 3.6 million b/d to 4.4 million b/d in 2035, a growth rate of 22.2 percent (Exhibit IV-6) (125).

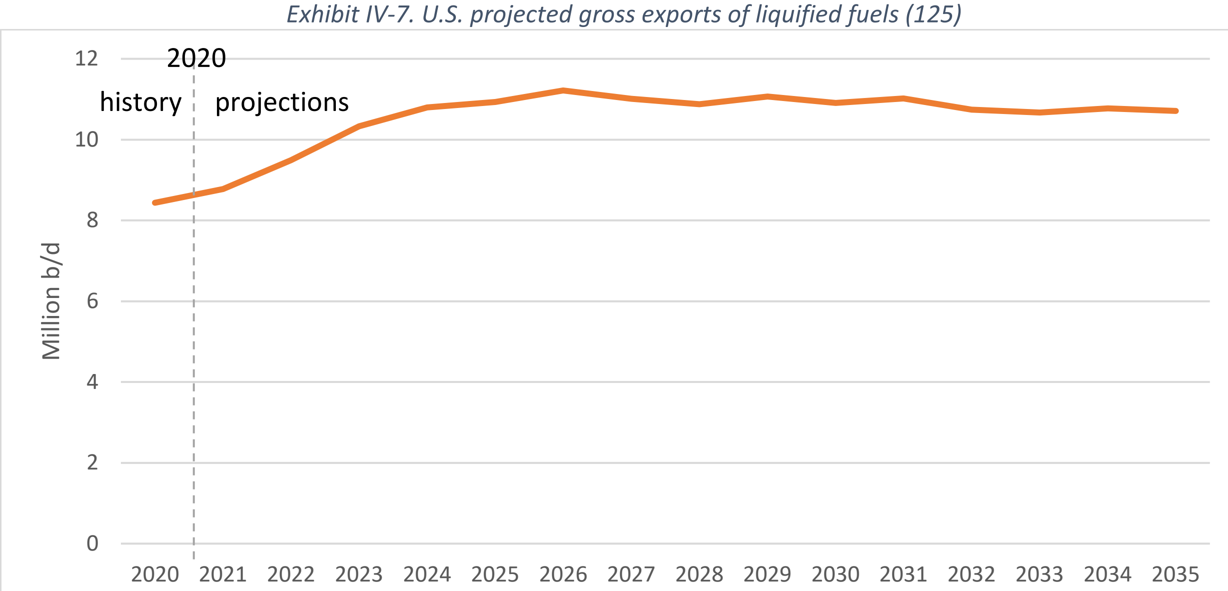
[34] Ethane and natural gasoline values included in the LPG data only account for the sums produced specifically from refinery processing and are exclusive of products produced at natural gas processing plants (i.e., NGPLs).

Exhibit IV-6. U.S. projected LPGs and other supply forecast (125)



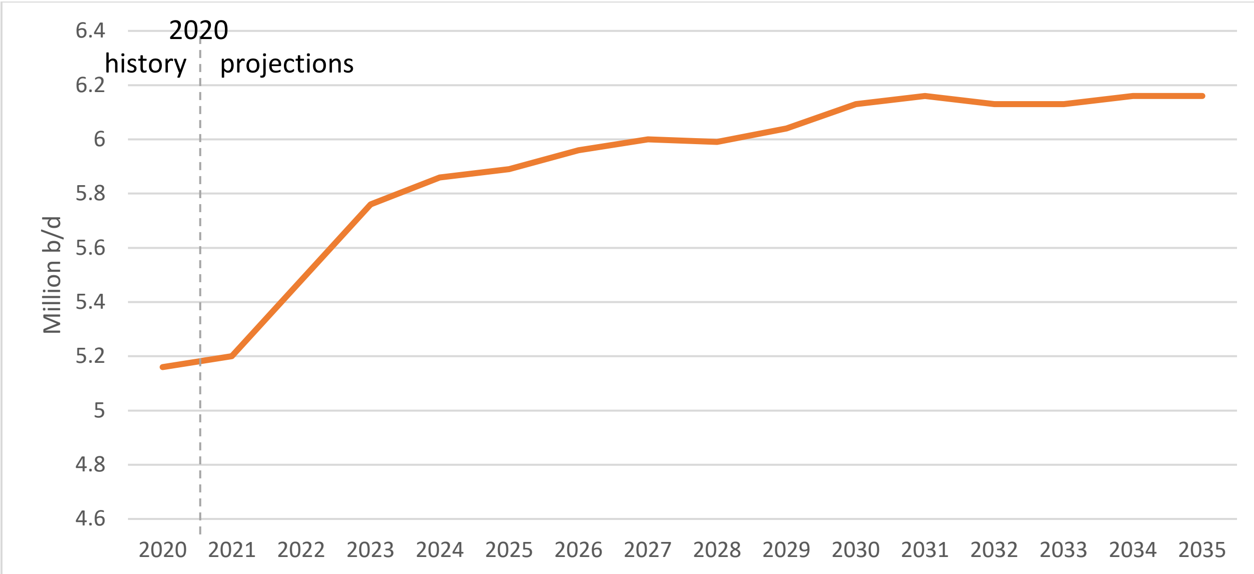
Gross exports of liquified fuels such as crude oil, gasoline, and ethanol, which include HGLs, are projected to grow from approximately 9.5 million b/d in 2022 to 10.7 million b/d in 2035, a 12.6 percent increase (Exhibit IV-7). Most of this growth is projected to occur between 2022 and 2026, during which exports of liquified fuels are projected to increase by approximately 17.9 percent. Conversely, exports of liquified fuels are projected to decrease by 4.7 percent between 2026 and 2035 (125).

Exhibit IV-7. U.S. projected gross exports of liquified fuels (125)



Total U.S. production of NGPLs, which includes ethane, is projected to increase from 2022 levels of 5.5 million b/d to 6.2 million b/d in 2035, a 12.7 percent increase (Exhibit IV-8) (126).

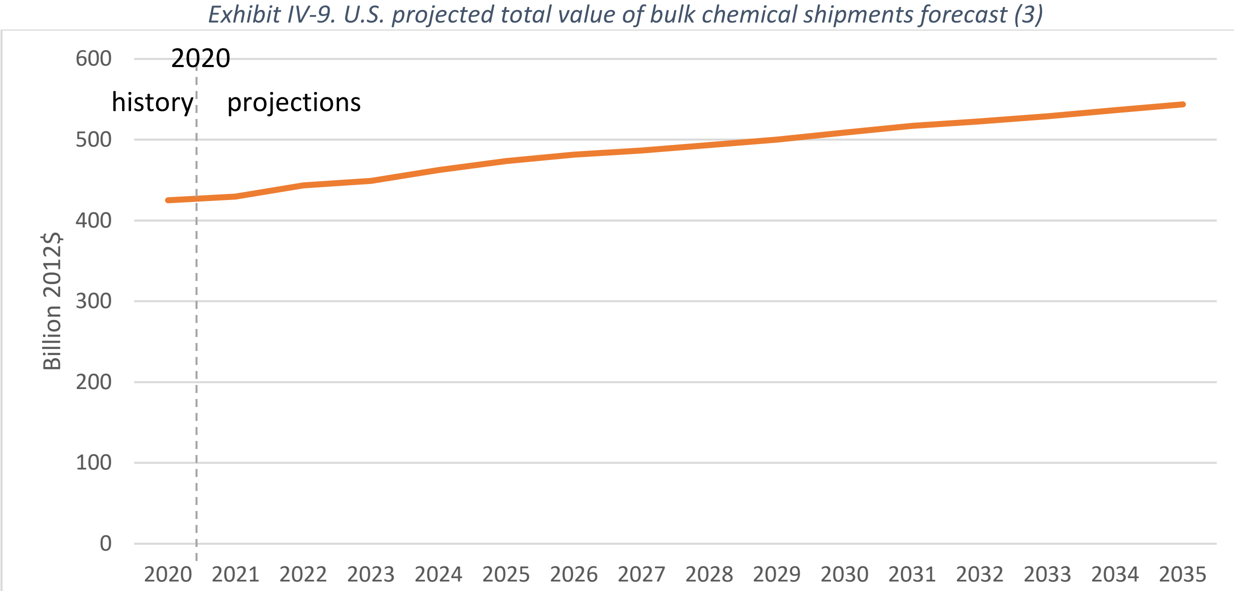
Exhibit IV-8. U.S. projected NGPL production (126)



4. *Bulk Chemicals Sector Shipments and Feedstock Energy Use*

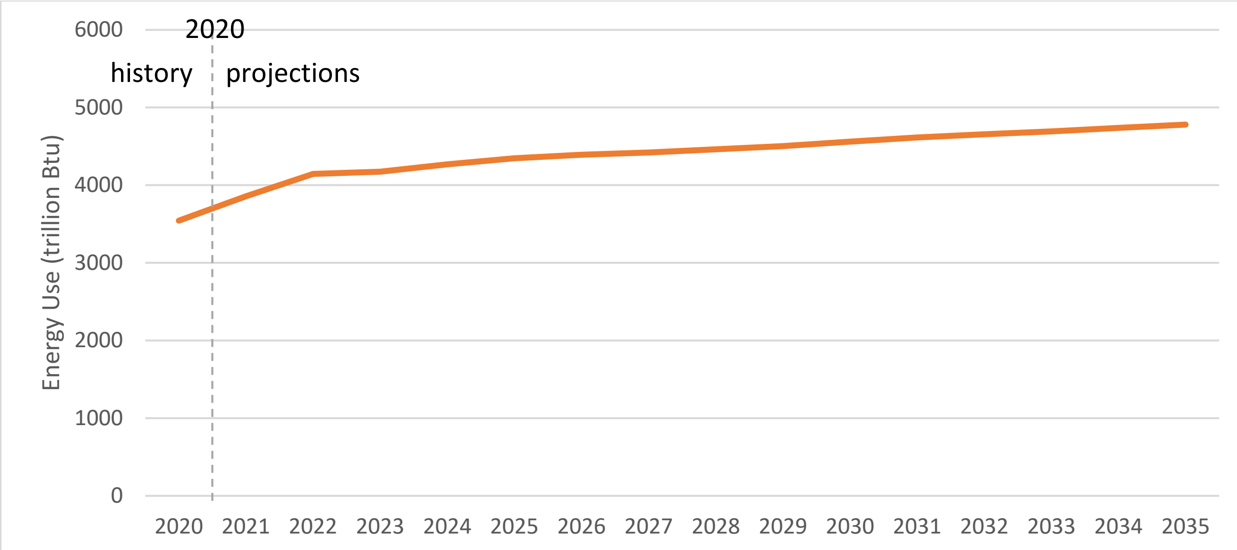
According to EIA, the total value of bulk chemical sector shipments is projected to increase from a 2022 level of 444 billion 2012$ to 544 billion 2012$ in 2035, a 22.5 percent increase (Exhibit IV-9). This value is projected to increase in a nearly linear fashion at approximately 7.7 billion 2012$ per year (3).

Exhibit IV-9. U.S. projected total value of bulk chemical shipments forecast (3)



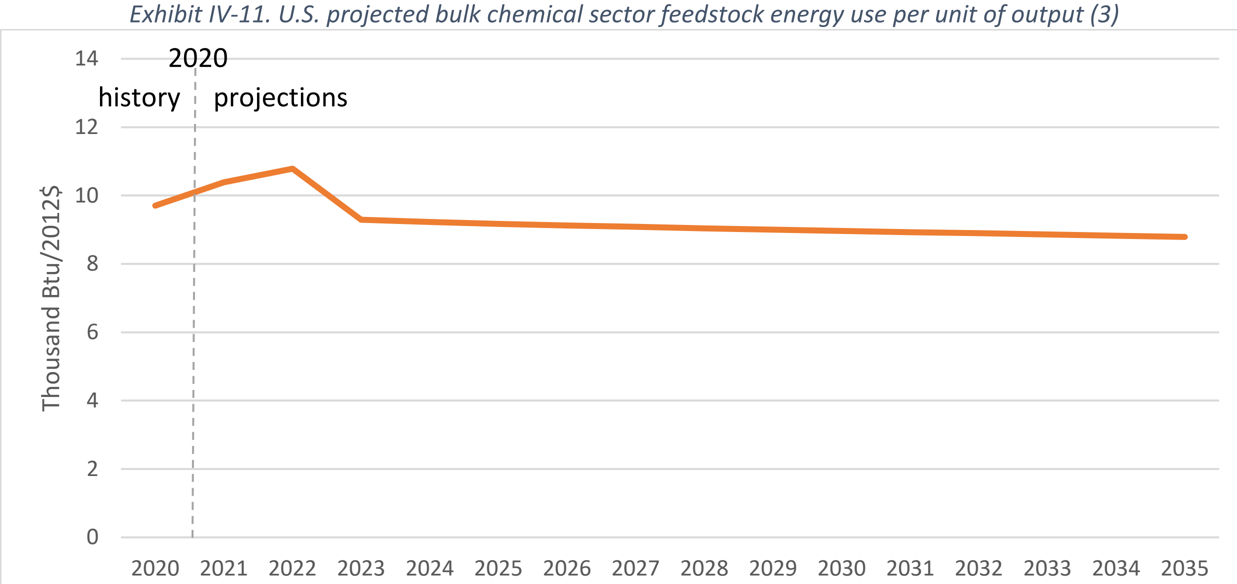
Total bulk chemical sector feedstock energy use, which includes HGL feedstocks, petrochemical feedstocks, and natural gas feedstocks, is projected to increase from 4,100 trillion Btu in 2022 to 4,800 trillion Btu in 2035, a 17 percent increase (Exhibit IV-10) (3).

Exhibit IV-10. U.S. projected total bulk chemical sector feedback energy use (3)



Bulk chemical sector feedstock energy use per unit of output is projected to decrease from 10,700 Btu per 2012$ in 2022 to 8,800 Btu per 2012$ in 2035, a 17 percent decline. Given the steady increase in total bulk chemical sector feedstock energy use, this decline likely reflects an increase in the use of more efficient feedstocks, resulting in less feedstock energy use required to produce one unit of output or use of alternative, non-fossil-fuel-based feedstocks (Exhibit IV-11) (3).

Exhibit IV-11. U.S. projected bulk chemical sector feedstock energy use per unit of output (3)



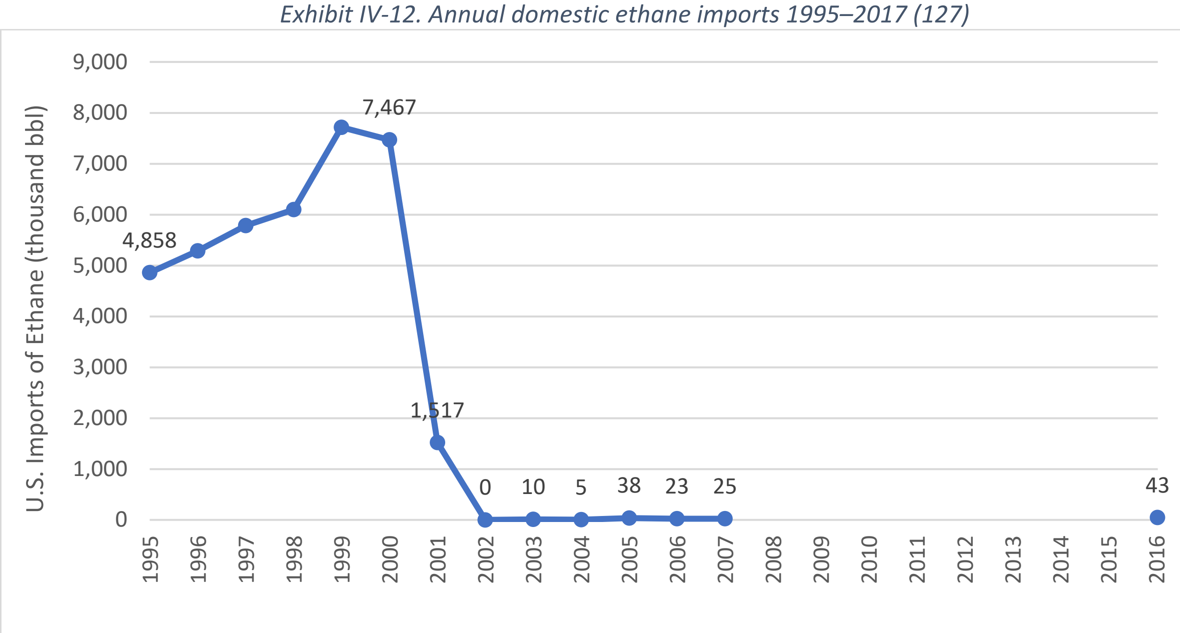
5. Imports into and Exports from the United States of Ethane, Ethylene, and Ethylene Derivatives

In general, commodity imports provide additional supplies for domestic producers engaged in production activities, whereas commodity exports provide alternative markets for industry output. The exportation and importation of commodities helps to grow national economies and expand the global market. Understanding how increased ethane availability in the United States might benefit the domestic economy requires a detailed understanding of the nation's engagement in the importation and exportation of ethane, ethylene, and ethylene derivatives.

A. Domestic Ethane Imports and Exports

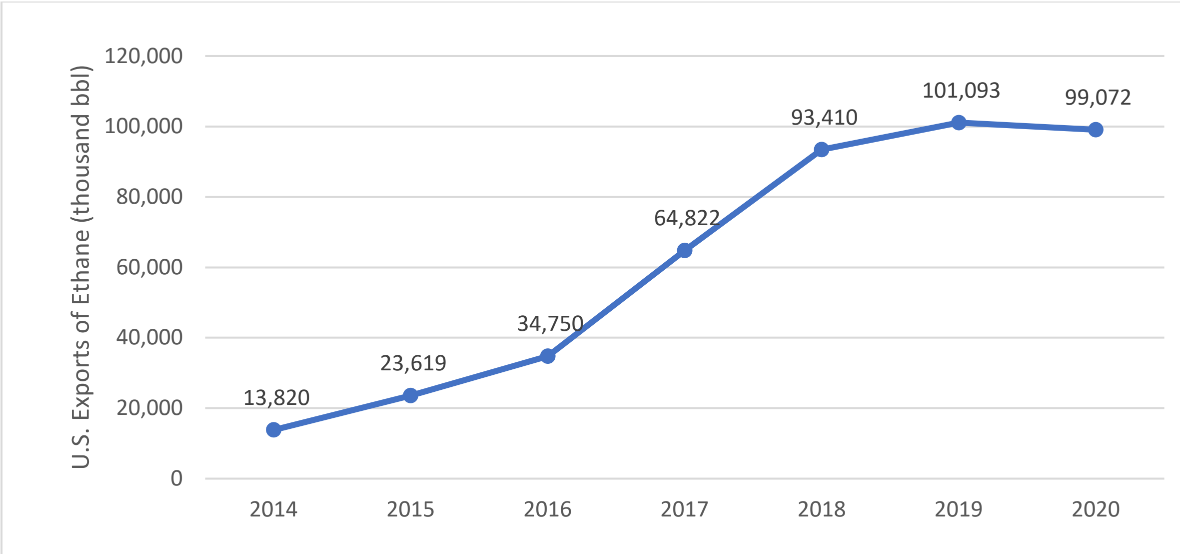
The United States has not imported ethane since 2016, when 48,000 bbls of ethane were imported from Norway (127). Prior to 2016, the last year in which the United States imported positive amounts of ethane was 2007 (127). U.S. ethane imports measured in thousand bbls per year between 1995 and 2016 are outlined in Exhibit IV-12 (127).

Exhibit IV-12. Annual domestic ethane imports 1995–2017 (127)



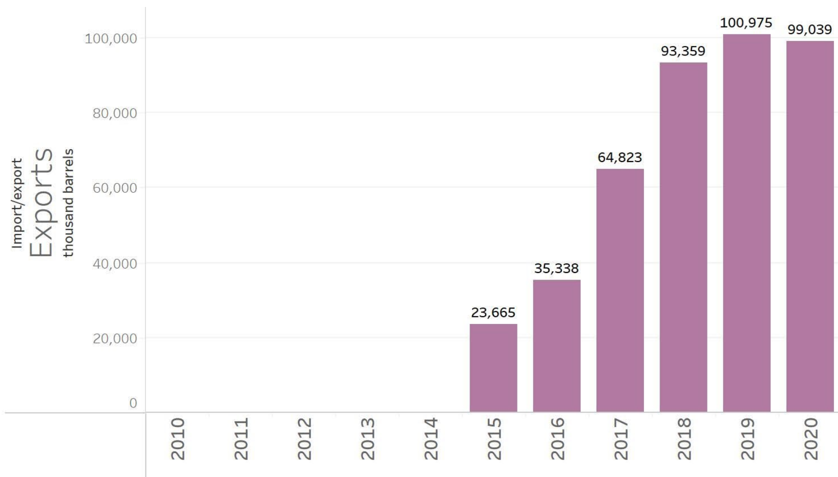
The United States has not imported ethane since 2016, when 48,000 bbls of ethane were imported from Norway (125). This ethane was imported for the purpose of cooling the export terminal, not for consumption, and was subsequently re-exported to Norway. Prior to 2016, all U.S. ethane imports came by pipeline from Canada. The last year in which the United States imported positive amounts of ethane was 2007 (125). U.S. ethane imports measured in thousand bbls per year between 1995 and 2016 are outlined in Exhibit IV-12 (127).

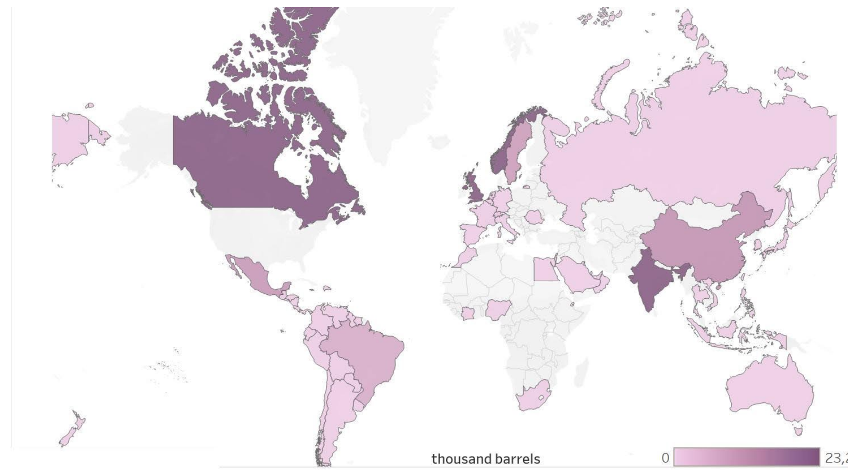
Exhibit IV-13. Annual U.S. ethane exports 2014–2020 (128)



U.S. ethane exports by country of destination between 2015 and 2020 are outlined in Exhibit IV-14. Ethane export data were collected from the U.S. Census Bureau and EIA, respectively (129) (130). Data collected from the U.S. Census Bureau corresponds to Harmonized Tariff System (HTS) Code 2901.10.1010 (130). Exports of ethane from the United States to Canada are based on reported estimates from EIA (129), and while exports of ethane from the United States to Canada have declined over time, exports to Canada on average have represented over 50 percent of all ethane exports from the United States (129). Other countries who imported large quantities of U.S. ethane between 2015 and 2020 included the United Kingdom, China, Norway, Sweden, and Mexico (129). Exports of ethane from the United States are projected by EIA to reach record highs in 2021 and continue to grow in 2022 (5). EIA suggests "the ability to produce ethane *in the United States* at low-cost relative to other feedstocks used in the petrochemical industry has provided U.S. petrochemical manufacturers with a competitive market advantage on the international market" (5).

Exhibit IV-14. Ethane exports by country of destination (2015–2020) (129) (130)





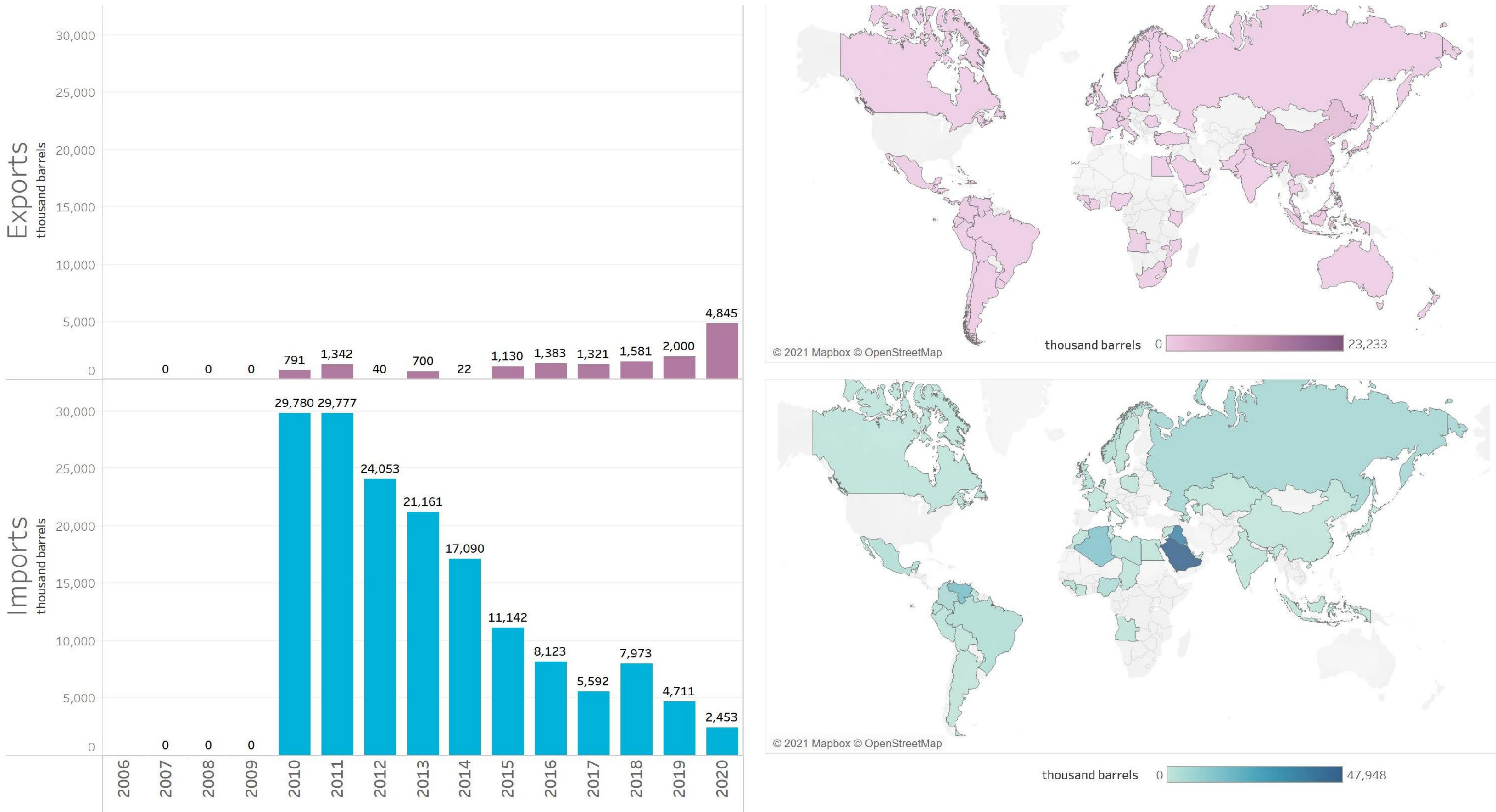
B. Domestic Ethylene Imports and Exports

Ethylene imports in the United States by country of origin and ethylene exports from the United States by country of destination between 2010 and 2020 are outlined in Exhibit IV-15. Data on ethylene imports and exports were collected from the U.S. Census Bureau and correspond to HTS Code 2901.21 (130). EIA says, "ethylene exports from the United States grew by 139 percent between 2019 and 2020" (5).

Between 2010 and 2020, China and Taiwan were the recipients of much of the ethylene being exported from the United States (130). As major petrochemical manufacturers, these two countries require large supplies of ethylene to meet the demand of downstream products manufacturers (131). Prior to 2020, EIA says that all ethylene exports from the United States were moved through the Galena, TX terminal (5). The Morgan's Point, Texas, export terminal became operational in 2020 (5) and ethylene is shipped overseas from there.

Demand for ethylene globally is projected to grow by four million metric tons in the year 2021 and grow by more than six million metric tons per year between 2022 and 2025 (132). Exports of ethylene from the United States represent one supply option for meeting projected global demand for ethylene. While the capacity to produce ethylene has grown over the last decade globally, particularly in the Middle East and in Asia, imbalances in production capacity and consumption requirements of ethylene exist in multiple regions (132). Exports of ethylene from the United States to global markets are expected to increase between 2021 and 2025 as new crackers are brought online (132). EIA says that more than 100 countries are currently importing ethylene from the United States (5).

Exhibit IV-15. Ethylene imports into the United States by country of origin and ethylene exports from the United States by country of destination (2010–2020) (130)



C. Domestic Ethylene Derivatives Imports and Exports

Import and export data for the following ethylene derivates were collected from the U.S. Census Bureau: 1) LDPE, 2) LLDPE, 3) HDPE, and 4) EDC. HTS codes used for LDPE and LLDPE included 3901.10; for HDPE included 3901.20; and for EDC included 2903.15 (130). Imports and exports of LDPE and LLDPE, HDPE, and EDC into and from the United States between 2010 and 2020 are outlined in Exhibit IV-16, Exhibit IV-17, and Exhibit IV-18.

Over the past 10 years, exports of ethylene derivatives from the United States have exceeded imports of ethylene derivatives into the United States. While imports of LDPE and LLDPE combined over the past 10 years have remained above 3,000,000 bbl per year, combined exports from the United States of these two products have been more than 9,000,000 bbl (130). Exports of these four ethylene derivatives from the United States are projected to increase over the forecast period of 2020–2035 (16).

According to EIA, ethylene derivatives, unlike ethane (Exhibit IV-14) and ethylene (Exhibit IV-15), can be moved through any port capable of receiving or delivering shipping containers (5). In addition, EIA reports that Canada and Mexico tend to import ethylene derivatives from the United States by land because it is cheaper than importing waterborne ethylene derivatives (5). As ethane availability in the United States increases, production and export of downstream products including ethylene and ethylene derivatives might represent one opportunity to increase manufacturing industrial output domestically.

Exhibit IV-16. LDPE and LLDPE imports into the United States by country of origin and LDPE and LLDPE exports from the United States by country of destination (2010–2020) (130)

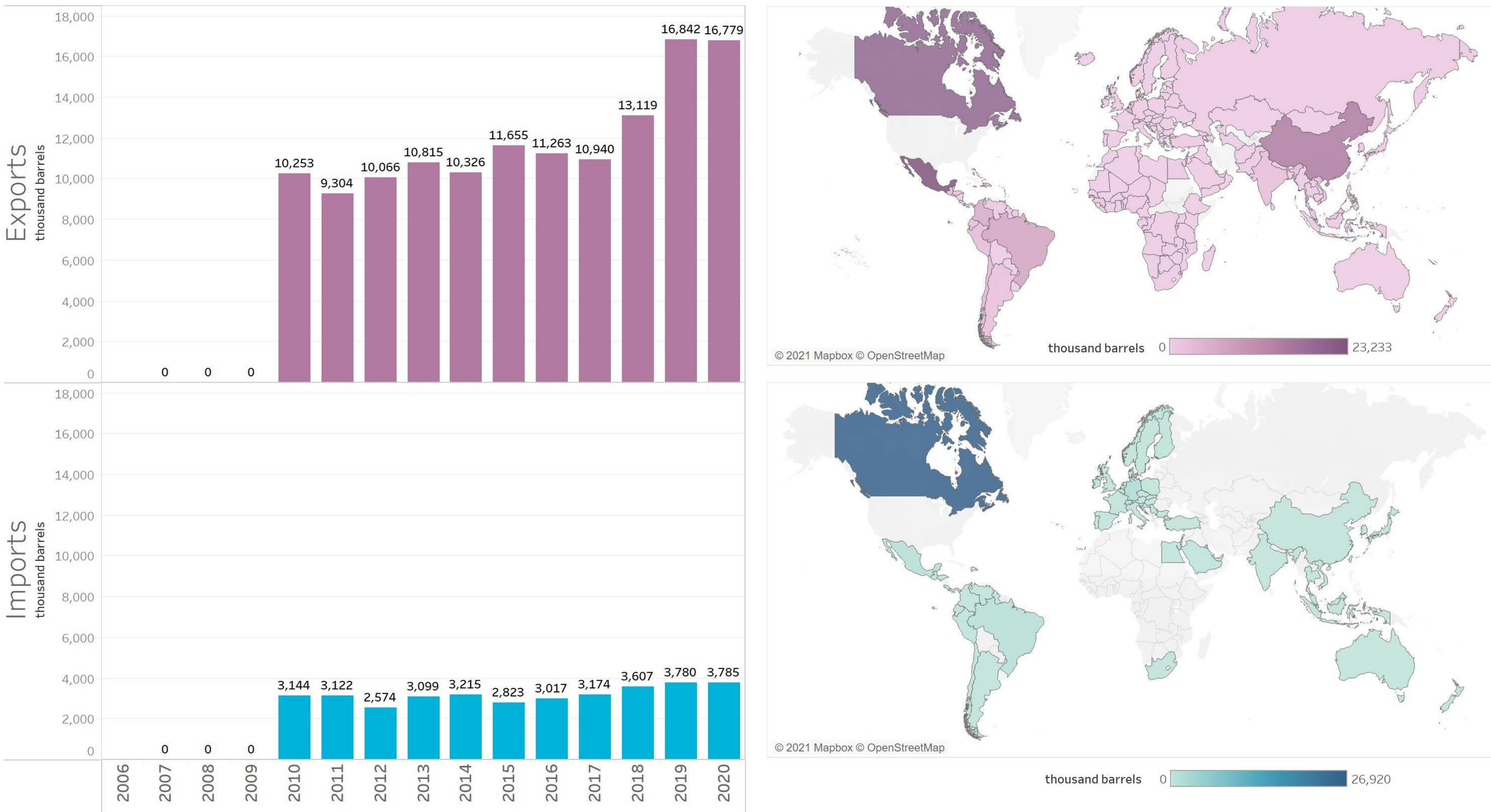


Exhibit IV-17. HDPE imports into the United States by country of origin and HDPE exports from the United States by country of destination (2010–2020) (130)

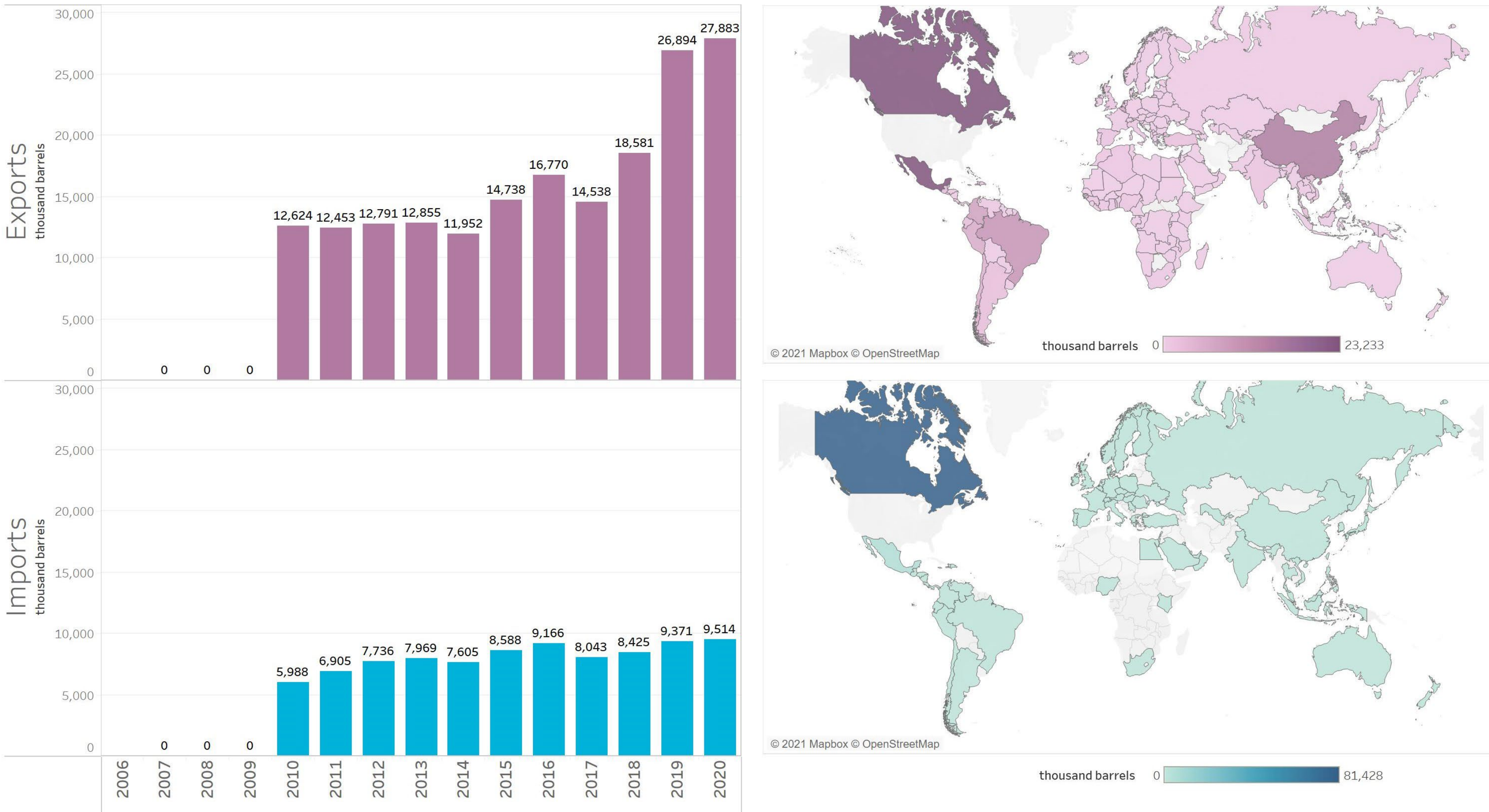
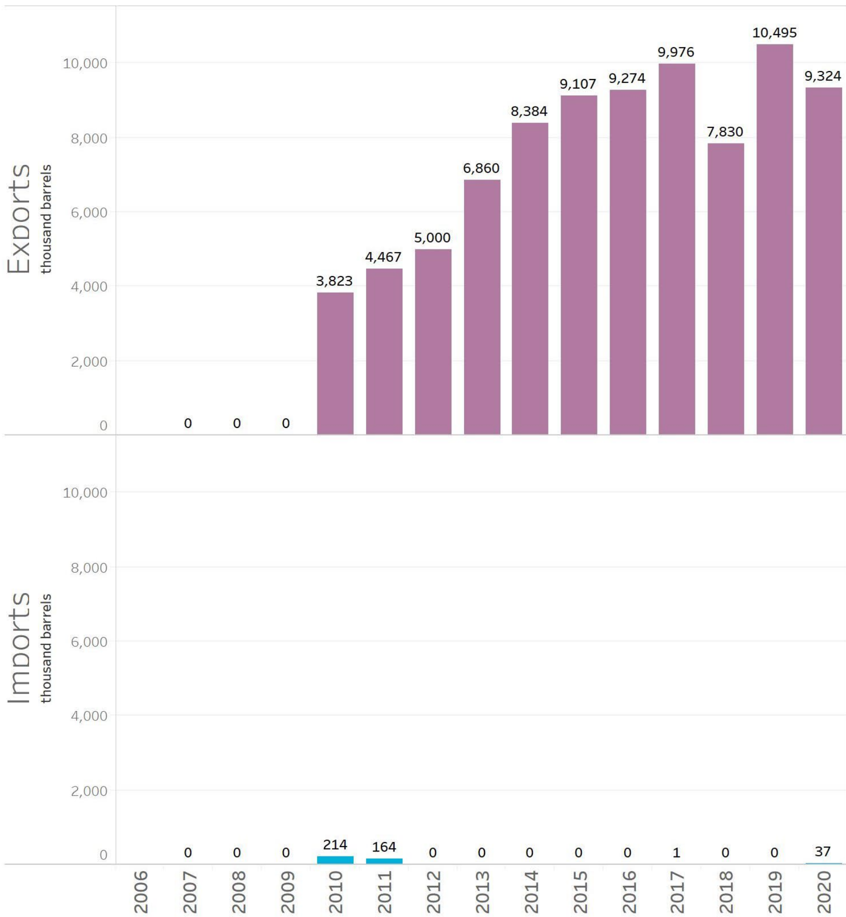
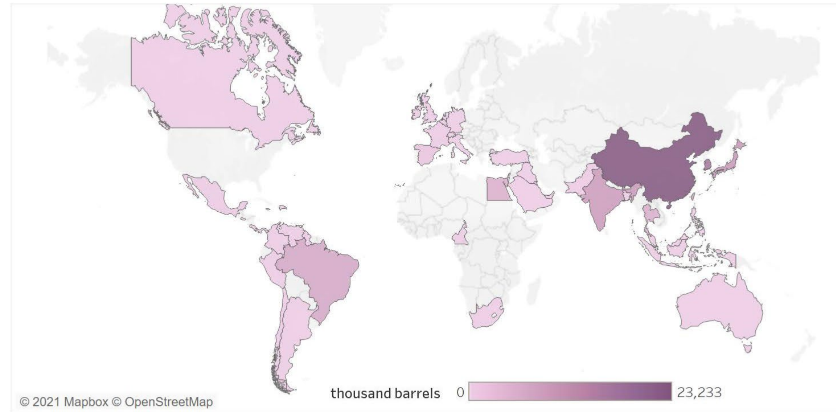
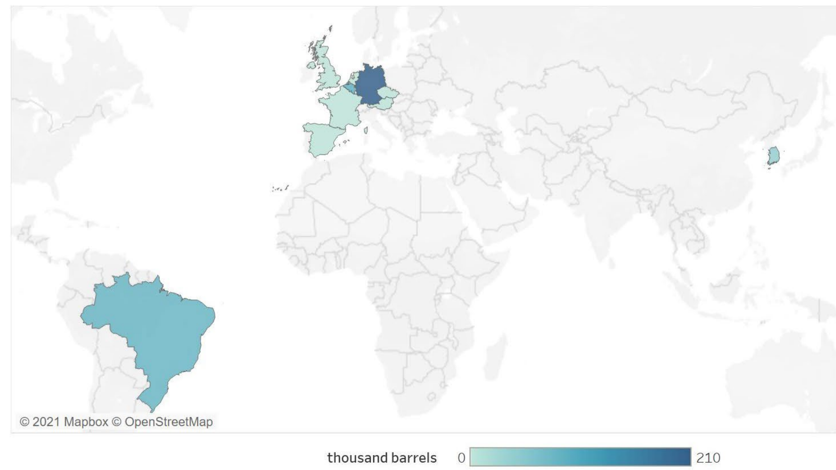


Exhibit IV-18. EDC imports into the United States by country of origin and EDC exports from the United States by country of destination (2010–2020) (130)


Exports
thousand barrels
Imports
thousand barrels
10,000
8,000
6,000
4,000
2,000
0
0 0 0 3,823 4,467 5,000 6,860 8,384 9,107 9,274 9,976 7,830 10,495 9,324
0 0 0 214 164 0 0 0 0 0 1 0 0 37
2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

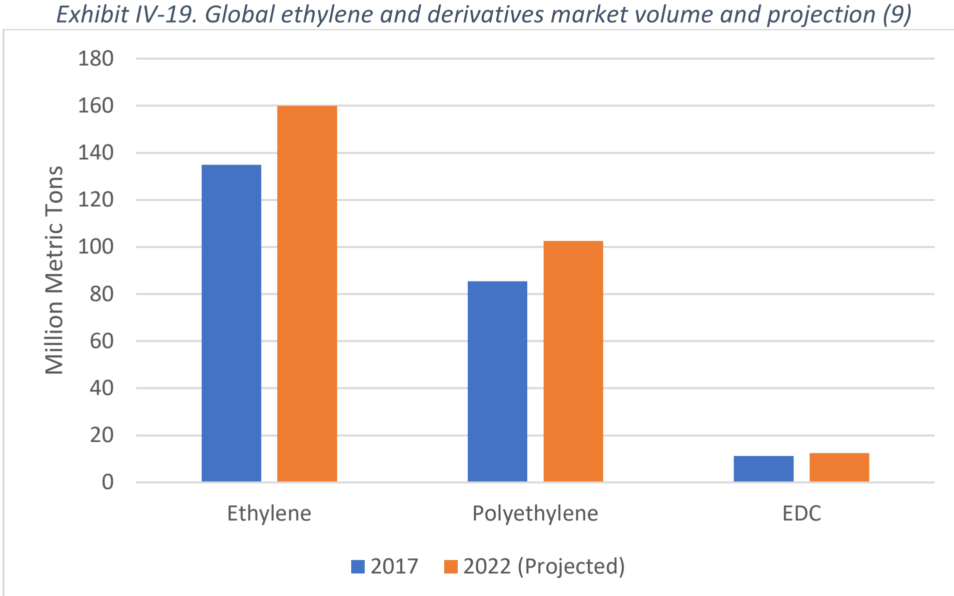

© 2021 Mapbox © OpenStreetMap
thousand barrels 0 23,233


© 2021 Mapbox © OpenStreetMap
thousand barrels 0 210

6. Global Demand Forecast for Ethylene Derivatives, U.S. Market Share, and Value Capture in Future Market Growth Under Two Scenarios

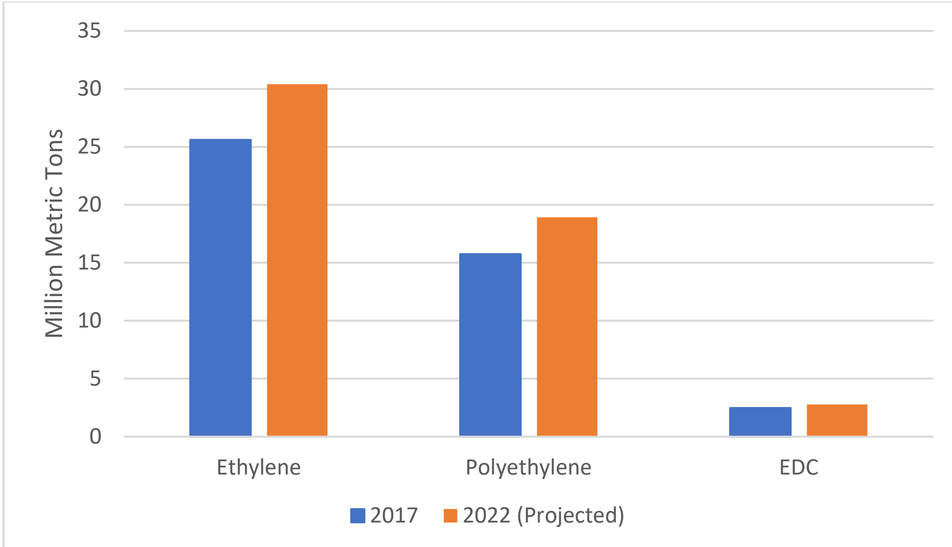
Global ethylene market volume is projected to grow by 18.27 percent from 2017 to 2022 (Exhibit IV-19). Global polyethylene market volume is projected to grow by 20.09 percent from 2017 to 2022, and global EDC market volume is projected to grow by 10.89 percent over the same period (9).

Exhibit IV-19. Global ethylene and derivatives market volume and projection (9)



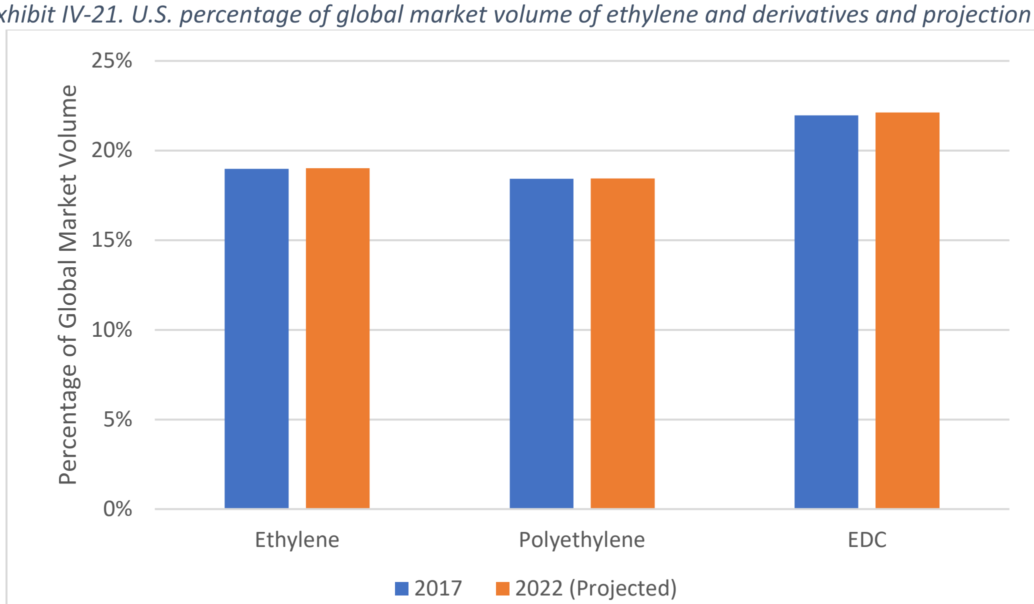
U.S. ethylene market volume is projected to rise 18.75 percent from 2017 to 2022 (Exhibit IV-20). U.S. market volumes of polyethylene and EDC are also projected to rise, with U.S. market volumes of polyethylene projected to experience 20.27 percent growth from 2017 to 2022 and U.S. market volumes of EDC projected to experience 11.69 percent growth over the same time period (9). This projected market value growth for ethylene, polyethylene, and EDC in the United States follows global market volume growth very closely, as can be seen in the percentage growth shown in Exhibit IV-20 and Exhibit IV-21.

Exhibit IV-20. U.S. ethylene and derivatives market volume and projection (9)



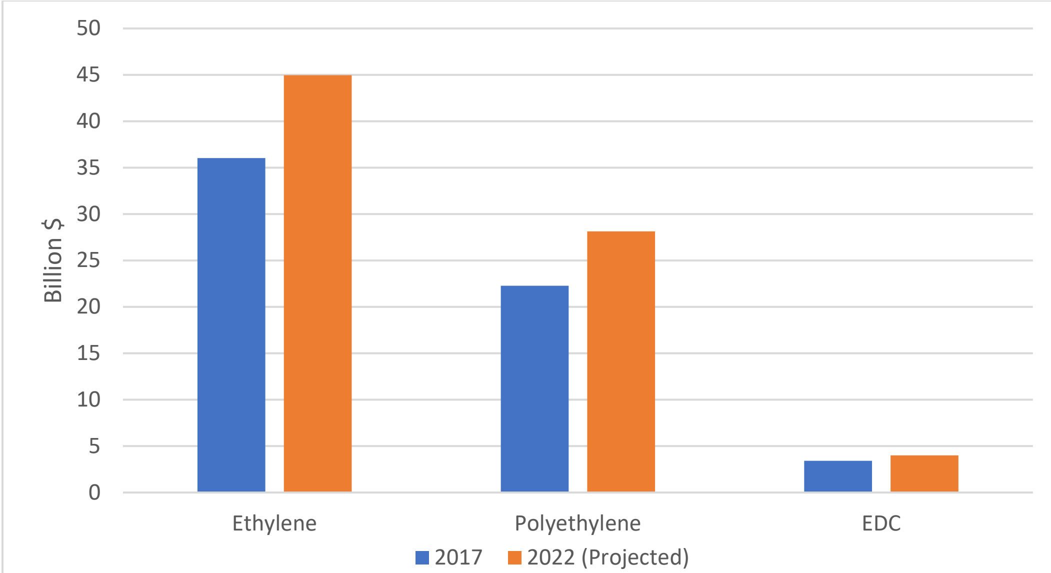
U.S. market volume of ethylene accounted for 18.98 percent of global market volume in 2017 and is projected to rise slightly to 19.01 percent in 2022 (Exhibit IV-21). U.S. market volume of polyethylene accounted for 18.42 percent of global market volume in 2017 and is also projected to rise slightly to 18.44 percent of global market volume in 2022. U.S. market volume of EDC accounted for 21.97 percent of global market volume in 2017 and, like ethylene and polyethylene, is expected to rise slightly to 22.12 percent in 2022 (9).

Exhibit IV-21. U.S. percentage of global market volume of ethylene and derivatives and projection (9)



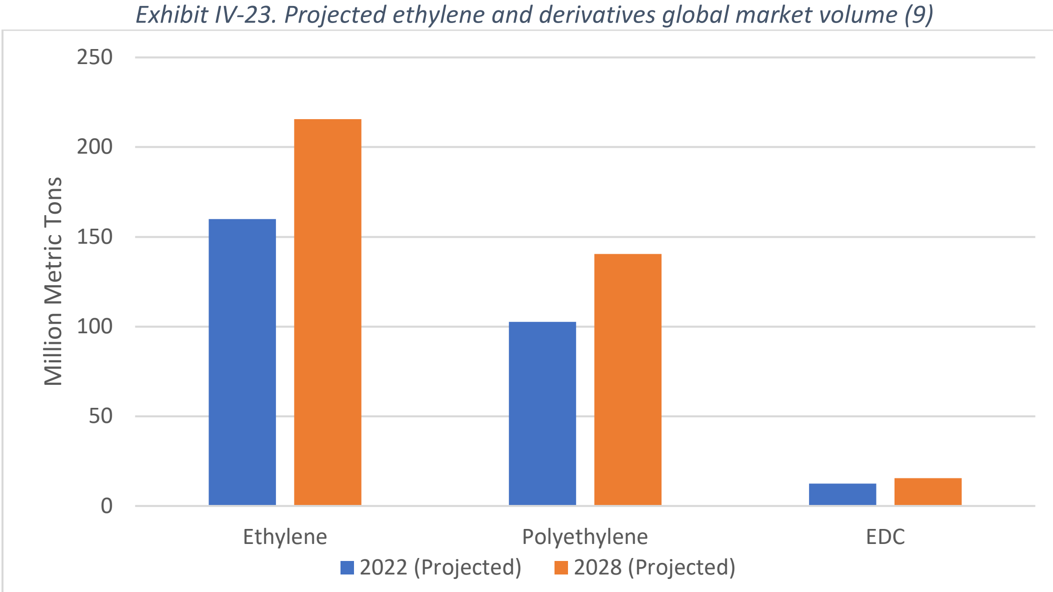
U.S. market revenue of ethylene is projected to rise by $8.92 billion from 2017 to 2022 (Exhibit IV-22). U.S. market revenues of polyethylene and EDC are also projected to rise, with U.S. market revenue of polyethylene rising by $5.87 billion from 2017 to 2022 and U.S. market revenue of EDC rising by $590 million over the same period (9).

Exhibit IV-22. U.S. market revenue of ethylene and derivatives and projection (9)



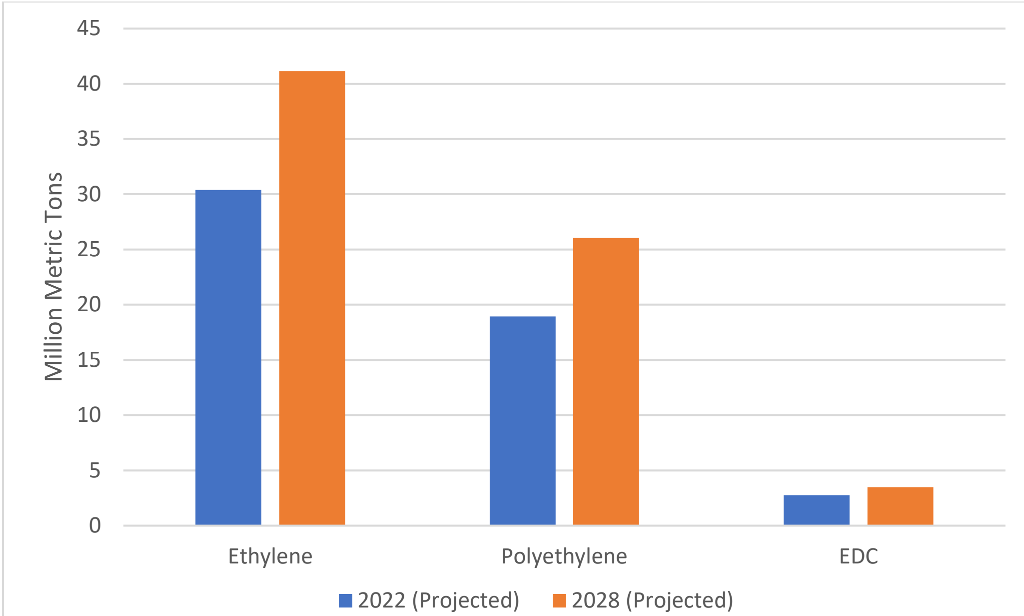
Global market volume of ethylene is projected to grow by 34.82 percent from 2022 levels through 2028 (Exhibit IV-23). Global market volume of polyethylene and EDC are also projected to grow through 2028. Specifically, global polyethylene market volume is projected to increase by 36.82 percent from 2022 to 2028, and global market volume of EDC is projected to rise by 23.48 percent over the same period (9).

Exhibit IV-23. Projected ethylene and derivatives global market volume (9)



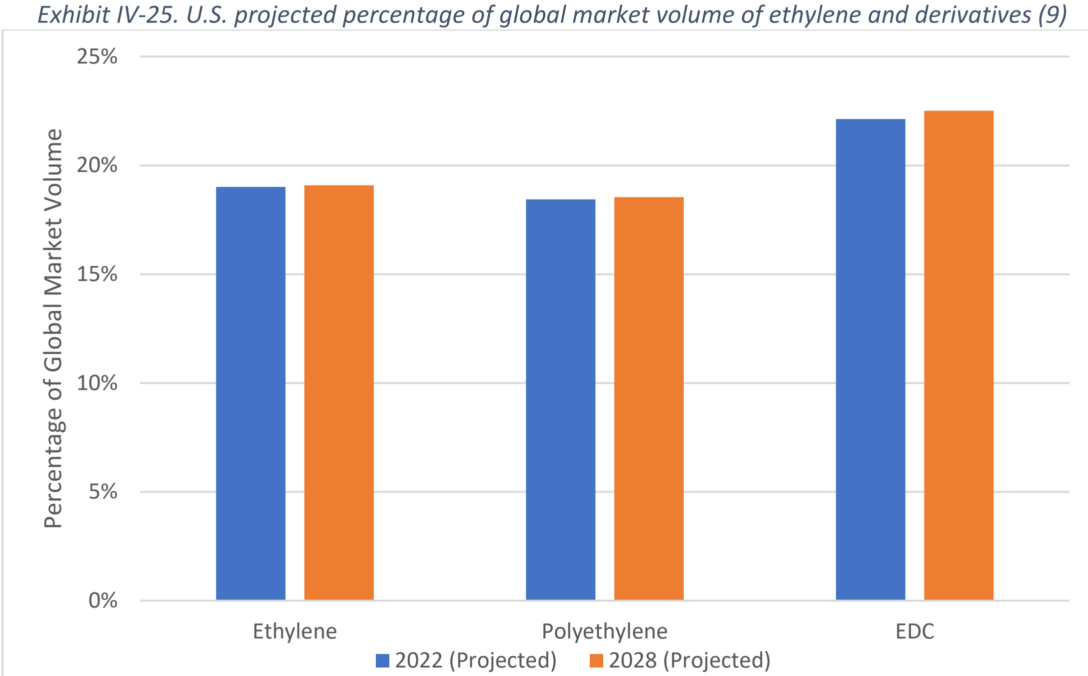
U.S. market volume of ethylene is projected to rise by 35.39 percent from 2022 to 2028 (Exhibit IV-24). U.S. market volume of polyethylene is also projected to rise 37.51 percent from expected 2022 levels to 2028. Additionally, U.S. market volume of EDC is projected to rise 25.63 percent from 2022 levels to 2028 (9).

Exhibit IV-24. Projected U.S. ethylene and derivatives market volume (9)



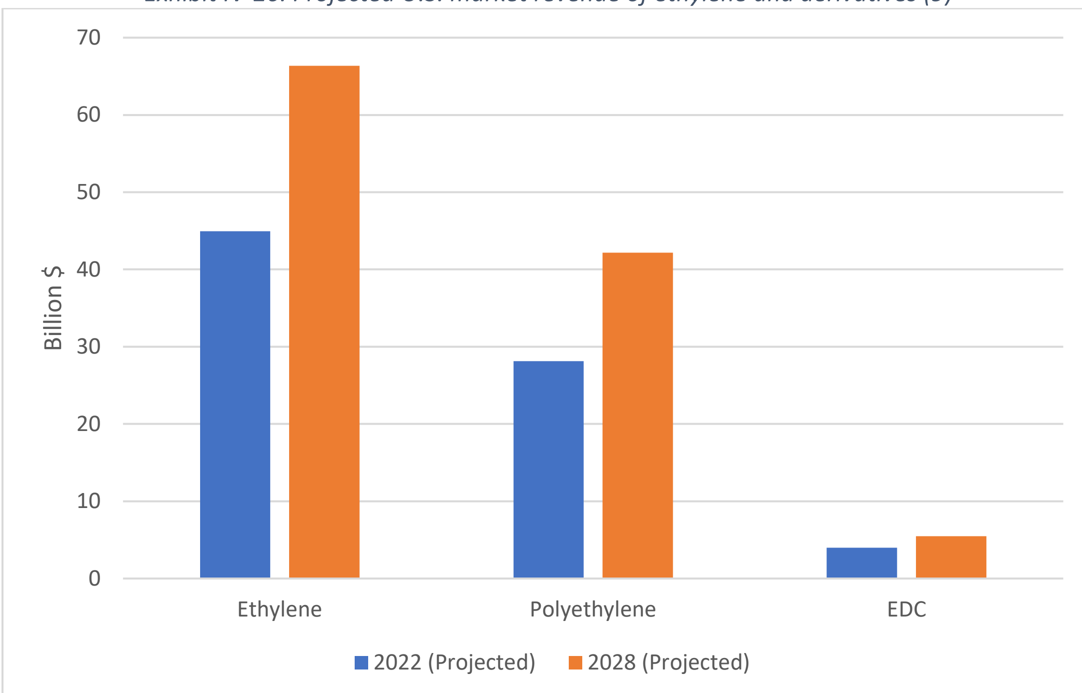
U.S. market volume of ethylene is projected to account for 19.01 percent of global market volume in 2022 and is projected to account for 19.09 percent of global production in 2028 (Exhibit IV-25). U.S. market volume of polyethylene is projected to account for 18.44 percent of global market volume in 2022 and 18.54 percent of global market volume in 2028. U.S. market volume of EDC is projected to account for 22.12 percent of global market volume in 2022 and 22.51 percent of global market volume in 2028 (9). As was observed with data extracted from 2017 to 2022 projections, U.S. market volume and global market volume tend to move in tandem, so the U.S. percentage of the global market volume changes very little.

Exhibit IV-25. U.S. projected percentage of global market volume of ethylene and derivatives (9)



U.S. market revenue of ethylene is projected to increase by $47.6 billion from 2022 to 2028 (Exhibit IV-26). U.S. market revenues of polyethylene and EDC are also projected to rise, with U.S. market revenue of polyethylene increasing by $14.04 billion from 2022 to 2028 and U.S. market revenue of EDC increasing by $1.47 billion over the same period (9).

Exhibit IV-26. Projected U.S. market revenue of ethylene and derivatives (9)



7. *Opportunity Cost of Exporting Available Ethane Supply in Terms of Jobs Created and Labor Income Generated*

An opportunity cost is defined as a forgone value or benefit from choosing one alternative over another (133). To estimate the opportunity cost of exporting domestically produced ethane in support of foreign manufacturing, the potential number of jobs created and the amount of labor income generated were both estimated for a series of competing scenarios. Values for the potential number of jobs created included estimates for both direct and indirect jobs created. Values for labor income are measured in thousands of chain-weighted 2012$.

The competing scenarios considered included the following:

1. Scenario 1: Increased domestic production of ethane is assumed to be used to meet export demand (i.e., the demand of foreign countries for ethane produced domestically).

2. Scenario 2: Increased domestic production of ethane is assumed to be used to support the domestic manufacturing of three ethylene derivatives: LDPE, LLDPE, and HDPE.

The results of Scenario 1 are subtracted from the results of Scenario 2 following equations (a) and (b):

$$Opportunity\ Cost_{Jobs} = \left[Jobs\ (\#)_{Scenario_2} - Jobs\ (\#)_{Scenario_1}\right] \quad (a)$$

$$Opportunity\ Cost_{Labor\ Inc} = \left[Labor\ Inc\ (\$)_{Scenario_2} - Labor\ Inc\ (\$)_{Scenario_1}\right]. \quad (b)$$

which generates the estimates of the opportunity cost of exporting domestic ethane in support of foreign manufacturing in lieu of using domestic ethane to produce the ethylene derivatives.

The potential number of jobs created and the amount of labor income generated under each scenario was estimated from the application of regionalization methods, as described by Jackson and Jarosi (134) to projected IO accounts and estimated values for labor income and employment by industry provided by BLS (135).[35] The forecast years considered included 2025–2029.[36] The projected IO accounts used, as well as the estimated values for employment and labor income by industry, were available at a 205 industrial-sector level of detail, classified according to the 2012 NAICS codes (136).

A review of the 2012 NAICS manual suggested Sector 36 (NAICS 3251)—basic chemical manufacturing—would likely be the manufacturing industrial sector responsible for the domestic production of ethane to be exported under Scenario 1.[37] Similarly, Sector 37 (NAICS 3252)—resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing—was identified as the manufacturing industrial sector likely to be responsible for the increased domestic production of the ethylene derivatives under Scenario 2.[38]

EIA "expects international demand for U.S. ethane exports to also grow as more petrochemical crackers around the world are completed…. [ethane exports are forecasted] to grow more than 50 percent, from 300,000 b/d in the first quarter of 2021 to 460,000 b/d in the fourth quarter of 2022" (1). Assuming exports of ethane continue to follow a similar pattern in later years, for this analysis, and some of this increase in ethane exports was already considered in the projected IO accounts

[35] Projected IO accounts contain data that show the flow of commodities from production through intermediate uses by industries to purchases by final users (135).

[36] At the time that this study was being implemented, projected IO accounts and estimates for employment by industry were available from BLS for the years 2024, 2026, 2028, and 2029. Labor income by industry was available from the BLS but only for the years 2024 and 2026. For a detailed explanation of how information from BLS was modified for the analysis completed, please see Appendix C: Input-Output Approach to Estimating the Opportunity Cost of Exporting Ethane in Support of Foreign Manufacturing Relative to Domestic Use.

[37] Basic chemical manufacturing industries include establishments primarily engaged in manufacturing chemicals using basic processes, such as thermal cracking and distillation. Chemicals manufactured in this industry group are usually separate chemical elements or separate chemically defined compounds. This includes industries engaged in petrochemical manufacturing.

[38] Resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing industries include establishments primarily engaged in one of the following: 1) manufacturing synthetic resins, plastics materials, and nonvulcanizable elastomers and mixing and blending resins on a custom basis; 2) manufacturing noncustomized synthetic resins; 3) manufacturing synthetic rubber; 4) manufacturing cellulosic (e.g., rayon, acetate) and noncellulosic (e.g., nylon, polyolefin, polyester) fibers and filaments in the form of monofilament, filament yarn, staple, or tow; or 5) manufacturing and texturizing cellulosic and noncellulosic fibers and filaments.

used, ethane exports were assumed to increase even further in increments of 20, 30, and 40 percent from their estimated base amount in each year of the forecast period considered (2025–2029).

The base amount of ethane imports was approximated to be equal to 1.39 percent of Sector 36 exports over the forecast period considered (130).[39] Following this result, under the regionalization approach applied, the base amount of Sector 36 exports assumed to already be represented by exports of ethane for each forecast year considered between 2025 and 2029 was 1.39 percent. To isolate the value of the impacts to labor income and employment from increased domestic production of ethylene derivatives, a key assumption was that the new domestic production of ethylene derivatives would substitute for projected imports of ethylene derivatives.[40] Current data suggests imports of the three derivatives are projected to continue to occur throughout the forecast period of 2025–2029, on average representing approximately 5, 12, and 8 percent of projected total available supply for domestic industries, respectively (16). The maximum amount of Sector 37 imports considered replaceable via the substitution of ethylene derivative imports was estimated to be 11.1 percent of projected imports for Sector 37.[41] [42] [43] Import substitution scenarios corresponding to 30, 60, and 90 percent replacement of the maximum possible were assessed for each forecast year of 2025–2029.

Under the assumptions outlined above, three separate versions of Scenario 1 and Scenario 2 were considered. The versions of Scenario 1 and Scenario 2 and their descriptions are provided in Exhibit IV-27.

[39] To estimate the amount of Sector 36 exports represented by ethane, data on exports of ethane between 2015 and 2020 were collected from the U.S. Census Bureau following the HTS codes. The HTS code used for ethane was 2901.10.1010 (130). Data on Sector 36 exports, classified as NAICS 3251, were also collected from the U.S. Census Bureau (130). Data come from customs reports produced by the U.S. Census Bureau between 2015 and 2020 on the domestic value of exports. Data gathered suggested over the 5-year period, on average 1.39 percent of Sector 36 imports comprised ethane imports corresponding to 2901.10.1010.

[40] Import substitution was assumed based on the regionalization approach taken for the analysis. For more information see . Additional crackers are projected to come online in 2022.
Appendix C: Input-Output Approach to Estimating the Opportunity Cost of Exporting Ethane in Support of Foreign Manufacturing Relative to Domestic Use.

[41] To estimate the amount of Sector 37 imports represented by ethylene derivates, data on imports of LDPE, LLDPE, and HDPE and imports of Sector 37 between 2010 and 2020 were collected from the U.S. Census Bureau (122).

[42] Research suggests imports of EDC are not projected to occur over the forecast period considered. As a result, an import substitution scenario was not examined for EDC.

[43] The value of imports is defined as the value of goods imported as appraised by U.S. Customs and Border Protection, excluding import duties, freight, insurance, and other charges incurred.

Exhibit IV-27. List and descriptions of scenarios considered for the opportunity cost calculations

Scenarios Considered

$Scenario_1$	$Scenario_2$
$Scenario_{1a}$: Domestically produced ethane is assumed to be used to meet export demand and exports of ethane are assumed to increase by 20% from their base	$Scenario_{2a}$: Domestically produced ethane is assumed to be used to support domestic manufacturing of three ethylene derivatives which will substitute for 30% of projected derivative imports
$Scenario_{1b}$: Domestically produced ethane is assumed to be used to meet export demand and exports of ethane are assumed to increase by 30% from their base	$Scenario_{2b}$: Domestically produced ethane is assumed to be used to support domestic manufacturing of three ethylene derivatives which will substitute for 60% of projected derivative imports
$Scenario_{1c}$: Domestically produced ethane is assumed to be used to meet export demand and exports of ethane are assumed to increase by 40% from their base	$Scenario_{2c}$: Domestically produced ethane is assumed to be used to support domestic manufacturing of three ethylene derivatives which will substitute for 90% of projected derivative imports

The results of the opportunity cost calculations performed are outlined in Exhibit IV-28 and Exhibit IV-29. Results are presented for the comparisons of potential returns, in terms of jobs created and labor income generated between Scenario 2a and 1a; 2b and 1b; and 2c and 1c.

Exhibit IV-28. Results of the opportunity cost calculations performed, as measured by the difference in the potential number of jobs created annually (2025–2029)

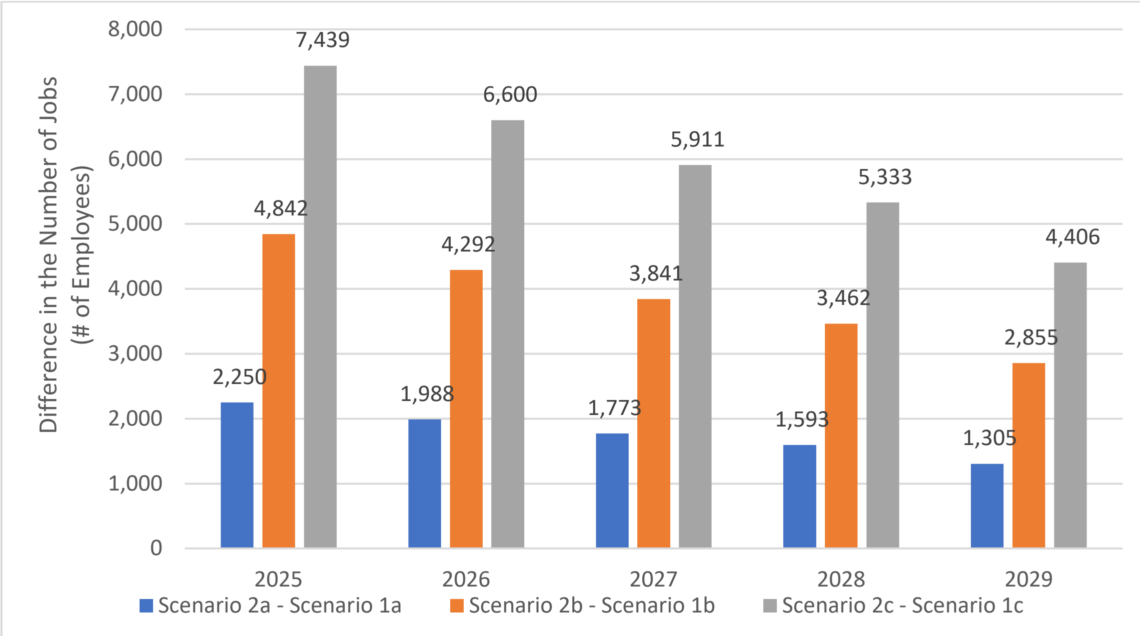
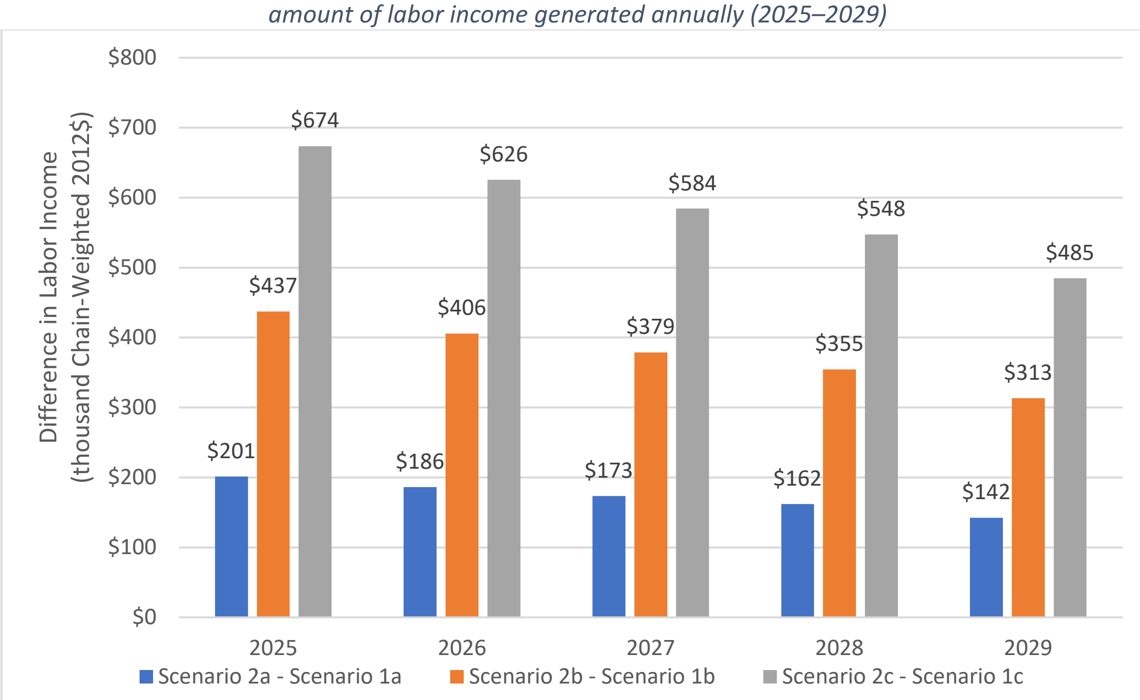


Exhibit IV-29. Results of the opportunity cost calculations performed, as measured by the difference in the potential amount of labor income generated annually (2025–2029)



Results of the comparisons suggest positive differences in the amount of labor income generated and the number of jobs created between the scenario comparisons considered, indicating that using domestically produced ethane to support the domestic manufacturing of ethylene derivatives yields higher returns than exporting domestically produced ethane.

Specifically, the forgone benefits of using domestically produced ethane to meet export demand instead of to support the domestic manufacturing of ethylene derivatives include $142,000–674,000 in labor income and 1,350–7,439 direct and indirect jobs. While the opportunity cost estimates might appear small, it is important to consider them in light of the assumptions from which they were derived. Changes in the assumptions, particularly increases in the amount of ethane exports and further substitution of ethylene derivatives, would likely yield different and potentially more impactful results.

Moreover, additional benefits might be realized under the scenario where the increased domestic production of ethylene derivatives were not only used by domestic industries to reduce their reliance on imports, but also to meet increased export demand for these products from the United States. As the United States continues to produce large quantities of ethane, ethylene, and ethylene derivates, there are ample opportunities for the nation to become more competitive on the global marketplace for these products (5). The ability of the United States to produce ethane at lower cost compared to global competitors also provides an opportunity for the United States to gain a competitive advantage and extract additional benefits from exporting ethane and/or using ethane to produce products domestically (5).

V. Impact of Tariffs on Value-Added Goods on U.S. Manufacturing: Case Study on China

1. *Punitive Tariffs Imposed by China*

From 2018 to 2019, the United States and China created tariffs and counter-tariffs on a wide variety of goods including steel, aluminum, automobiles, aircraft, agricultural and manufacturing machinery, chemicals, energy, and food and drink (137) (138). At the time the Phase One trade deal was signed (on January 15, 2020), the United States had raised tariffs on about $335 billion of Chinese goods and China had raised tariffs on about $120 billion of U.S. goods (139). While the trade deal did contain a commitment from the United States to “modify its … tariff actions in a significant way,” (140) tariffs were not immediately reduced. Trade discussions between the United States and China are ongoing as of the writing of this report (141).

2. *Impact on American Manufacturing*

Retaliatory tariffs between the United States and China have had a profound effect on global trade and economics, disrupting supply chains worldwide and impacting consumer prices on a wide variety of goods. Negative effects of United States/China tariffs on U.S. industries include but are not limited to 1) substantial increases in prices of intermediate and final goods, 2) large changes to supply-chain networks, 3) reductions in the availability of imported varieties, and 4) complete pass-through of tariffs into domestic prices of imported goods (142).

3. Polyethylene Under Tariffs and COVID-19 Pandemic

Polyethylene is among the many products affected by the retaliatory tariffs between the United States and China. China is the biggest net importer of polyethylene, and it is forecast to be responsible for 55–60 percent of all global net polyethylene imports over the next decade (30). China imports polyethylene from a variety of countries including the United States, Saudi Arabia, Iran, Singapore, Qatar, the United Arab Emirates, South Korea, Russia, India, Thailand, and Taiwan.

On July 6, 2018, China imposed a 25 percent tariff on a selection of U.S. products that included all grades of LDPE and a small percentage of LLDPE grades accounting for 0.4 percent of U.S. LLDPE production in 2017 (143). This tariff was overridden on August 23, 2018, with a 25 percent tariff on a new selection of U.S. products that included ethylene, HDPE, and most grades of LLDPE. The grades of LLDPE included in this tariff accounted for 93 percent of Chinese imports in 2017 (143). While tariffs on LDPE were removed, tariffs on HDPE and many additional grades of LLDPE were imposed. In September 2019, tariffs on polyethylene were raised an additional five percent to a total of 30 percent (31).

U.S. polyethylene exports to China decreased significantly due to increased tariffs. Chinese imports of U.S.-produced LLDPE and HDPE reached a peak of 560,000 metric tons per year in 2018, but dropped by 60 percent to 225,000 metric tons per year in 2019 (144). In the first half of 2019, the U.S. polyethylene industry successfully compensated for the decrease in Chinese imports of HDPE and LLDPE by raising exports to other destinations such as Europe, Turkey, Malaysia, Singapore, and Vietnam (31). Exports to China generally result in better margins as higher export volumes support greater economies of scale and reduced logistics costs. Shifting exports to smaller markets to compensate for loss of export volume to China results in higher trader and distributor fees. A sustained shift of U.S. export flows away from China, however, could lead to decreased profitability for U.S. chemical manufacturers (30).

China compensated for the decrease in U.S. imports due to increased tariffs on U.S. goods by importing polyethylene from the Middle East, Russia, India, and Southeast Asia (144). Over the last 10–15 years, China has significantly reduced its dependence on U.S. exports of HDPE and LLDPE as imports from the Middle East and Southeast Asia have increased in importance or held steady. In 2007, HDPE imported from the United States accounted for eight percent of China's total HDPE imports; in 2017, that figure dropped to five percent. The same trend can be seen in LLDPE imports, with U.S. market share dropping from 11 percent in 2007 to seven percent in 2017. In comparison, HDPE imports from Iran to China increased from 0.5 percent in 2007 to 17 percent in 2017 (31).

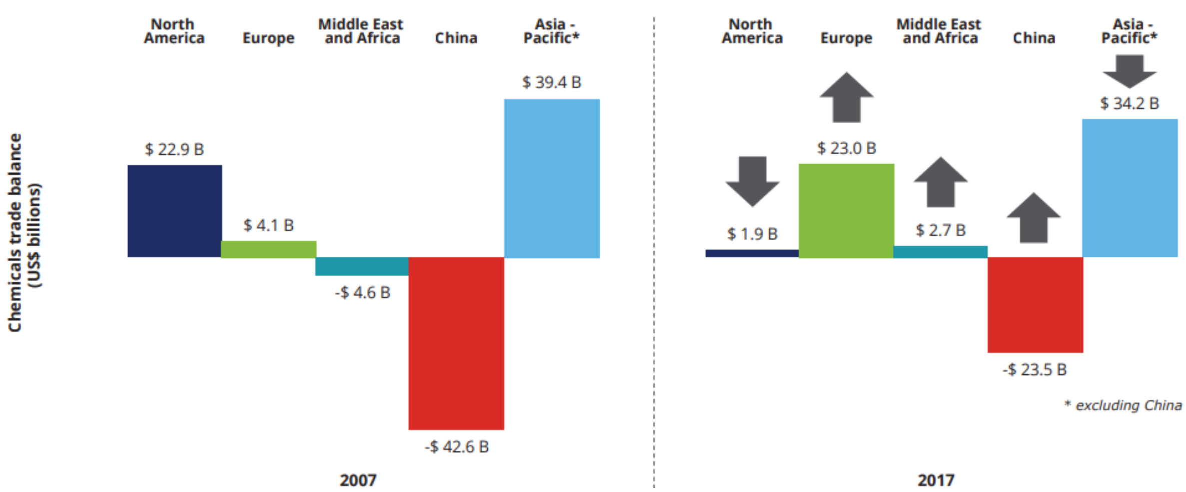
The COVID-19 pandemic caused polyethylene production, export, and demand to shift globally. Initial COVID-19 lockdowns in the United States in March 2020 caused domestic polyethylene demand to decrease significantly. In China, the gradual lifting of COVID-19 restrictions in March and April of 2020 resulted in increased demand for polyethylene imports. Beginning in April 2020, U.S. polyethylene export to China increased significantly (32). This increase in exports was made possible due to exemptions from the Chinese tariffs imposed on U.S. LLDPE and HDPE. In February 2020, China began offering waivers on the additional tariffs imposed on U.S. polyethylene, among other chemicals. Chinese importers were able to apply for a waiver, lowering tariff rates from 34 percent to the pre-adjusted duty of 6.5 percent (145). These waivers supported China's efforts to contain and mitigate the COVID-19 pandemic through imports of medical supplies and equipment, such as ventilators and temperature sensors, from the United States (146).

These tariff exemptions allowed U.S.-produced HDPE and LLDPE to be priced competitively against polyethylene produced in the Middle East, resulting in increased exports of U.S. polyethylene to China (32). These tariff waivers also enabled China to fulfill its commitment to buying more U.S. goods as outlined in the Phase One trade deal. As part of the trade deal, China agreed to buy $52.4 billion in additional energy purchases from the United States over a two-year span over a 2017 baseline of $9.1 billion (137). However, partially due to the adverse economic effects of the COVID-19 pandemic, this agreement was not fulfilled. As of July 2021, China's imports of energy products from the United States were $10.6 billion compared with a year-to-date target of $20.0 billion (138).

4. China's Push Toward Petrochemical Self-Sufficiency

China is actively working to increase self-sufficiency across the petrochemical industry, including the ethylene value chain, to bolster supply security and add economic value. China is specifically looking to decrease its dependence on U.S. ethane and potentially expand and diversify the countries it engages in trade to import ethane. China's push toward petrochemical self-sufficiency and the gains made in this regard can be seen in the reduction of its chemicals trade balance (Exhibit V-1). From 2007 to 2017, China reduced its chemicals trade deficit from $42.6 billion to $23.5 billion (33).

Exhibit V-1. Chemicals trade balance by region, 2007 and 2017 (33)



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A. China's Ethylene Production

China is the world's second largest producer of ethylene and is also one of the most significant global importers of ethylene. In 2018, ethylene production in China reached over 18 million metric tons (28). In 2019, China imported 2.51 million metric tons of ethylene in total, valued at $2.4 billion (28). While Chinese ethylene imports are decreasing year to year as Chinese domestic ethylene production capacity increases, China will continue to import ethylene from the United States to satisfy its ethylene requirements.

Ethylene produced in China is primarily made from naphtha, gas oil, and coal, whereas ethylene in the United States and in the Middle East is primarily produced from ethane. Producing ethylene from ethane has a lower initial investment cost per unit as well as a higher ethylene yield fraction (29). This means that it is economically viable both for China to import U.S. ethylene produced from ethane and to import ethane to use as a feedstock to produce ethylene domestically. China produces a small amount of ethane it uses as a feedstock for petrochemical manufacturing; however, it still depends heavily on significant volumes of ethane imported from the United States. China is working to limit this dependency by growing domestic ethane production and engaging trading partners other than the United States to diversify its ethane supply sources.

B. China's Policies Supporting Petrochemical Self-Sufficiency

China implemented three major economic and geopolitical policies indicating a drive toward industrial diversification and self-sufficiency: *Made in China 2025*, the *Belt and Road Initiative*, and the *Iran-China 25-Year Cooperation Program*.

Made in China 2025

In 2015, China released *Made in China 2025 (MIC 2025)*, a broad industrial plan that seeks to achieve a stronger, more efficient, and more integrated industry, and to boost China's economic competitiveness by advancing its position in the global manufacturing value chain and reducing its reliance on foreign firms (147). A major goal of this plan is to raise the domestically produced content of core components and materials to 40 percent by 2020 and 70 percent by 2025 (148). This plan leverages both state involvement and market mechanisms to achieve these goals. The plan also calls for Chinese firms to increase their investments abroad and become more familiar with international cultures and markets.

Belt and Road Initiative

China's *Belt and Road Initiative (BRI)* is a long-term policy and investment program that aims to significantly improve infrastructure and economic integration among countries along the route of the historic Silk Road. Examples of *BRI* infrastructure investments include ports, skyscrapers, railroads, roads, airports, dams, and railroad tunnels. The *BRI* was announced in 2013 by Chinese President Xi Jinping and was known as *One Belt One Road* until 2016. The project has a target completion date of 2049, coinciding with the centennial of the founding of the People's Republic of China.

There are more than 71 countries that are part of the *BRI*, representing more than one-third of the world's GDP and two-thirds of the world's population (149). By connecting these diverse countries and economies, China gains access to cheaper sources of energy and labor; food grown and produced yet unaffected by China's water, soil, and air pollution issues; and an expansive, tariff-free market for Chinese intermediate and finished goods.

Iran-China 25-Year Cooperation Program
The underlying geopolitical strategy of the *BRI* may harm the United States as China builds relationships and strengthens trade deals with countries in the *BRI*. By partnering strategically with *BRI* countries, China could cut the United States out of certain supply chains.

One example of this is China's relationship with Iran. China and Iran already have a strong polyethylene trading relationship, and in 2019, China imported 1.5 million metric tons of HDPE from Iran, or approximately 19 percent of its total HDPE imports. This made Iran China's second-largest trading partner for HDPE behind Saudi Arabia (150). In addition, Iran was China's largest trading partner for LDPE in 2019, supplying 3.2 metric tons, or 22 percent of China's total imports (150).

On March 27, 2021, China and Iran signed the *Iran-China 25-year Cooperation Program*, an agreement in which the two countries agreed to increase bilateral trade more than 10-fold to $600 billion over the next decade (151). The New York Times reported that China will invest $400 billion in Iran's economy in exchange for a steady and heavily discounted supply of oil (152). Further details of the agreement have yet to be released.

A strategic value chain could be created through the *BRI* between Iran and China to maximize the strengths of both economies (152). Iran could export crude oil to China at the low prices promised in the cooperation agreement. China could then convert that crude oil into intermediate goods such as polyester fibers. Those intermediate goods could be exported to factories in Iran where labor costs are lower than they are in China. The finished goods produced by factories in Iran could then be exported back to China and other *BRI* countries duty free or with low tariff rates. In this scenario, the United States is completely pushed out of the value chain and Chinese market.

VI. Capital Flight and Reshoring

1. Understanding Capital Flight

Capital flight refers to large-scale outflows of assets or capital from a country due to currency devaluation, political or economic instability, or strict capital controls. There is not a universally accepted definition or criteria for defining capital flight and, therefore, no definitive measurement of what would be considered capital flight as opposed to normal outflows of investment in an open economic system. That said, the generally accepted standard is "larger than normal" (153) (154).

Capital flight is typically triggered by currency devaluation but can also be triggered by government policies that make investors fearful of economic fallout or political instability. Other examples include, but are not limited to, nationalization of private assets, economic sanctions due to military aggression, significant tax increases or declining interest rates, or changes in investor preferences. Countries with highly specialized economies are particularly vulnerable to capital flight from changes in investor preferences, as they have little method of shifting their economic output to other industries if investment declines (153) (154).

Capital flight, although a serious risk, is not a normal occurrence. Very few countries throughout history have experienced full-scale capital flight, and governments have ways to prevent it from happening. Open economies, like the United States, are the least vulnerable to capital flight as increased transparency between government policy and investors leads to greater confidence from investors, which is likely to lead to increased domestic investment. Additionally, the more confidence investors have in moving capital to a particular country, the more likely this capital will be the preferred foreign direct investment (FDI) as opposed to foreign portfolio investment (154).

FDI refers to tangible capital, such as purchase of businesses or companies that require long-term commitments. Foreign portfolio investment refers to investing financial assets, such as buying stock in a company. In attempting to avoid capital flight, FDI is a preferred approach as it is much easier to quickly sell off stocks and other financial investments than it is to sell an entire company. When FDI is tied to a country for a longer term, the risk of capital flight is much lower (155).

2. Manufacturing Industry Trends

Although the United States is not currently at risk of capital flight, domestic U.S. manufacturing operations leaving the country for cheaper labor abroad is a well-documented occurrence. Manufacturing's total share of U.S. GDP has remained mostly stable since the 1940s, at approximately 11–13 percent, but manufacturing's share of total employment has declined sharply, from approximately 30 percent in 1950 to 8.51 percent in 2019 (34) (35).

Increased globalization has allowed for manufacturing to occur in a "fractured" model, where different parts of the production process occur in different locations. Instead of designing, manufacturing, and assembling products domestically, it has become cheaper for companies to design the products domestically and subsequently have them manufactured abroad and shipped from that country back to them. This had led to what is known as the "Apple effect," named after aspects of the trillion-dollar technology company's business practices of the late 1990s and early 2000s. Specifically, Apple's manufacturing model created a blueprint for other U.S. companies in which they would design and distribute their products in the United States but manufacture everything in China where workforce wages were significantly lower. This trend can also be seen in industries such as electronics and clothing manufacturing in which design processes are conducted in the United States, but the physical goods are manufactured in countries with cheap labor before being brought back to the United States for subsequent sale (156).

In their article, "The Surprisingly Swift Decline of US Manufacturing Employment," Pierce and Schott detail U.S. policies that led to the sharp drop in U.S. manufacturing employment after 2000. The authors find a link between a sharp decline in U.S. manufacturing employment and the United States granting Permanent Normal Trade Relations (PNTR) to China. PNTR was passed by Congress in October 2000 and was made effective when China entered the World Trade Organization (WTO) in 2001. PNTR reduced uncertainty over U.S. import tariffs on Chinese goods, as prior to this point, low Normal Trade Relations tariff rates applied to China but needed to be renewed every year—a contentious and political process that didn't necessarily guarantee success. The uncertainty over these negotiations was removed with the passage of PNTR, permanently setting U.S. tariffs on Chinese imports at Normal Trade Relations levels. The authors describe three ways in which the change impacted U.S. manufacturing employment (36).

First, PNTR incentivized U.S. companies to shift operations to China or establish relationships with Chinese producers, as the sunk costs associated with offshore operations were no longer as risky as had previously been the norm. Without concern over changes in tariffs for their goods, manufacturers could rely on more stable costs for their operations. Second, Chinese producers were provided with an incentive to invest in the U.S. market, resulting in increased competition for U.S. manufacturers. Third, it boosted the attractiveness of investments in capital more closely related to U.S. comparative advantage for U.S. manufacturers. These include investments in skill-intensive production technologies or less labor-intensive products, as the United States had a comparative advantage in terms of high-skill labor, particularly when compared to China (36).

Baily and Bosworth also find evidence supporting growth in real output in U.S. manufacturing despite a long decline in manufacturing's total employment. In their article "US Manufacturing: Understanding Its Past and Its Potential Future," the authors outline two contradictory trends in the manufacturing sector: a constant level of manufacturing share in the U.S. economy, in terms of GDP (price adjusted), but a long-term decline in the share of total employment in manufacturing. The authors outline three main reasons why this trend, i.e., a long-term decline in manufacturing employment, should be a cause for concern (37).

First, although the manufacturing sector's share of GDP has remained stable for the past 50 years, this is due to the expansion of the computer and electronics industry, which accounts for only 10 percent of the total share of manufacturing. The share in GDP of the other 90 percent of manufacturing has fallen rapidly and only experienced modest productivity growth. Second, the total share of U.S. manufacturing employment over the past 50 years has declined from approximately 24 percent in 1960 to approximately 9 percent in 2011. The authors attribute this fall in manufacturing employment to the trade imbalance with China from the PNTR in 2000. Third, the U.S. manufacturing sector has a massive trade deficit that increased from $316 billion in 2000 to $460 billion in 2012. Asia accounted for over 75 percent of the deficit in 2000 and for 100 percent in 2012. Additionally, the share of the trade deficit with Asia attributable to China increased from approximately 30 percent in 2000 to 72 percent in 2012 (37).

3. Reshoring Trends

Given the previously described issues with U.S. manufacturing, including trade deficits, large declines in employment, and reliance on trade with specific countries such as China, reshoring of U.S. manufacturing has become a larger focus in policy discussions. Reshoring is the practice of transferring a business operation that was moved overseas back to its country of origin. In this specific case, it is used to refer to the return of U.S. businesses that previously moved some or all their business operations offshore (157). Reshoring companies have been gaining a growing amount of attention, including Apple, General Electric, and Ford Motor Company. There are several reasons why these trends are occurring (38).

First, emerging countries that were once used by companies as sources of cheap labor are becoming more expensive than they were initially. For example, China has been experiencing an increase in average hourly wages of 15–20 percent per year. Second, as echoed by Baily and Bosworth in their discussion of the computer and electronics industry, is the fact that new digital technologies related to information, communication, and automation will make production processes less reliant on cheap labor costs, meaning there is less of an incentive to continue operating in emerging economies with access to cheap labor (38).

According to the Reshoring Initiative's 2020 Data Report, reshoring and FDI job announcements increased by 160,649 that year, raising the total reshoring and FDI job announcements since 2010 above one million. Allowing for a two-year lag from job announcement to hiring, this means approximately 787,000 of these positions have been filled as of 2020. After dropping to a record low of 11.45 million in 2010, manufacturing employment had been increasing through 2020 to 11.5 million, despite a slight decrease in 2020 due to the global COVID-19 pandemic. Additionally, the share of new manufacturing employment attributed to reshoring (as of 2020) has exceeded FDI for the first time since 2013 (158).

Pegoraro et al. cite evidence on the de-globalization of the world's economy and how this relates to reshoring practices by emphasizing changes in FDI trends and firms' reshoring strategies. Both outward and inward global FDI have stagnated recently due to less FDI flowing from advanced economies to developing economies. The amount of FDI being invested by advanced countries in Asia has dropped substantially, while FDI being invested in advanced countries from other advanced countries, like the United States and Europe, has risen by approximately 32 percent. This increase has been concentrated in certain manufacturing sectors, with most notably a 60 percent increase in chemical and chemical product manufacturing from 2016 to 2017, suggesting a refocusing of where production was occurring (39).

The authors also suggest that while reshoring has become somewhat of a buzzword recently, with prominent cases such as General Electric, Caterpillar, and Walmart generating headlines, trends suggest that reshoring activity is increasing more broadly. There are multiple factors that the authors describe as "push and pull" that can explain reshoring as a response to increasing complexity across the value chain or strategies to increase international competition. Key push factors, or those that occur in offshore locations that would cause firms to reshore, are mainly related to long-term costs that weren't considered or underestimated by companies when they originally decided to move operations offshore. These can include monetary issues such as exchange rate fluctuations and time to deliver products between countries, as well as political risk factors such as regime changes and macro-political changes like taxes. An analysis was conducted by Gray et al. in which 19 American companies were studied based on their decisions to reshore. The report findings found that reshoring decisions were made in response to steadily rising intangible costs incurred overseas (39).

Key pull factors, or those that occur in home countries that would cause firms to reshore, are mainly related to supply chain issues involving responsiveness and flexibility. For example, the rise of e-commerce has necessitated firms moving to secure greater control of regional logistical requirements underpinning their respective shopping platforms. Proximity to consumers, control over the supply chain, and proximity to suppliers all reduce costs and have convinced firms to reshore. Firms that sell products directly to consumers without an intermediate party have reaped the benefits of shorter delivery times and less friction encountered within their supply chains by reshoring and moving closer to their end markets. Additionally, access to skilled labor and technology innovations (and supporting infrastructure) is something that is generally lacking in emerging economies, incentivizing firms to reorganize their production and return home to spur innovation and technological development (39).

4. Supply Chain Disruptions and Policy Changes

According to a June 2021 survey of the National Association of Chemical Distributors, approximately 85 percent of 84 distributors total reported at least one item as out-of-stock, compared to 47 percent in March (40). Plastics production has experienced severe shortages for plastic raw materials, base plastics, and compounded plastics, even as demand for plastics has continued to surge. As ethane is a feedstock for plastics production that is relatively low cost and plentiful here in the United States, reshoring can provide distinct advantages (41).

The Associated Press reports that the price of many plastics feedstocks have soared, including a 70 percent increase in the price of PVC, a 170 percent increase in the price of epoxy resins, and a 43 percent increase in the price of ethylene. China has also been experiencing a slowdown in exports, with petrochemical exports continuing to slow due to supply chain issues. China accounts for more than 30 percent of global demand for petrochemicals, so any delay or disruption to exports can cause a significant global supply chain disruption. For the United States, this means that scaling up domestic production of petrochemicals will significantly lessen the impact of supply chain disruptions (42).

The Biden-Harris Administration has been addressing the challenges facing the manufacturing sector through policies designed to improve U.S. competitiveness against China and other competitors. Several legislative changes such as the Strategic Competition Act of 2021, the Endless Frontier Act, and the CHIPS for America Act, all part of the Innovation and Competition Act of 2021, were passed by the senate in early June 2021. When signed into law, these bills would allocate approximately $200 billion in new spending, increase Federal financial support for strategic sectors, and emphasize an increase in resources committed to research and development and capital-intensive manufacturing (44).

According to an ICIS report, reshoring of manufacturing plants is anticipated to provide continued growth for the U.S. chemical industry. Disruptions to supply chains have also accelerated reshoring, as manufacturers are incentivized to bring their production closer to their U.S. demand centers. In particular, reshoring of chemicals manufacturing operations was kickstarted by the aftermath of the Fukushima earthquake, which caused massive supply chain disruptions for critical petrochemicals, and the COVID-19 pandemic, which further disrupted supply chains and provided additional incentive for manufacturers to close the distance between their production and demand centers. Additionally, the relative U.S. cost advantage is expected to continue through at least 2024 as the chemical industry domestically benefits from higher oil prices since U.S. chemical producers rely primarily upon gas-based feedstocks such as ethane (43).

VII. U.S. Regulatory Framework for Ethane Development

This section of the report addresses the regulatory framework for the midstream and downstream portions of the ethane supply chain; however, a discussion of upstream regulations and policies is outside the scope of this report (159). This section focuses on environmental safety and health regulations preventing or minimizing air and water pollution and occupational hazards associated with petrochemical manufacturing.

1. Key U.S. Regulations and Policies

A. Health and Safety

Health and safety regulations for the petrochemical manufacturing sector focus on worker and operational safety as well as consumer safety. The Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety & Health (NIOSH) monitors and provides guidance on operational and workforce safety. OSHA and industry trade and standards organizations, such as the American Petroleum Institute and AFPM, inspect petrochemical operations to ensure compliance with government and industry standards. In addition to workplace and operational safety, ethane is listed in the Toxic Substances Control Act inventory, requiring specific handling and labeling procedures. Consumer goods produced from derivatives of ethylene, specifically food packaging, are also regulated by the Food and Drug Administration under 21 Code of Federal Regulations (CFR) 177 (Polymers) (160).

Non-governmental organizations (NGO), such as the International Organization for Standardization (ISO), play a significant role in establishing industry standards and certifications for quality and environmental management, food and health safety, and security. Compliance with ISO and other industry accepted standards and certifications are enforced through industry associations and internal procurement practices.

B. Transportation

Regulations affecting the transportation of ethane and ethylene derivatives fall into two categories: hazardous material safety and transportation access. Both categories are further defined by the transportation mode: pipeline, marine, rail, ground, and air. Due both to the volumetric and technical limitations of transporting ethane by other means, much of the existing regulatory coverage centers on pipeline and marine transportation.

The Federal Energy Regulatory Committee (FERC) reviews, approves, and regulates the construction and operation of interstate pipelines. However, FERC does not have jurisdiction over the safety or security of pipelines. The Pipeline and Hazardous Materials Safety Administration, housed within the Department of Transportation, oversees compliance and enforcement of the transportation of hazardous materials and pipeline operational safety writ large.

Transportation of ethane and ethylene derivatives by water and air outside of U.S. air space and waterways is regulated by international bodies, specifically the International Maritime Organization (IMO) and International Civil Aviation Organization, agencies of the United Nations. The IMO maintains and updates the International Maritime Dangerous Goods code, which sets standards on labeling and handling of hazardous goods, including ethane and ethylene derivatives (161). The IMO and International Civil Aviation Organization established principles for the management of hazardous goods transported by air under Annex 18 to the Convention on International Civil Aviation (162).

The Jones Act impacts the cost effectiveness of marine shipments of ethane between U.S. ports. The Jones Act requires goods shipped between two or more U.S. ports to be shipped on U.S.-flagged vessels. U.S.-flagged vessels are typically built, owned, and operated by U.S. citizens or permanent residents. The act ensures intra-domestic waterborne vessels meet specific levels of safety inspection and certification (163). The high cost of domestic manufacturing and operations of U.S.-flagged ships may be associated with a decrease in the number and aggregate capacity of U.S.-flagged tankers since the early 1980s, limiting the supply of compliant vessels. In general, it costs three to four times as much to manufacture a ship in the United States than in higher-volume shipyards based in Korea, China, and Japan, and about three times as much to operate on domestic routes than a foreign-flagged ship (163). The limited number of compliant shipping vessels may restrict domestic ethane-feedstock consumers to locations with ethane pipeline access, specifically the Midwest, Gulf Coast, and Central Atlantic. Similarly, ethylene and ethylene derivatives consumers may be restricted to rail networks and ground freight that have limited capacity when compared to transporting these commodities via marine vessels.

2. Environmental Impacts and Protection

Ethane is exempted from EPA's definition of volatile organic compounds (VOC) (164). However, EPA does regulate ethane, ethane mixes, ethylene, and ethylene derivatives under EPA's Risk Management Plan Program with thresholds assigned for accidental release prevention (165). Ethane is listed as a hazardous substance under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and is regulated by Section 112(r) of the Clean Air Act (CAA) that requires covered facilities to develop and implement a risk management program to prevent accidental releases of regulated substances. The specific steps required for the prevention program depend on the level of risk posed by a process and the complexity of the process (166). EPA also regulates emissions from refineries, crackers, and petrochemical manufactures under the CAA (166).

State Regulations

Petrochemical entities may be required to meet state specific regulations on air and water-quality, greenhouse gas (GHG) emissions, royalties, spills, and siting and permitting. Petrochemical refining and processing operations are primarily regulated through environmental regulatory agencies. The states with the greatest volume of NGPLs and ethylene production are shown in Exhibit VII-1. Significant trends and provisions of these state regulators are discussed below.

Exhibit VII-1. Top NGPL and ethylene producing states (167) (168)

NGPL Production	Ethylene Production
Texas	Texas
Oklahoma	Louisiana
New Mexico	Kentucky
North Dakota	Iowa
Colorado	Illinois
	Pennsylvania (under construction)

Steam crackers

Steam crackers and petrochemical industrial complexes are tightly regulated in terms of the air emissions and waste byproducts associated with operations. State air quality regulations, through CAA State Implementation Plans, are required to be reviewed and approved by EPA under the CAA (169). Each state, and in some cases individual counties, maintain an environmental agency or air-quality bureau responsible for monitoring, permitting, and enforcing their EPA-approved State Implementation Plan, which must meet federal CAA requirements, unless specifically exempted. EPA similarly engages with state agencies to establish state-level, water-quality regulations in compliance with both the U.S. Clean Water Act and the Safe Drinking Water Act (170).

Doing Business

In addition to considering permitting timelines and environmental compliance requirements, petrochemical investors must assess how tax regimes will affect their operations. Corporate, gross receipt taxes are outlined in Exhibit VII-2. States may also provide tax exemptions or other incentives to encourage the development of a local petrochemical industry including state job creation tax credits, investment tax credits, workforce retraining tax exemptions on manufacturing machinery, and research and development tax credits. While not discussed in this report, regulatory requirements in upstream oil and gas operations may also impact the ease of establishing a petrochemical manufacturing business, due to the limitations in geographic distribution of natural resources and the costs and delays associated with permitting and subsequent infrastructure buildout enabling subsequent transportation, storage, and pipeline distribution. Final investment decisions are influenced by many factors and not tax rates alone; however, U.S. taxes are significantly lower than other producing countries.

Exhibit VII-2. Corporate tax rates in leading NGPL and ethylene producing states (181) (183)

State	Corporate Tax Rate (2021)
Colorado	4.55%
Iowa	5.5–9.8%
Kentucky	5%
Louisiana	4-8%
New Mexico	6%
North Dakota	1.4–4.31%
Oklahoma	4–6% (171)
Pennsylvania	9.99%
Federal	21%
Gross Receipts Taxes (2020)	
Texas	0.333–0.75%

Other Impactful State Regulations

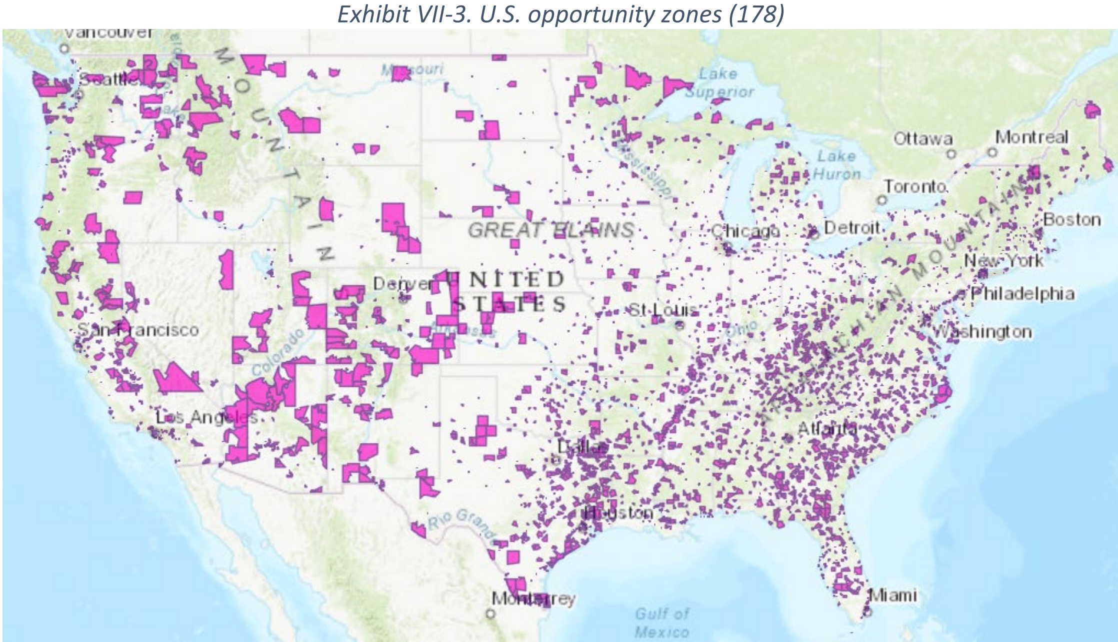
A final regulation to consider when examining state regulatory impacts on the U.S. petrochemical industry is the impact of consumer regulation on producers. California (CA) provides a useful case study; as the largest U.S. economy, California policies introducing specific labeling requirements, such as the California Recycling Market Development Act (172) and California's Proposition 65 (173), have a direct impact on petrochemical manufacturers who plan to sell to California end markets. Policies in California heavily support petrochemical reform that enables a transition toward a more circular economy, particularly with regard to the recycling and reuse of plastics. The impact of advancements in plastics recycling technology and adoption could have significant impact on customer demand for "virgin" feedstocks, specifically ethane and ethylene.

3. Promotive Petrochemical Policies

Domestic petrochemical manufacturers may benefit from the Research and Development Tax Credit (174), the Employer Tax Credits (175), Work Opportunity Tax Credit (176), and the Coronavirus Aid, Relief and Economic Security Act (177). Few of the federal tax incentives selectively benefit the petrochemical manufacturing industry, but rather provide general support for U.S. manufacturing.

U.S. opportunity zones allow businesses located in designated regions, and meeting specific requirements, to temporarily defer tax on capital gains if they invest their capital gains in a Qualified Opportunity Fund. Like Federal tax credits, Federal opportunity zones are not inherently specific to the petrochemical industry; however, opportunity zones do overlap with notable shale deposits, specifically the Permian Basin and the Marcellus-Utica shale plays (Exhibit VII-3) that feed their manufacturing operations that are in close proximity to where their feedstocks are produced.

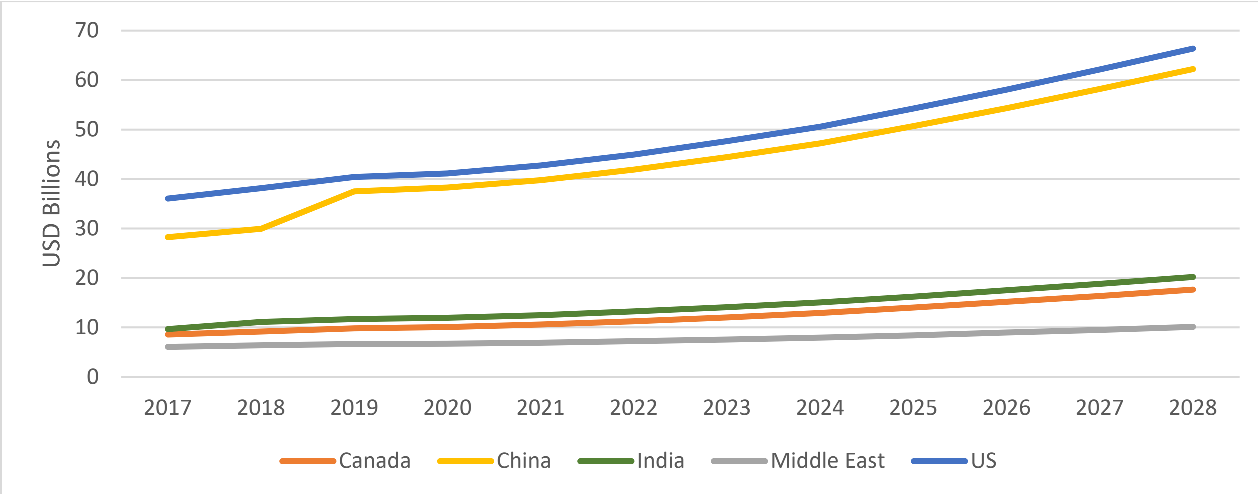
Exhibit VII-3. U.S. opportunity zones (178)



VIII. Country and Market Comparisons: Support for Petrochemical Industry in Other Countries

The following provides a brief assessment of key foreign governments' approaches to regulating and incentivizing domestic petrochemical industrial growth. Countries were selected as illustrations of approaches to government engagement with the petrochemical industry (Exhibit VIII-1). Canada has established specific policies targeting use of domestically produced ethane. China and India are reviewed as significant importers of U.S. ethane. Reviewing their petrochemical policy stances provides insights into opportunities and challenges U.S. producers may face in the short and long term. Ethane exporter Norway and ethylene exporter Saudi Arabia were selected as examples of U.S. market competitors in the ethane and ethylene markets to be further examined.

Exhibit VIII-1. Ethylene revenue forecast, by product, 2017–2028 (9)



1. Canada

Canada is the largest market for U.S. ethane exports and has a well-developed petrochemicals industry. According to EIA, the United States exported 33,768 million bbls of ethane (179) to Canada—accounting for approximately 27 percent of Canadian ethane consumption.

The province of Alberta alone has four ethane cracking plants, two of which have the world's largest combined annual ethylene output capacity (4.1 million metric tons) (9). In Alberta's Natural Gas Vision and Strategy (October 2020), the province set goals to become a top 10 global producer of petrochemicals (180). To reach this goal, the province established multiple programs including the Petrochemicals Diversification Program and Alberta Petrochemicals Incentive Program. The Petrochemicals Diversification Program provides a royalty incentive for petrochemical facilities, specifically those producing consumer materials such as plastics, fabrics, and fertilizers (181). The Alberta Petrochemicals Incentive Program provides direct government grants to projects that use natural gas, NGLs, or petrochemical intermediaries such as ethylene, propylene, and benzene, among others (182).

Canada recently established a CO_2 tax of $24 per metric ton of CO_2, and intends to increase to $135.33 per metric ton by 2030 (183). Major Canadian refineries and large emitters have incorporated carbon pricing into their business modeling. In October 2021, Dow Chemical announced a plan to build the world's first net-zero ethylene plant just outside Edmonton, Alberta, by expanding and retrofitting an existing facility with carbon capture technology. The new project is projected to add approximately 1.8 million tons of capacity to its existing facility by 2030, allowing it to produce about 3.2 million metric tons of low- or zero-carbon ethylene (184).

2. China

China is the world's second largest producer of ethylene, and its ethylene production continues to grow, as does its demand for ethane, including imported ethane. In 2018, ethylene production reached over 18 million metric tons. However, the growth of ethylene production is lower than the growth of market demand, and the gap between supply and demand is increasing, which drives the continuous expansion of the production capacity of the ethylene industry. In 2019, China's ethylene import volume was 2.51 million metric tons (27).

China's HGL production is rising and its demand for petrochemical feedstocks, specifically ethane, exceeds its rate of production, requiring continued imports. Between late 2020 and mid-2021, China announced numerous investments in petrochemical complexes. These included the Amur Gas Chemical Complex and the SABIC-China's Fujian Petrochemical Industrial Group Co., Ltd. joint-venture, both mega-petrochemical complexes requiring significant long-term access to stable feedstock supplies. In response, Chinese demand for imported ethane from the United States is forecast to increase nearly four-fold between 2020 and 2022, partially due to the Zhejiang Satellite Petrochemical Lianyungang steam cracker imports from the Nederland, TX, ethane terminal. The steam cracker in Lianyungang[44] is reported to be China's first petrochemical plant fed exclusively with ethane (185). Feedstock for the cracker is expected to ship through Energy Transfer's Nederland Terminal in Nederland, Texas, a joint venture between Satellite Petrochemical USA Corp[45] and Dallas-based Energy Transfer LP. A continued rise in Chinese imports of U.S. ethane is expected due to the Lianyungang cracker ethane feedstock requirements.

While Chinese ethane demand has increased, as of 2020, several steam cracker projects were under construction that require a combination of naphtha, LPG, and ethane, allowing the country to maintain flexibility in its array of petrochemical feedstocks (186). China's largest state-owned oil company, China National Petroleum Corporation, by way of its PetroChina Tarim Oilfield in northwest China, began an ethane from natural gas recovery project in August 2021. The facility was designed to process up to 10 billion cubic meters of natural gas annually, with an output of 366,000 tons of LPG, 762,000 metric tons of ethane, and 75,000 metric tons of stable light hydrocarbons per year (187).

During August 2019, amid the United States-China trade disputes, Chinese imports of U.S.-LPG dwindled to zero and Northeast Asian countries increased U.S. LPG import volumes. To partially circumvent the tariffs, China procured LPG from neighboring Northeast Asian countries through a swap market, paying a swap premium below the full 25 percent tariff. A similar swap market could provide China potential avenues to access tariffed NGLs from the United States, indicated by an

[44] The cracker is operated by Lianyungang Petrochemical Co. Ltd a subsidiary of Zhejiang Satellite Petrochemical Co. Ltd.

[45] Satellite Petrochemical USA Corp. is a U.S.-based subsidiary of the Chinese-based, Zhejiang Satellite Petrochemical Co. Ltd. Orbit Gulf Coast NGL Exports, LLC (Orbit) is the joint venture between Satellite Petrochemical USA Corp. and Energy Transfer LP.

increase in Japanese, Korean, or Taiwanese procurement of NGLs, as seen with LPG markets in 2019 (188).

Growth in the Chinese petrochemical industry may also be in response to the previously mentioned June 2015 MIC 2025 policy that indicates a plan to vertically integrate China's manufacturing supply chain to incorporate greater upstream and downstream capabilities (189). The MIC 2025 strategy also seeks to strengthen the Export-Import Bank of China's services for domestic manufacturers who export and may contribute to China's forecasted ethylene revenue growth through 2028. The MIC 2025 policy, natural gas subsidies, access to swap markets, and investment in direct access to cost-efficient U.S. ethane resources indicate that China will likely continue to seek opportunities to fully integrate its petrochemical supply chain.

3. India

India is actively seeking to develop its domestic petrochemicals industry. In 2020, India produced approximately 8.9 million metric tons of ethylene and is forecast to increase production by over 46 percent by 2028 (9). In 2019, the country announced the Make in India initiative under its Department of Chemicals and Petrochemicals (190). The policy establishes a minimum percentage of local content—the use of domestic suppliers, products, or services—for public procurements ranging from 50 percent in 2019 to 80 percent by 2025 (191).

4. Norway

Norway and the United States are the only countries that ship ethane internationally, and Norway occupies the number two position. Although Norway's ethane output has been declining, Norwegian steam crackers continue to operate due to the availability of U.S. ethane imports (46). Norwegian regulatory frameworks are not specifically supportive of new investments in extractive industries; however, the country's historic operations, existing petrochemical infrastructure, and emissions tax rates may lead to continued procurement of U.S. ethane over higher emitting feedstocks.

In 2020, Norway produced an average of 288,000 b/d of NGL (192). Most Norwegian NGPLs are produced at the Kårstø processing plant, north of Stavanger, Norway, which can process more than 3.1 bcf per day of wet natural gas and unprocessed condensate. The plant receives NGPLs from several fields on the Norwegian continental shelf. While the port of Kårstø is one of Europe's largest LPG gas export facilities and Norway's LPG exports continue to rise, the country's ethane output has gradually declined (46). Ethane production at Kårstø was previously shipped to petrochemical crackers at Rafnes, Norway, and Stenungsund, Sweden. Diminishing ethane output made it no longer sufficient for Ineos at Rafnes and Borealis at Stenungsund to operate their plants at full capacity. In March 2015, Ineos began importing ethane from the United States to the Rafnes plant, where it is used to produce ethylene. U.S. ethane exports to Norway, averaging approximately 25,000 b/d, have also allowed the Kårstø terminal to expand export destinations (46). Starting in mid-2017, Norway began exporting ethane, potentially supplied in part by the

United States, to the TotalEnergies SE Antwerp petrochemical cracker in the Netherlands at an annualized rate of nearly 10,000 b/d (46).

5. Saudi Arabia

Saudi Arabia is a large ethylene exporter, but relies on imports of ethane, including shipments from the United States (193). Exports of commodity group 3901, "Polymers of ethylene, in primary forms," amounted to 3.83 percent of total exports from Saudi Arabia (cumulative merchandise exports from Saudi Arabia in 2019 totaled $251 billion). In 2019, Saudi Arabia exported $11.1 billion in ethylene polymers. The main destinations of Saudi Arabia exports of polymers of ethylene were China (19.8 percent), Singapore (19.1 percent), Malaysia (7.39 percent), United Arab Emirates (6.15 percent), and Belgium (4.35 percent) (45). That same year, Saudi Arabia's second largest supplier of imported "polymers of ethylene, in primary forms" was the United States (12.8 percent) (45).

Seventy percent of Saudi Arabia's export earnings come from petroleum and petroleum derivatives (193). Acknowledging a need to diversify its economy, in 2016, Saudi Arabia introduced Vision 2030 (194). The strategy supports leveraging Saudi Arabia's existing petrochemical capabilities to further develop and add value to its domestic petroleum value chain through investments in downstream industries. State oil and gas company Saudi Aramco's consortium with French-owned TotalEnergies SE and efforts to build a 1.5 million metric ton per year mixed-feedstock cracker provides an example of this economic diversification strategy (195). The shift from raw material supplier to value-added supplier introduces further competition for U.S. ethane-fed steam crackers seeking export markets for ethylene and derivatives.

Saudi Arabia does have domestic ethane-producing assets; however, operational challenges and limited supply have led to ethane supply shortages causing the temporary shutdown of multiple Saudi Arabian ethane-fed steam crackers in 2021 (196). Saudi Arabia's state-owned chemical manufacturing company, SABIC, through a joint venture with ExxonMobil, is set to begin operations of a 1.8 million metric tons ethane steam cracker on the U.S. Gulf Coast. Saudi Arabia's decision to invest heavily in one of the world's largest ethane-fed steam crackers, and locating it in the United States, is indicative of the economic competitiveness of U.S. ethylene production from U.S. domestically sourced ethane feedstocks. Saudi Arabia currently does not have a carbon tax; however, the country's Public Investment Fund in collaboration with the Saudi Tadawul Group (Saudi Stock Exchange) has announced plans to establish a voluntary exchange platform for carbon offsets and credits within the Middle East and North African region (197). The impacts of the exchange are currently unknown but may provide incentive for lower emission feedstocks for Saudi Arabia's growing petrochemical industry.

6. Country Comparison Take-aways

There is little evidence indicating foreign government involvement in encouraging the domestic use of ethane over export, because the financial benefit of exporting versus upgrading is market dependent. While ethylene revenue in major petrochemical hubs is forecast to continue its ascent, only Canada and India have seen ethane exports grow in recent years (80). Ethane producing countries, like Saudi Arabia, do not export a significant amount of domestically produced ethane, and instead manufacture ethylene and ethylene derivatives for export. The decision to domestically crack ethane and export the value-added ethylene produced rather than the feedstock is likely based on the limited export market for ethane. Alternatively, other top petrochemical producing countries, like Norway, have experienced declines in their production of ethane, leading to increased demand for U.S. imports. Downstream petrochemical hubs with steam cracking capabilities, like China, are not seeking to export ethylene but rather to domestically consume ethane and ethylene for production of consumer products, like plastics, for eventual domestic and international sale.

IX. Environmental Impacts and Stakeholder Concerns

1. Overview

Plastics, manufactured from ethylene and its derivatives, are integral to many commercial and industrial applications as well as countless consumer products. Plastics present many challenges from a sustainability perspective, including waste and resource management challenges that accompany these activities and end uses—from GHG emissions and air pollution tied to manufacturing operations to litter and ocean debris, expanding landfill accumulation, and low recycling rates downstream of plastics production. However, in some cases, plastics are the best-suited material for existing needs and cannot be readily replaced by other materials using current technologies.

This section focuses on some of the environmental impacts of ethane development once the resource arrives at a petrochemical manufacturing facility as well as when it is transported, stored and distributed via pipeline systems leading up to customer delivery including export of either ethane or finished products (i.e., ethylene derivatives). As such, the environmental issues covered in this report largely focus on petrochemical plant air emissions (including GHGs) and chemical exposure issues.

In addition, President Biden's Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," directs federal agencies to prioritize opportunities for stakeholder engagement, ensure environmental justice, and facilitate economic opportunities for disadvantaged communities that have historically experienced a disproportionate share of the adverse health, environmental, and climate impacts of pollution from industrial operations—including such activities as fossil energy production and petrochemical manufacturing. Consistent with this Executive Order, DOE hosted a virtual public meeting in August 2021 to engage a wide range of stakeholders, including frontline community residents, environmental advocates, and industry representatives. Feedback from these stakeholders helped DOE develop a more balanced analysis of the community impacts of ethane development. To learn more about the virtual public meeting DOE hosted last August and the diverse perspectives that were shared, please refer to Appendix A.

This report does not directly address the environmental impacts of upstream oil and natural gas development, nor does it focus on the pollutants and risks generated by such activities. DOE and the Environmental Protection Agency (EPA), however, have previously published reports on these topics.[46]

- The Secretary of Energy Advisory Board's Shale Gas Production Subcommittee published a report in 2011 describing measures that could be taken to reduce the environmental impacts of and to help assure the safety of shale gas production. It included twenty recommendations for implementation by federal and state agencies, and by industry.

- DOE's 2014 *Addendum to Environmental Review Documents Concerning Exports of Natural Gas from the United States* was a literature review of existing studies and analyses on topics including water use and protection, air quality, greenhouse gas emissions, land use impacts, and induced seismicity.

- EPA's 2016 report *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources* was a review of scientific literature and data on the possible impacts on drinking water resources of activities including water withdrawals, chemical mixing, injection of hydraulic fracturing fluids into production wells, and wastewater management.

This report also does not address downstream issues associated with end use and final disposition of products derived from ethane and ethylene, including plastics.

A. Emissions Associated with Petrochemical Facilities

This section will cover the four primary air pollutants that are of greatest concern in steam cracker operations: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), VOCs, and CO_2, and will address some emission reduction strategies in use or under consideration.

Sulfur Dioxide

SO_2 is a colorless, toxic gas created from the combustion of sulfur or materials that contain sulfur. As an air pollutant, SO_2 in high enough concentrations poses significant risks and potential adverse impacts to human, plant, and animal health. Short-term exposure to SO_2 can harm the respiratory system, making it difficult to breathe. Asthmatics, especially children, have an increased sensitivity to SO_2 (198). According to the U.S. Department of Health and Human Services, the threshold for

[46] The 2011 report by the Secretary of Energy Advisory Board's Shale Gas Production Subcommittee is available at https://www.energy.gov/sites/prod/files/90day_Report_Second_11.18.11.pdf; DOE's 2014 *Addendum to Environmental Review Documents Concerning Exports of Natural Gas from the United States,* is available at https://www.energy.gov/sites/prod/files/2014/08/f18/Addendum.pdf; and EPA's 2016 report *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources,* is available at https://www.epa.gov/hfstudy.

harmful SO_2 exposure is 100 parts per million (ppm). Although ethane cracker plants emit SO_2, their emissions are significantly below that threshold. According to EPA, CAA national emissions control programs have had a significant impact on declining U.S. SO_2 emissions, which fell by 82 percent between 2000 and 2016.

Petrochemical plant operators utilize different technologies to reduce SO_2 emissions, including dry sorbent injection (DSI). DSI not only effectively removes SO_2 but can remove other harmful pollutants like hydrochloric acid. EPA testing has shown that effective DSI systems can remove over 80 percent of SO_2 from waste streams prior to being emitted into the atmosphere (199). Babcock and Wilcox, a global leader in providing energy and environmental management technology solutions, has developed DSI systems for petrochemical manufacturers, coal-fired plant operators, and other industrial facilities, providing affordable, air emissions control technology solutions that efficiently capture and control SO_2 and other acid gases (whether separate or combined) emitted from boiler operations (200).

Wet scrubbers are another commonly used alternative to reduce SO_2 emissions. They use a sorbent slurry, typically comprising lime or limestone, which is injected into the gas to effectively scrub gas of its SO_2 content. Commercial and governmental efforts have continued over the past few decades to improve the efficiency of wet scrubbers—i.e., removing over 95 percent of SO_2 from a flue gas stream—and to lower operating costs (201).

Nitrogen Dioxide

NO_2 is a toxic gas that is reddish-brown at temperatures above 70.2 °F and becomes a yellow-brown liquid below 70.2 °F (202). Of all NOx gases, NO_2 is the one most commonly found in steam cracker emissions. Chronic exposure to NO_2 can adversely affect the respiratory system of healthy individuals, including airway irritation and inflammation, and cause further harm for people with asthma. Although ethane crackers emit NO_2, their concentrations are well below levels that, if reached, would endanger human health (150 ppm) (203).

Petrochemical plant operators can now reduce NO_2 emissions with the use of flameless oxidation, a process where flue gas can be run through a preheated and inert ceramic media bed, transferring enough heat to decompose NO_2 while simultaneously remaining under the flammability temperature limit of the gas. Furthermore, the oxidation process decomposes the NO_2 into the following products: N_2, water vapor, and CO_2, all of which are less harmful and toxic on a ppm basis when compared to NO_2. Flameless oxidation is a highly effective approach to this type of emissions reduction, capable of decomposing over 99 percent of the NO_2 from a flue stream (204).

Volatile Organic Compounds

VOCs are organic chemicals commonly found in petrochemical manufacturing operations that have a high vapor pressure at ambient temperatures (i.e., a low boiling point). This means an increased number of the chemical's molecules evaporate, a trait called "volatility." Common sources of VOCs include crude oil and condensate, NGLs, solvents, sealants, aerosols and paints. VOCs are a common pollutant that can be found in household products, building materials, and office materials. Chronic exposure to VOCs can lead to the following health effects: irritation (in the eyes, nose, and mouth), headaches, nausea, dizziness, liver damage, kidney and central nervous system impairment, and allergic reactions when coming into skin contact. More notably, EPA reports that, "some organics can cause cancer in animals, [and] some are suspected or known to cause cancer in humans" (205).

Carbon Dioxide

Ethylene cracking requires enormous amounts of energy as temperatures reach over 800°C (1472°F) in the furnaces. This heat is generated from the combustion of fossil fuels, which generates GHG emissions. According to EcoCatalytic, a company seeking to develop more sustainable methods for ethylene production and use, ethane cracking generates about 1.5 metric tons of CO_2 for every metric ton of ethylene produced. Steam crackers contribute 0.87–1.04 percent of CO_2 emitted nationally, and 3.00–3.60 percent of the total volume of CO_2 emitted by the United States industrial end-use sector (206).

Some petrochemical manufacturers are looking at ways to reduce CO_2 emissions and even develop "net-zero" facilities. One such development involves the Dow Chemical Company, which has announced its intention to develop the very first net-zero, carbon emissions petrochemical manufacturing facility in the world. In general, carbon capture technologies provide opportunities for steam cracker plants to lower CO_2 emissions, both for future implementation during plant construction, as well as through retrofitting existing plants. While significant funding and research has been allocated toward carbon capture and storage (CCS), by DOE and the NETL as well as by industry, no U.S. steam cracker has fully implemented operational CCS. One of the largest challenges remains the high cost of implementation and operation as well as the issue of carbon storage, or more specifically, how plant operators should dispose of or utilize the captured CO_2.

An emerging technology option that could be used in steam crackers is cryogenic carbon capture. Cryogenic carbon capture cools the flue gas to -140°C (-220°F) to deposit the gas into a solid. At this temperature, the CO_2 and other pollutants are frozen while the innocuous molecules in the flue remain gaseous, allowing for a simpler and more cost-effective separation of products (207). An additional benefit of cryogenic carbon capture is its cheaper cost, taking on less than a 15 percent parasitic load and costing less than $30 per ton of captured carbon. Using cryogenic carbon capture has additional applicability for steam crackers as the technology also removes SO_2 and NO_2 throughout the deposition process (208). While this developing technology is promising, cryogenic carbon capture has only been applied to coal-fired power plants to date, and further research and development is needed to understand the modular applicability to steam cracker operations (207).

Another approach industry is considering to lower emissions from steam crackers is to change the production process of ethylene. The three primary technological opportunities for lower emission ethylene production are deploying electric ethylene furnaces, producing ethylene from CO_2, and using catalytic routes to produce ethylene. Companies like Shell and Dow have announced their efforts to create electric furnaces that would harness the necessary electricity from clean, renewable sources to provide the heat for cracking ethane feedstocks, which could reduce emissions at plants by up to 50 percent. However, the intermittency of renewable energy technologies remains the primary challenge of this developing technology.

Companies like Opus 12 and Braskem are investing in research to create ethylene from CO_2 that would otherwise be emitted, but the technology remains expensive relative to standard cracking, up to four times the cost per ton of ethylene produced. Dow has successfully demonstrated the catalytic conversion of propane to propylene on a commercial level and has determined that the same catalytic technology is possible with converting ethane to ethylene. This technology could reduce emissions by up to 40–50 percent, but extensive work is still needed to properly convert and apply the catalytic technology for it to work with ethane to ethylene conversion (209).

2. Regulatory Opportunities

Stakeholders (including environmental organizations and members of local communities) have suggested several opportunities for both legislative and regulatory changes that could improve local environmental conditions for communities near petrochemical facilities. These include:

- Modifications to current industrial flaring regulations
- Updating and expanding emissions reporting requirements
- Increased funding for environmental oversight and enforcement

A. Modifications to Current Industrial Flaring Regulations

Industrial flares are employed at petrochemical plants to combust excess waste gases that arise during manufacturing processes—activities that generate smog-forming VOCs as well as benzene and other air pollutants that create exposure risks for residents, workers, and visitors to adjacent communities. Furthermore, when flaring devices fail, they emit methane, which creates climate change risks and impacts. Although EPA has the legal authority under the CAA to review industrial flaring guidelines, these regulatory requirements have not been revisited by EPA in over three decades (210).

As EPA prepares to undertake new CAA rulemakings focused on oil and natural gas, and associated environmental protection and climate mitigation opportunities along the value chain (including ethane fed steam cracking), stakeholders have suggested that the agency reconsider and make more robust the industrial flaring regulations now in place. Specifically, EPA should determine how these requirements might be modified to limit potential environmental impacts and risks—from increased air pollution to GHG emissions contributing to the accelerating rate of climate change.

B. Updating and Expanding Emissions Reporting Requirements

Stakeholders have noted that one of the most difficult challenges in accurately estimating the air emissions footprint of these manufacturing plants is identifying and separating petrochemical sector emissions from an aggregate collection of numbers reported by law under different categories to EPA. Coming up with precise and accurate emissions estimates solely from petrochemical manufacturing within these industrial site boundaries is inherently difficult for various reasons (211). For example, emissions tied to ethane cracking often represent only a subset of the pollutants emitted from a larger industrial complex, such as an elaborate U.S. petroleum refining operation or a massive chemical plant where the production of ethane and other petrochemical feedstocks are but one part of the total production inventory of emissions generated within the boundaries of the site.

In addition, there are missed opportunities under current federal regulations as prospective emissions from newly permitted facilities, once constructed, often produce emissions of various pollutants that are at a level below current CAA thresholds that would trigger the law's reporting requirements for major sources. If those unreported emissions, the ones that fall below a given CAA regulatory threshold, were quantified and aggregated, they would reveal a significant missed opportunity for emissions reduction within the U.S. petrochemical manufacturing sector.

Stakeholders have also suggested that EPA could issue new requirements to monitor and subsequently report emissions from plant shutdown, maintenance, and startup, as well as from unplanned incidents that arise and lead to uncontrolled emissions for some duration of time—often an extended period (for example, days rather than hours). Given advancements in handheld, fenceline, and aerial emissions monitoring technologies and approaches (from drones to aircraft), petrochemical manufacturers have more opportunities than ever before to invest in, monitor, and reduce their GHG and other air emissions.

In response to calls from various stakeholders to either modify or create new CAA regulatory requirements to begin to close this reporting gap, EPA may consider proposing new emissions monitoring, quantification, and reporting requirements for U.S. petrochemical manufacturing operations. For example, EPA could concentrate monitoring efforts on the exponential emissions growth—of VOCs, NO_2, SO_2, HAPs, particulate matter (PM), etc.—accompanying rapid and significant economic growth in fossil fuel-related industries (including petrochemical manufacturing) dating back to the onset of the shale revolution in the early 2000s.

According to the Environmental Integrity Project (EIP), a national environmental organization, additional regulatory opportunities for shrinking the emissions footprint of ethane cracking and petrochemical manufacturing in general could include the following:

> EPA needs to require much more accurate methods to monitor emissions of greenhouse gases and other pollutants from leaking tanks, process equipment, and

> flares with poor combustion efficiency … Permits should require fenceline monitoring to help identify and reduce dangerous concentrations of toxic gases before they cross plant boundaries. These systems would allow community members and health and emergency professionals access to important information about the health impacts of air emissions, as well as provide companies with information needed to correct otherwise invisible or undetected problems at a plant that result in considerable emissions of harmful air pollutants and greenhouse gases (212).

C. Increased Funding for Environmental Oversight and Enforcement

Stakeholders have suggested that Congress and state legislatures, respectively, should consider allocating additional budgetary resources for enhancing Federal-state partnership efforts focused on advancing environmental protection and climate mitigation efforts—primarily through increased regulatory oversight, from emissions monitoring to compliance assurance, training, and inspections and enforcement. According to a 2019 report by EIP, key states where petrochemical manufacturing activities are on the rise (including Texas, Louisiana, and Pennsylvania) have steadily slashed government funding available for environmental oversight, technical assistance, and regulatory enforcement (213). These budgetary reductions have left far too few regulatory resources for state regulatory bodies to successfully staff essential environmental protection and inspection efforts, oversight activities essential to keeping pace with expanding petrochemical manufacturing operations within their respective boundaries.

At the national level, reductions in EPA appropriations to help fund environmental monitoring and control efforts—for overseeing petrochemical and other industrial sector operations—declined by approximately 16 percent (when adjusted for inflation) from 2008 to 2018 (213). Notably, this decade of decline in federal spending occurred during the height of the shale gale, economic growth that fueled the rapid expansion of oil and gas production and petrochemical manufacturing as well; however, a reversal of these funding declines may be on the horizon.

D. Emissions Monitoring

Deploying fenceline monitoring systems throughout neighboring communities—to alert plant operators to how their emissions controls are functioning across their facilities—could help operators ensure air quality levels that don't impact human health and safety. In a specific response to Shell's PA plant now under construction, the Clean Air Council—an environmental organization serving the Mid-Atlantic Region—states:

> An active fenceline monitoring system is essential for determining what emissions are leaving the facility and escaping into the community. Monitoring can be done for various pollutants of concern, including volatile organic compounds and hazardous air pollutants. Fenceline monitoring serves as an important early response system. With this technology, Shell and the community will be able to

> identify the exact amount, location, and type of emissions coming from the facility into nearby neighborhoods. These systems are becoming more and more common around refineries and chemical manufacturing facilities throughout the nation. If Shell wishes to be a 'good neighbor,' they should at least implement the same technology used in their other facilities across the nation; technology that will stop leaks and protect public health (214).

In what could become a landmark case for future steam crackers, Shell was engaged in two-years of litigation with both the regional Clean Air Council and the EIP, a national environmental organization, over emissions transparency. In 2015, those two environmental groups appealed Shell's air permit and requested that the company provide greater air monitoring measures to maintain safe air quality in neighboring communities. Shell settled the lawsuit by agreeing to install continuous air monitors across the fenceline boundaries of the Beaver County plant (215).

New innovations in air quality monitoring have been piloted in major cities around the world. One technology that has been developed by the Environmental Defense Fund (EDF) and Google is working to provide mobile sensors to provide real-time air quality insights in major cities, though nothing indicates that the technology could not be implemented in smaller communities in close proximity to crackers. London, United Kingdom; Houston, Texas; and Oakland, California, are cities around the globe that have participated in pilot programs to utilize stationary sensors as well as mobile sensors that are currently deployed on Google Street View Cars (216). The efforts in London, which are unfolding under the auspices of the larger Breathe London organization, are to date the most developed part of a program that also extends to providing citizens with their own personal sensors. The sensors Breathe London provides to interested citizen are solar powered with a 15-day internal battery, include multi-network cellular connectivity, and provide a simple user interface to visualize air quality (217).

E. Non-Environmental Impacts on Local Communities

Building a new steam cracker can create jobs and economic growth for the surrounding communities. The Shell complex in Beaver County, Pennsylvania, has already created 7,500 temporary jobs across the past six years of construction (218). In addition, it is estimated that American steam cracker facilities can create anywhere from 350 to 1,200 permanent jobs not related to construction (219). Shell's plant in Beaver County is projected to create at least 700 full-time jobs in the county (220).

Because cracker plants require hundreds of acres of land to operate, new facilities generally need to be in smaller towns and more rural areas. Some small surrounding towns do not have the existing transportation infrastructure to efficiently handle the influx of workers as these plants are constructed and become operational. Using the Shell plant in Pennsylvania as an example of future opportunities, the new employees at the Shell plant will place traffic burdens on the Monaca and Potter Township communities, which currently have populations of 5,521 and 574, respectively.

With a proportionately large influx of people moving into these small communities, both the population growth and the economic stimulus to the community will impact education, local real estate, and the economic performance of the surrounding communities.

The land footprint of the plants will also affect the local natural environments. The Shell plant in Pennsylvania occupies 386 acres, and the land disturbance in the surrounding ecosystem will be significant with such a large area having been leveled and subsequently built up (221) (222). With the construction of Shell's plant in Pennsylvania, part of the agreement for their acquisition of the land is the planned remediation from the zinc smelting plant that previously occupied the land, a one-time EPA Brownfields site. Under Pennsylvania's Land Recycling (Act 2) program, Shell has created and submitted a comprehensive plan, which was approved by the Pennsylvania Department of Environmental Protection. Additionally, Shell developed and successfully submitted a plan to the Pennsylvania Department of Environmental Protection for water remediation efforts and is collecting all storm water that would be potentially contaminated during construction and is treating it before discharging the water. Lastly, all groundwater use at the site is restricted under an environmental covenant following the completion of Act 2 of Pennsylvania's Land Recycling Program (223).

F. Plant Safety

Steam cracker facilities have operational risks common to all petrochemical facilities. These steam cracker facilities sited throughout the United States have a strong history of safety, with the sole accident in 20 years occurring on June 13, 2013, at the Williams plant in Geismar, Louisiana. Two workers died from the explosion and an additional 114 were injured (224). According to the U.S. Chemical Safety and Hazard Investigation Board, the cause of the incident was described as follows:

> The incident occurred during nonroutine operational activities that introduced heat to a type of heat exchanger called a "reboiler" which was offline, creating an overpressure event while the vessel was isolated from its pressure relief device. The introduced heat increased the temperature of the liquid propane mixture confined within the reboiler shell, resulting in a dramatic pressure rise within the vessel due to liquid thermal expansion. The reboiler shell catastrophically ruptured, causing a boiling liquid expanding vapor explosion … and fire (225).

The Chemical Safety and Hazard Investigation Board's findings emphasized that Williams' safety culture had to be improved, suggesting the need for employing tools like process hazard analyses, management of change reviews, and pre-startup safety reviews. Several plants have implemented the findings from this report, producing improved plant safety and zero casualties since 2013.

X. Concluding Remarks

The United States' significant natural resource endowment of ethane, a high yield cost-effective petrochemical feedstock, has secured the country's position as a critical player in the global plastics supply chain. U.S. volumetric NGPL production is anticipated to increase by 20 percent over the next 3 decades, with ethane production continuing to account for over 40 percent of U.S. NGPLs by volume through 2050.

What is the potential value (direct investment, direct and indirect job creation, tax generation, etc.) of domestic manufacturing growth based on available domestic ethane supply?

Studies on the economic impacts of U.S. steam crackers on employment show that counties containing steam cracker plants have approximately 10.8 percent higher per capita employment and 12.8 percent higher per capita earnings than those without steam cracker plants. Results also show that bordering counties have negative impacts to net employment and positive impacts to earnings. However, certain industries in bordering counties experience positive impacts to net employment such as petrochemical and plastics manufacturing despite an overall drop in net employment. There is also statistical evidence that earnings in counties with a steam cracker increase as employment in petrochemicals, plastics, and resins manufacturing increases. For example, the Beaver County project in Pennsylvania is projected to generate $73 million from construction and $683 million from operations in state income taxes (21) (22) (23).

There is conflicting evidence that petrochemical facilities will provide the benefits evidenced in these studies. Reports from The Institute for Energy Economics and Financial Analysis and ORVI call into question whether new petrochemical plants will continue to be profitable in the long term due to increasingly prevalent market barriers, and whether they will provide the economic and employment benefits that were projected. Economists and engineers have also voiced concerns through a letter to governors Tom Wolf of Pennsylvania, Mike DeWine of Ohio, and Jim Justice of West Virginia as to whether petrochemical plants will provide the economic and employment benefits that were predicted due to economic and technological complications such as declines in investment and manufacturing complications (24) (25) (26).

To provide additional information on the potential value of domestic manufacturing growth in response to increased ethane availability, an analysis was performed to estimate the potential number of jobs supported in industries identified as likely to be involved in the ethane value chain. Results of the analysis suggested nationally, for every million dollars in output generated by industries involved in the ethane value chain, 1–13 jobs could be supported depending on the industry under consideration.

Given demonstrated historical investment in ethane-based domestic manufacturing, and assuming it will continue given sufficient projected ethane supply, what is the opportunity cost of exporting available ethane supply in support of foreign manufacturing?

To estimate the opportunity cost of exporting available ethane in support of foreign manufacturing, the potential number of jobs created and amount of labor income generated were compared across a series of two competing scenarios. Data for the analysis included modified versions of the projected IO accounts and estimated values for labor income and employment (jobs) by industry provided by BLS.

Under the first scenario, increased domestic production of ethane was assumed to be used to meet export demand and ethane export demand was assumed to increase by 20, 30, and 40 percent from its projected base amount over the forecast period of 2025–2029. Under the second scenario, increased domestic production of ethane was assumed to be used by domestic producers to manufacture three ethylene derivatives: LDPE, LLDPE, and HDPE. The manufacturing of the ethylene derivatives by domestic producers was assumed to replace the need to import these derivatives by 30, 60, and 90 percent from their projected amounts over the forecast period (2025–2029). The difference between the number of jobs created and the amount of labor income generated between the first and second scenario provided the estimated values for the opportunity cost calculations performed.

Results suggested the potential opportunity cost (measured by the difference in the number of jobs created and labor income generated) from exporting available ethane instead of using it domestically to manufacture the ethylene derivatives LDPE, LLDPE, and HDPE, included $142,000–674,000 in labor income (chain-weighted 2012$) and 1,350–7,439 jobs (direct and indirect jobs combined).

What is the impact of progressive import tariffs (such as those imposed by China where value-added goods are tariffed at higher rates than the raw materials used to make them are tariffed) on ethane, ethylene, and polyethylene?

China is actively working to increase self-sufficiency across the petrochemical industry, including the ethylene value chain, in order to bolster supply security and add economic value. China has imposed and adjusted tariffs on polyethylene imported from the United States multiple times since the onset of the trade war in 2018. U.S. polyethylene exports to China have decreased significantly due to the hikes in tariffs that reached 25–30 percent for some derivative products.

Chinese imports of U.S.-produced LLDPE and HDPE reached a peak of 560,000 metric tons per year in 2018 but dropped by 60 percent to 225,000 metric tons per year in 2019 (144). In the first half of 2019, the U.S. polyethylene industry successfully compensated for the decrease in Chinese imports of HDPE and LLDPE by raising exports to other destinations such as Europe, Turkey, Malaysia, Singapore, and Vietnam (31). Exports to China generally result in better margins as higher export volumes support greater economies of scale and reduced logistics costs. Shifting exports to smaller markets to compensate for loss of export volume to China results in higher trader and distributor fees. A sustained shift of U.S. export flows away from China, however, could lead to decreased profitability for U.S. chemical manufacturers (30).

Could these strategies by other countries result in capital flight from the United States to other countries where U.S. raw materials will be upgraded to higher value-added goods and sold back to America?

Differential tariffs on raw materials or feedstock versus final products are imposed by countries to incentivize the development of a sector on the domestic territory, i.e., to attract foreign companies to invest in domestic productive capacity. This has also been China's strategy in the development of various sectors including the petrochemical manufacturing sector. Globalization has allowed for increased specialization where different parts of a product can be produced in different areas of the world. Increased specialization allows firms to benefit from advantages, which, in the case of China, include cheap and abundant labor. However, companies typically also take greater risks by moving some of their operations overseas.

One major risk, for example, is the sudden and unpredictable change in tariffs imposed by the host country. This risk can be mitigated through trade agreements. Several studies found a robust link between a sharp decline in U.S. manufacturing employment and the United States granting PNTR to China (36) (37). The PNTR came into effect in 2001 when China joined the WTO. The PNTR permanently set U.S. tariffs on Chinese imports at Normal Trade Relations levels, thereby significantly reducing the risk of tariff changes on U.S. companies producing in China. The PNTR encouraged further specialization in the industry with U.S. investments being more closely aligned with the U.S. sector's comparative advantage, for example, the use of skill intensive production technologies that are less labor intensive (36).

In recent years, a reshoring trend (the return to the domestic territory of U.S. businesses that previously moved operations offshore) has been observed (38). This trend is driven by a variety of factors that include the rising costs of labor in host countries; the availability of new digital technologies in information, communication, and automation processes; and exchange rate fluctuations, shipping delays, supply chain issues, and political risk in host countries.

Reshoring has contributed to a slight recovery in manufacturing jobs in recent years. After dropping to a record low of 11.45 million in 2010, manufacturing employment has been increasing through 2020 to 11.5 million, despite a slight decrease in 2020 due to the global COVID-19 pandemic (38). Globally, flows of FDI have stagnated in recent years due to reduced flows from advanced economies to developing economies (particularly Asia). However, flows of FDI among advanced economies, such as the United States and Europe, that are concentrated in manufacturing sub-sectors have increased by about 32 percent. Most notable is the 60 percent increase in FDI flows in chemical product manufacturing from 2016 to 2017 (39).

Throughout the COVID-19 pandemic, plastics manufacturers have experienced severe shortages for raw materials while demand for plastics has continued to surge. The price of many plastics feedstocks has increased substantially, including a 70 percent increase in the price of PVC, a 170 percent increase in the price of epoxy resins, and a 43 percent increase in the price of ethylene. As ethane is the primary feedstock for plastics production in the United States, and because it is relatively low cost and plentiful, reshoring can provide distinct advantages (41). These domestic advantages for the U.S. chemical industry are exacerbated by the fact that most of its international competitors rely on naphtha as feedstock (43). The U.S. relative cost advantage for the chemical industry is also expected to continue through at least 2024 as oil prices are expected to remain at least seven times higher than those for ethane (43).

The Biden-Harris Administration has been addressing the challenges facing the manufacturing sector through policies designed to improve U.S. competitiveness relative to China and other competitors. Several legislative changes such as the Strategic Competition Act of 2021, the Endless Frontier Act, and the CHIPS for America Act, all part of the Innovation and Competition Act of 2021, were passed by the U.S. Senate in early June 2021. When signed into law, these bills would allocate approximately $200 billion in new spending, increase Federal financial support for strategic sectors, and emphasize an increase in resources committed to research and development and capital-intensive manufacturing (44).

Have other countries enacted policies around use versus exporting purity ethane?

Specific governmental policies requiring the domestic use versus exportation of ethane were not found during the development of this report. However, outside of the U.S., some ethane producing countries, like Saudi Arabia, do not export a significant amount of their domestically produced ethane, and instead convert the feedstock into ethylene and ethylene derivatives for export. In 2019, exports of polymers of ethylene accounted for 3.83 percent of Saudi Arabia's total annual exports. The decision to domestically crack ethane rather than export it is likely based on the country's limited export market for ethane and the strength of Saudi Arabia's domestic petrochemical industry. However, Saudi Arabia's Vision 2030 (194) encourages the development of greater downstream capabilities, indicating the country prefers exporting value-added petrochemicals, such as ethylene, rather than bulk feedstock such as ethane.

Alternatively, other top petrochemical producing countries, like Norway, have experienced declines in their production of ethane, leading to increased demand for U.S. imports. Norwegian petrochemical firms continue to both produce ethylene domestically and export purity ethane (46). In closing, from the research conducted, there is little evidence indicating foreign government involvement in encouraging the domestic use of ethane over export as the financial benefit of exporting versus upgrading is market dependent.

Additional Conclusions About U.S. Ethane

To date, approximately 80 percent of U.S. annual ethane production is consumed by the domestic petrochemical industry. Ethane exports are expected to grow by 20 percent between 2020 and 2022 to meet growing Chinese, European, Canadian, and Indian demand. However, U.S. production is expected to increase at a greater rate than exports, providing continued supply availability for the growing U.S. petrochemical industry. The world's top ethylene consumers, including China and India, are investing in expanding domestic ethylene production. While foreign ethylene-suppliers, including Saudi Arabia, are expected to increase exports over the next decade, Chinese tariff regimes and Indian local content policies provide preference for procuring feedstocks over ethylene derivatives. Countries like China and India are expected to continue to be net importers of both ethane and ethylene to meet their growing manufacturing needs. Moreover, international emissions reduction targets may further increase demand for U.S. ethane in European Union petrochemical manufacturing hubs, like Germany and Belgium, which are looking to decrease the industry's emissions footprint by transitioning away from high emitting feedstocks.

The ethane life cycle does produce lower emissions than crude oil and coal-based petrochemical feedstocks. However, ethane-fed steam crackers still produce HAPs, including NO_2, SO_2, VOCs, and CO_2, which cause community and global harm through reduced air quality and increased atmospheric presence of GHGs associated with global climate change. Further domestic investment in upgrading ethane to higher-value compounds, namely ethylene, should consider the potential economic value as well as local, national, and global environmental impacts. Through effective monitoring of pollutants, neighboring communities can stay informed should emission levels ever reach unsafe conditions and require plant intervention. U.S. chemical companies are also investing in technologies that may help achieve greener ethylene production to help meet net-zero ambitions (226). Large steam crackers and petrochemical complexes have a direct impact on communities that extend beyond emissions and environmental impacts, including local job and supplier development, as well as regional economic stimulus.

Global consumer preferences have begun to reorient the plastics industry to emphasize waste reduction, biodegradable or reusable packaging, growth in the circular economy, and investment in advanced recycling technology. Governments, including California and European Union member states, have enacted policies to drive reduction in demand for raw feedstocks in the plastics industry, which may have long-term effects on ethane demand. While investment in advanced plastics recycling technologies is actively underway, including a $27 million DOE project (2020) (227), meeting the globally rising demand for ethylene and ethylene derivatives will require continued large-scale production from virgin feedstock. Advancements in ethane-fed steam crackers provide a near-term opportunity to transition toward emission reductions in the petrochemical industry, both domestically and internationally, and may drive greater market demand for U.S. ethane.

Appendix A: August 2021 DOE FECM Virtual Public Meeting and Listening Session: "Understanding the Impact of Ethane Development on the Environmental and Health Conditions for Local Communities as well as the Global Carbon Budget"

1. Listening Session Highlights

On August 24, the United States (U.S.) Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM) held a Virtual Public Meeting and Listening Session, focused on the following topic: "Understanding the Impact of Ethane Development on the Environmental and Health Conditions for Local Communities as well as the Global Carbon Budget." The purpose of the meeting was to obtain data, information, and perspectives from stakeholders on the following topics: local, environmental, health, and community impacts associated with petrochemical manufacturing, including ethane crackers and pipelines; health and safety risks to local communities from accidents and system failures associated with petrochemical facilities and supporting infrastructure along the value chain; greenhouse gas (GHG) emissions from such petrochemical facilities and supporting infrastructure; and opportunities to reduce the environmental, safety, and health impacts locally and across the value chain, including up to product export and customer delivery of both feedstocks and finished goods.

This stakeholder engagement was held to help inform the FECM Report to Congress, a study designed to examine the long-term trends related to the domestic production and consumption of ethane, the export of ethane, and the opportunities for (and economic benefits of) investments for further domestic use. DOE was directed to develop the Report to Congress through the passage of the Consolidated Appropriations Act of 2021 (Public Law 116-260). A notice of the meeting was published in the Federal Register on August 9, 2021.

Over 180 participants registered for the Virtual Listening Session. Participants included individuals from environmental, clean energy, community development, public health, and religious organizations; industry; and academia, as well as concerned citizens. The session included remarks from the FECM Principal Deputy Assistant Secretary (PDAS) Dr. Jennifer Wilcox, and Acting Deputy Assistant Secretary for the Office of Oil and Natural Gas, Ryan Peay. Additional presentations from ORVI and Policy Matters Ohio were featured and followed by a 90-minute listening session. Participants were encouraged to share their views on the X-Leap platform, a collaborative online software tool designed to capture extensive comments and other inputs from individuals participating virtually. In addition, the participants were offered opportunities to make oral comments.

A. Remarks and Presentations

FECM PDAS Dr. Jennifer Wilcox began the meeting by outlining the Biden-Harris Administration's aggressive strategy that seeks to significantly cut carbon emissions, which includes a 50 percent reduction in emissions by 2030, 100 percent clean electricity use by 2035, and net-zero emissions by 2050. Dr. Wilcox also said, in many cases, that health and environmental impacts of fossil energy development impact the frontline communities that do not necessarily experience the greater energy access and economic benefits of these activities. The Biden-Harris Administration is dedicated to addressing these inequities and issues, and environmental justice, equity, and workforce development will be top priorities moving forward. DOE is also supportive of a just transition that will support a sustainable environment and produce good-paying, clean-energy jobs through investments directed toward traditionally disadvantaged communities. Acting Deputy Assistant Secretary Ryan Peay subsequently provided an overview of the Report to Congress and indicated it is expected to be finalized by the end of 2021 and will be publicly available.

B. Formal Stakeholder Presentations

There were two formal presentations from participating stakeholders. The first was given by Sean O'Leary, Senior Researcher for ORVI. ORVI is a non-partisan, policy development group that focuses on advancing sustainable economic development for the greater Ohio Valley and Appalachia. In his remarks, Mr. O'Leary highlighted several recent papers that ORVI had released, analyses that found that a potential expansion of the petrochemical sector regionally would not help the community nor necessarily produce substantial job growth. He also noted that estimates indicate air pollution in Appalachia has caused as many as 4,600 premature deaths between 2004 and 2016 and that adverse climate impacts during this period were as high as $94 billion in costs. Mr. O'Leary stated the Shell ethane cracker facility currently being constructed in Beaver County, Pennsylvania, could emit as much as 2.2 million tons of GHG emissions. He also noted the recent gains of Centralia, Washington—a community that lost a significant number of coal sector jobs. Centralia began an economic transition program in 2015, which distributed $55 million in grants through a weatherization fund, an economic development and community fund, and an energy technology fund. This funding has allowed Centralia's gross domestic product (GDP) to grow at twice the national average and added approximately 2,800 jobs. Mr. O'Leary claimed this model could also work well for the Appalachian region.

The second presentation was given by Amanda Woodrum, Senior Researcher for Policy Matters Ohio. Ms. Woodrum began her presentation by outlining the respective benefits and challenges that the petrochemical industry has brought to Appalachia. Although the industry has produced good paying jobs, dependence on extractive industries has created social, economic, and societal challenges. Instead of continuing down this path, there should be a greater focus on creating a "21st Century Appalachia," a vision that should focus on creating good paying jobs that would benefit workers, the community, the environment, and the local economy. Ms. Woodrum also discussed Reimagine Appalachia, which is a diverse stakeholder coalition that is working to develop a climate infrastructure plan for the region, one which would call for $24.5 billion in investments that could create over 500,000 jobs moving forward.

C. Listening Session and Remarks

After the formal presentations, the 90-minute listening session began, facilitated by Lauren Illing of BCS, LLC. Feedback from the session was provided by stakeholders through a combination of written stakeholder input from the X-Leap platform that was used by DOE to obtain comments and inputs from the participants. The following section presents a series of key themes that emerged from individual stakeholder written inputs and the oral remarks received.

Environmental, Health and Community Impacts

The Health and Environmental Impacts of Fossil Energy Have Severely Affected Frontline Communities

In her opening remarks, Dr. Wilcox stated DOE is aware that, in many cases, energy infrastructure sited in frontline communities do not necessarily experience the energy access and economic benefits so often asserted by energy and petrochemical manufacturing firms. Meeting participants made several recommendations on ways that DOE can take action to address this shortfall. One individual referenced the Biden-Harris Administration's Justice40 initiative, a whole-of-government effort launched to ensure that the federal government works closely with states and communities to deliver at least 40 percent of the overall benefits from federal investments in climate mitigation and clean-energy development to disadvantaged communities. Furthermore, that same individual said this new approach needs to be more than a talking point. Participants also highlighted some of the environmental justice burdens experienced within poorer communities, especially those consisting of people of color. They recommended that DOE do what it can to ensure these communities have access to clean air, clean water, productive land, and a healthy climate for generations to come.

One participant called for DOE to conduct a study with other Federal agencies that would assess the best available technologies and practices that reduce or eliminate the environmental justice and pollution impacts of petrochemical and plastic facilities, and their associated infrastructure. This study could be used to inform the U.S. Environmental Protection Agency's (EPA) revision of regulations to mitigate these impacts. Another participant suggested that DOE should incentivize research and development for the development of materials that could replace fossil-based plastic, such as biomaterials that are biodegradable and compostable. Other recommendations from participants included employing workers to plug methane leaks from orphaned wells, and to provide funding for solar and other renewable sources of energy in frontline communities. Several participants also urged DOE not to pursue carbon capture and storage and hydrogen production from natural gas as potential clean energy solutions.

Petrochemical Plants Adversely Impact Public Health and Safety

Several participants expressed their individual concerns about the public health impacts of petrochemical plants. They said emissions from natural gas and petrochemical plants create toxins, volatile organic compounds (VOC), and nitrogen oxides. These pollutants haven been linked to cancer and childhood leukemia; brain, liver, and kidney problems; infant mortality; and various birth defects. There was also a discussion focused on the Shell ethane plant in Beaver County and that it could emit as much as 500 tons of VOCs per year and 30 tons of hazardous air pollutants (HAPs), including carcinogens such as benzene, toluene, and formaldehyde. One participant also expressed concerns about ethylene and ethylene oxide, especially since these chemicals can cause headaches, nausea, difficulty in breathing, exhaustion, and burning. In addition, these compounds can explode if not handled properly. Several participants also expressed their concerns that an expansion of the petrochemical industry in the Ohio Valley could transform it into the next "Cancer Alley."

Petrochemical Plant Safety Regulations Need Improvement

Several participants suggested ways that petrochemical plants could improve safety. One participant recommended that a fee be established that would require annual testing for up to 10 years on any facilities that have had a major incident impacting water wetlands, agricultural areas, and public spaces such as parks. A toxic alert system could also be established that would notify the community of emergencies that would be similar to a weather or amber alert. Another participant suggested that there should be mandatory monitoring of particulate matter and VOCs throughout vulnerable communities, and that this monitoring system information be made publicly accessible.

Other participants commented that both the Emergency Planning and Community Right to Know Act and state reporting requirements in Pennsylvania (PA) have been effective in keeping communities updated on the presence and release of chemicals at individual facilities.

Plastic Production is Harmful to the Environment

Several participants provided statistics and other supporting information on the various negative environmental impacts of plastics production. One participant said that as much as 8 million tons of plastic is disposed of in the ocean, an amount that would be the equivalent of dumping one garbage truck into an ocean every minute; if no action is taken, this is likely to increase to two trucks per minute by 2050. Another participant said the plastic in the world's oceans degrades and becomes methane and ethylene, and marine microorganisms subsequently ingest microplastics, a disturbing and growing trend that reduces their ability to store carbon.

Expansion of the Petrochemical Industry in Appalachia Could Lead to Increased Hydraulic Fracturing

Several participants expressed their concerns that an expansion of the petrochemical industry in Appalachia would be detrimental to public health, safety, and air quality because it would necessitate increased hydraulic fracturing. Participants noted that ethane crackers are dependent on natural gas, and that the Ohio Valley is being looked at for a potential expansion of the petrochemical industry due to its proximity to the Marcellus and Utica shales and the ethane they produce used in petrochemical manufacturing, even though the Appalachian region already suffers from poor air quality.

Impacts to Climate Change

Several participants expressed their concerns that an expansion of the petrochemical industry in Appalachia would exacerbate climate change risks, impacts, and concerns. One participant cited a study that found that the current rates of emissions from the plastics sector could trigger climate impacts that cannot be reversed. Another participant said the climate impacts of petrochemical production are enormous, and it would steer both the United States and the world as a whole in the wrong direction, especially since every stage of the plastics lifecycle results in large GHG emissions. Other attendees commented the United States cannot afford to build any new facilities if it wants to meet its climate goals.

Participants also discussed the Shell ethane plant that is being constructed in Beaver County and said that it could emit over 2.2 million tons of CO_2 per year, which would be the same as the emissions from over 430,000 passenger vehicles. A participant said the plant proposed by PPT Global for a potential site in OH could emit an additional 1.79 million tons of CO_2 per year. Another participant said that by 2050, GHG emissions from the plastics sector could reach over 56 gigatons, which would be over 10 percent of the carbon budget.

Impacts of Pipeline Expansion

Several participants expressed their concerns that the expansion of pipelines in Appalachia could be detrimental to public health and the environment. One participant discussed the Revolution pipeline, which had an explosion in Beaver County. Another participant said the pipeline construction brings substantial risks to human health, habitat and species, soils, water, and air quality. In addition, a participant representing the U.S. Gulf Coast region said that incident rates for gas pipelines (including ethane) are the highest along the Texas and Louisiana Gulf Coast. Other participants disagreed and said that pipelines are seen as the safest means of transportation and that, according to the Association of Oil Pipelines and the American Petroleum Institute, respectively, liquid pipelines have safety delivery rates of over 99 percent. In addition, most pipeline incidents are extremely limited events with minimal environmental impact. In addition, ethane pipeline operators are overseen by the Pipeline and Hazardous Materials Safety Administration and are regularly inspected to make sure that they are operated in accordance with federal operational and safety standards.

Economic Impacts of Expansion of Petrochemical Operations in Appalachia

Expansion of the Petrochemical Industry in the Region Would not Necessarily Fuel Economic Growth

In addition to the two formal presentations from ORVI and Policy Matters Ohio, which both asserted that the benefits that the petrochemical industry have brought to the Appalachian region have been mixed, meeting participants were critical of the tax subsidies that PA had offered to Shell to build the ethane plant in Beaver County. One participant said that the subsidy was approximately $1.6 billion. Another participant said the American Chemistry Council’s (ACC) estimate that the Shell plant could create as many as 17,000 jobs, $1 billion in wages, and $169 million in tax revenue was overly optimistic as the facility would more likely employ approximately

600 people (Note: the ACC estimate of 17,000 jobs included not only the facility jobs created once construction is completed but other 'permanent jobs' tied to the activities at the Shell plant). Written testimony submitted by ACC said that companies around the world are investing in new petrochemical capacity, which has led to new jobs; over 447,000 direct and indirect jobs could be generated because of new manufacturing processes, which could result in $310 billion in new economic output.

Creating an Economy Based on Clean Energy Investments Would be More Beneficial than Expanding the Petrochemical Industry

The formal presenters and other participants discussed the potential economic benefits related to clean energy infrastructure. One participant highlighted *reimaginejobs.org* as a regional website that features opportunities in renewable energy, sustainable construction and building weatherization, green chemistry, sustainable agriculture, recreation, tourism, grid modernization and broadband expansion, sustainable transportation, and land conservation. Another participant highlighted sustainable agriculture and noted that the U.S. Department of Agriculture has identified Appalachia as a region that will have growing importance with respect to potential growth in U.S. food supply. Another participant said that New York state has provided $1.5 billion to create 40,000 jobs in the clean energy sector and that other states should consider similar investments.

Environmental Justice Concerns

In addition to Appalachia, several groups from the U.S. Gulf Coast region also attended the listening session and provided feedback on their experiences related to environmental racism and harmful community impacts from the petrochemical industry. Several participants discussed how an area of LA that has several petrochemical plants is called "Cancer Alley" because the risk of getting cancer from pollution tied to these manufacturing options is significantly higher than in other parts of the United States. Another participant discussed Mossville, Louisiana, a predominantly Black community that was originally founded by slaves. The community is home to a petrochemical plant that has leaked ethylene dichloride into the groundwater. Because of this spill, many residents suffered adverse health impacts and were forced to accept buyouts to leave the community. Other participants called the U.S. Gulf Coast a petrochemical and fossil fuel sacrifice zone and said that, in many cases, state legislators and regulators in the U.S. Gulf Coast region have supported the petrochemical industry through regulatory and tax policies at the expense of disadvantaged communities.

Several participants were critical of DOE for focusing the listening session on Appalachia and said that it should have included speakers from the U.S. Gulf Coast as well as from Black and Indigenous communities.

Conclusion of the Listening Session

At the end of the session, Dr. Wilcox commented she agrees that emissions from fossil energy should be minimized and that the listening session on August 24, 2021, would be the first of many conversations that FECM would be holding with frontline communities; and she said that DOE will also consider traveling to impacted communities in the future. Dr. Wilcox also highlighted work that FECM is doing to support clean energy, including the reuse of byproducts—coal waste and produced water—to find rare earth elements that will be essential for the development of windmills, batteries, magnets, and other renewable anergy applications. Dr. Wilcox concluded by saying DOE is increasing funding for clean energy training for Historically Black Colleges and Universities, as well as other minority-serving institutions.

Ryan Peay also made a few closing remarks and explained the reason why this listening session was focused specifically on Appalachia was because it was being used to inform the Report to Congress mentioned at the beginning of the meeting that is focused in part on potential petrochemical manufacturing growth in the region. Mr. Peay said any future sessions would likely be a more traditional format where participants have a set amount of time to speak. He also mentioned that the comments from X-Leap and the WebEx chat would be provided to any interested parties.

2. Breakdown of 8/24 Virtual Public Meeting Participants

Academia	Industry	NGOs	Government	Other
Universities	Oil and Gas	Environmental	State	Concerned Citizens
	Petrochemical	Clean Energy	Local	Press
	Industry Consultants	Community Development		
		Research		
		Public Health		
		Religious		

3. Meeting Agenda

The agenda for DOE's Virtual Public Meeting & Listening Session, "Understanding the Impact of Ethane Development on the Environmental and Health Conditions for Local Communities as well as the Global Carbon Budget," held August 24, 2021, was as follows:

11:30 – 11:45 am	Welcome and Acknowledgements (Dr. Jennifer Wilcox, DOE PDAS of the Office of Fossil Energy and Carbon Management)
11:45 am – 12:00 pm	Overview of the Congressional Request and Meeting Objectives (Ryan Peay, DOE Acting Deputy Assistant Secretary of the Office of Oil and Natural Gas)
12:00 – 12:30 pm	Community - Based Perspectives on Petrochemical Development **Ohio River Valley Institute**: Guiding the Greater Ohio Valley to Advance Clean Energy and Clean Manufacturing (Sean O'Leary, Senior Researcher)

	Reimagine Appalachia: A 21st Century Blueprint for Investing in Cleaner, More Energy Efficient Manufacturing (Amanda Woodrum, Senior Researcher of Policy Matters Ohio)
12:30 – 12:40 pm	Listening Session Instructions: Collaboration Website Tutorial (Lauren Illing, BCS, LLC.)
12:40 – 2:00 pm	Listening Session

Individual Participant Viewpoints RE: Community, Economic, and Environmental Impacts from Ethane Development

Key Questions:

1. What are the local environmental, health, and community impacts associated with petrochemical manufacturing, particularly from ethane crackers and pipelines?
2. What are health and safety risks to local communities from accidents and system failures associated with such facilities and infrastructure?
3. What are the greenhouse gas emissions from ethane facilities and related infrastructure, including natural gas extraction?
4. What are some opportunities to reduce environmental and health impacts of such facilities locally and along the value chain, up to and including product export?
5. What are the economic opportunities and challenges for job creation?
6. What kinds of arrangements with developers can help assure that communities receive an adequate share of benefits from ethane and other kinds of petrochemical industry development?
7. How can DOE be helpful to communities?

Appendix B: U.S. Ethane Crackers

A list of sites with established ethane crackers and number of known ethane fed crackers at each site is provided in Exhibit A-1.

Exhibit A-1. List of ethane crackers (81) (228)

Company	Site Name	State	County	Number of Ethane Fed Crackers at Each Site
BASF Fina Petrochemicals	Port Arthur (BASF)	TX	Jefferson	1
Chevron Phillips Chemical Co. LP	Port Arthur (Chevron)	TX	Jefferson	1
Chevron Phillips Chemical Co. LP	Sweeny	TX	Brazoria	3
Dow Chemical Co.	Plaquemine	LA	Iberville	2
Dow Chemical Co.	Taft	LA	St. Charles	2
Dupont	Orange	TX	Orange	1
Eastman Chemical Co.	Longview	TX	Gregg	3
Equistar Chemicals LP	Channelview	TX	Harris	2
Equistar Chemicals LP	Clinton	IA	Clinton	1
Equistar Chemicals LP	Corpus Christi	TX	Nueces	1
Equistar Chemicals LP	Morris	IL	Grundy	1
ExxonMobil Chemical Co.	Baytown	TX	Harris	3
ExxonMobil Chemical Co.	Beaumont	TX	Jefferson	1
Flint Hills Corp.	Port Arthur	TX	Jefferson	1
Formosa Plastics Corp.	Point Comfort	TX	Calhoun	3
Huntsman Corp.	Port Neches	TX	Jefferson	1
Occidental Chemical/Mexichem	Ingleside	TX	San Patricio	1
Sasol North America Inc.	Lake Charles	LA	Calcasieu	1
Shell Chemicals Ltd.	Deer Park	TX	Harris	1
Shell Chemicals Ltd.	Norco	LA	St. Charles	2
Westlake Petrochemicals Corp.	Calvert City	KY	Marshall	1
Westlake Petrochemicals Corp.	Sulphur	LA	Calcasieu	2
Williams Olefins	Geismar	LA	Ascension	1
Chevron Phillips Chemical Co. LP	Cedar Bayou	TX	Harris	2
Dow Chemical Co.	Freeport	TX	Brazoria	3
Equistar Chemicals LP	Chocolate Bayou (Equistar)	TX	Brazoria	1
Equistar Chemicals LP	La Porte	TX	Harris	1
ExxonMobil Chemical Co.	Baton Rogue	LA	E. Baton Rouge	1
INEOS Olefins and Polymers	Chocolate Bayou (INEOS)	TX	Brazoria	2
LyondellBissell & Sasol	Louisiana Integrated PolyEthylene JV LLC	LA	Calcasieu	1

Company	Site Name	State	County	Number of Ethane Fed Crackers at Each Site
Shintech	Plaquemine	LA	Iberville	1

*Notes: Idorama, Lake Charles, was previously owned by Equistar who idled the plant in 2001. It is now owned and operated by Idorama Ventures (229). Additional crackers are projected to come online in 2022.

Appendix C: Input-Output Approach to Estimating the Opportunity Cost of Exporting Ethane in Support of Foreign Manufacturing Relative to Domestic Use

Generally, the opportunity cost of an activity or alternative is defined as the forgone value or benefit (i.e., the cost) of engaging in a higher valued activity or pursing a higher-valued alternative. Directly or indirectly, opportunity cost underpins most economic decisions involving society's scarce resources (230). To estimate the opportunity cost of exporting available ethane in support of foreign manufacturing, this report compared economic outcomes under two competing scenarios. Under the first scenario, increased domestic production of ethane (or increased ethane availability) was assumed to be used to meet export demand. Under the second scenario, increased domestic production of ethane is assumed to be used to support the domestic manufacturing of three ethylene derivatives: LDPE, LLDPE, and HDPE.

Increased domestic production of ethylene derivatives has the potential to offset the need for imports. While the nuances of trade policy are complex, all else equal, reducing imports of foreign commodities should result in a positive impact on U.S. GDP. The same, however, can be said if, all else equal, exports of domestically produced ethane were to increase. As such, the below analysis focuses on the trade-off (i.e., opportunity cost) of increasing domestic production of ethane to be exported versus using it to produce three ethylene derivatives domestically, which would lower domestic industrial requirements for ethylene derivative imports.

The trade-offs are identified by conducting economic impact assessments of the two scenarios and then calculating the difference in the number of jobs created (including direct and indirect jobs) and labor income (thousand chain-weighted 2012$) generated between competing scenarios. This report relies on reported information for investment in ethane-based manufacturing from the June 2021 STEO to inform model assumptions.

1. Economic Impact Assessment

Economic impact assessments are often conducted using IO analysis. The foundation for applying IO analysis is the establishment of an accounting framework, known as IO accounts, that characterizes the purchases and sales of industries within a local economy. The first step in conducting an economic impact assessment using IO accounts is to define the boundaries of the local economy (i.e., study area). For the purposes of this study, the local economy was defined as the United States. As such, results of the impact assessments conducted produce estimates of national changes to jobs and labor income.

The second step in conducting an economic impact assessment using IO accounts is to define the industrial sector (or industrial sectors) of interest and collect data that describes the linkages between the identified industrial sector (or industrial sectors) and other industrial sectors as they exist within the local economy. Industrial sectors of interest for this study included industries engaged in the production of ethane or industries engaged in the production of ethylene derivatives (i.e., commodities that make use of ethylene produced from ethane as a feedstock). Identification of industries was informed by the ethane value chain (see Exhibit II-11) and information reported by EIA and Enterprise Products Partners L.P. on NGLs.

The third step in conducting an economic impact assessment is to characterize the economic shock under consideration. The two economic shocks under consideration for this report include 1) an increase in the demand for ethane exports being met by increased domestic production of ethane and 2) an increase in domestic production of ethylene derivatives to be used by domestic industries resulting in lower requirements of these industries for ethylene derivative imports.

2. *Input-Output Accounting Framework*

National IO accounts are produced by both the Bureau of Economic Analysis and subsequently by BLS. These accounts provide a coherent, comprehensive, and full accounting of industrial sector and final-use transactions that occur within the U.S. economy. The IO accounts used for this analysis consisted of a series of tables (i.e., matrices) that showcase the commodity inputs used by each industry to produce its output, the commodities produced by each industry, and the use of resulting commodities by final consumers. The use of commodities by final consumers is more frequently referred to as the components of final demand, which include consumption, investment, government expenditures, and net exports (commodity exports minus imports).

The IO accounts consist of two basic national-accounting tables: a make table and a use table. The make table shows the value of the commodities produced by domestic industries. The use table shows the value of commodities used by intermediate domestic industries and final demand activities. The use table also contains information on the components of value added, which generally includes compensation to employees by industry (labor income), payments to governments including taxes on production and imports less subsidies, and gross operating surplus. Together, the components of the make and use tables provide a consistent, commodity-by-industry (C x I) IO accounting framework that can be used to estimate economic impacts. Exhibit C-1 provides an example of the generalized C x I accounting framework, as showcased by Jackson and Jarosi (134).

Exhibit C-1. Commodity-by-industry IO accounting framework

	Commodities	Industries	Final Demand	Total Output
Commodities		U	e	q
Industries	V			g
Value Added		va		
Total Input	q’	g’		

Note: U = use table; V = make table; e = components of final demand; va = components of value added; q = total commodity output (found by summing the commodities rows of U and e); g = total industry output (found by summing the columns of U or rows of V)

To execute the IO analysis using the accounts, they must first be balanced. That is, the sum of output by industry was equal to the sum of commodity output. A balanced (C x I) accounting framework can be represented mathematically by the following equations:

$$Ui + e = q \tag{1}$$

$$V\boldsymbol{i} = g \tag{2}$$

$$V'\boldsymbol{i} = q \tag{3}$$

and behavioral relationships

$$B = U\hat{g}^{-1} \tag{4}$$

$$U = B\hat{g} \tag{5}$$

$$D = V\hat{q}^{-1} \tag{6}$$

$$V = D\hat{q} \tag{7}$$

where $\boldsymbol{i}$ is a summing vector of appropriate dimension, $'$ indicates transpose, and ^ indicates diagonalization (134). Equation (4) defines the production requirements of commodities per industry dollar of output (134). Equation (5) describes the industry-based technology assumption that commodities are produced in fixed quantities (134).

To accommodate an economic system open to trade with the rest of the world, the C x I accounts were regionalized following the approach discussed by Jackson and Jarosi (134). To begin this approach, this study specified a commodity-space analogue to the equation for regional supply percentages, which express a region's ability to supply its own demand, an equation presented in Jackson and Jarosi (134) as follows:

$$Q = \left(\iota V - \widehat{ex} + m\right)^{-1}(\boldsymbol{i}V - ex) = (q - \widehat{ex} + m)^{-1}(q - ex) \tag{8}$$

where ex and m represent vectors of export and import values by commodity and all other variables are as defined previously. To transform commodity space to industry space and accommodate imports, a matrix $\widetilde{D}$ is defined as

$$\widetilde{D} \equiv D\hat{Q} \tag{9}$$

and substitute equation (8) into equation (9) to obtain equation (10) as follows:

$$\widetilde{D} = D\left(\iota V - \widehat{ex} + m\right)^{-1}(\widehat{\iota V - ex}) = D(q - \widehat{ex} + m)^{-1}(\widehat{q - ex}) \tag{10}$$

Multiplying the commodity balance equation

$$U\boldsymbol{i} + C + G + I \equiv q - ex + m \tag{11}$$

by the right-hand side of equation (9), substituting Bg for $U\boldsymbol{i}$, using equation (8), and rearranging to isolate g, obtains

$$g = \left(I - \widetilde{D}B\right)^{-1}\left(\widetilde{D}[C + G + I] + D[ex]\right) \tag{12}$$

Whereas classical IO impacts assessment applications evaluate the impacts of final demand changes on output and other interest variables assuming a constant structure of production, the analysis reported here modifies the interindustry structure of the economy and quantifies the impacts of those modifications on interest variables while holding final demand constant. Modeling changes in economic structure are achieved by directly editing appropriate values in the make table and in the level of ethylene derivative imports or in the level of ethane exports. Variables that depend on values in $V$and m or ex will also change, including $q, g, Q, D, \widetilde{D}$. Matrix B effectively captures the technology of production, which is assumed to remain unchanged. With this understanding, each scenario will result in different total production requirements, and each will generate a unique solution for g.

To estimate changes in the number of jobs and labor income by industry resulting from the realization of each economic shock considered, estimates of impacts on g between each scenario were multiplied by the ratio of employment (# of jobs by industry) to industry output and labor income by industry-to-industry output. Lastly, it was assumed that no cost advantage existed for either shock.[47]

3. Data Resources and Programming Languages Used

To conduct the economic impact assessments, this study relied on publicly available, projected IO accounts and estimates of employment and labor income by industry, all of which are produced by BLS. Information was available at 205 industry and commodity level of detail. Industries and commodities are classified based on the 2012 NAICS codes.[48] While the industry level of detail is consistent across the data sources provided by BLS, the years for which the projected values of the data are made available differs. Specifically, projected IO accounts and estimates for employment by industry are available for the years 2024, 2026, 2028, and 2029. Projected values for labor income by industry are only available for 2024 and 2026, the last year for which the BLS produced projected values for labor income by industry. Additionally, the dollar value is not consistent across the projected data resources provided by the BLS. Specifically, the values reported for the projected IO accounts for 2024 and 2026 are measured in chain-weighted 2009 dollars, while the values reported for the projected IO accounts for 2028 and 2029 are measured in chain-weighted 2012$.

To combat potential issues with the data, the following steps were taken:

1. Linear interpolation was applied to the components of the projected IO accounts (i.e., the make and use tables, as well as the components of final demand) and estimated values of employment by industry for the years 2028 and 2029. The results of the linear interpolation were used to estimate the components of IO accounts and values for employment by industry for the years 2025, 2026, and 2027. As such, all values were measured in chain-weighted 2012$.

[47] One reason an industry might substitute for the commodities it uses to produce its output is because there is a cost-advantage to the substitute (i.e., it lowers the industry's costs of production). Under a scenario where there is not a cost-advantage, reasons an industry might substitute for one of the commodities it uses to produce its output include but are not limited to, lower risk of supply chain shortages, increased flexibility, shorter delivery times, no longer having to rely on imported goods.

48 See Exhibit C-7. for a complete list of industries and commodities. Refer to the 2012 NAICS manual for more information.

2. To project labor income by industry for the forecast period of 2025–2029, the ratio of labor income by industry to output by industry in 2024 was multiplied by the projected values for output by industry for each year of 2025–2029. [49]

The baseline and estimated impacts of relevant variables were generated using a modeling framework developed for this project in GNU Octave 6.1, a freely available, redistributable software application used to solve linear and nonlinear mathematical problems using a language that is mostly compatible with MATLAB (231). The modeling framework makes use of the equations represented above.

4. Design Parameters and Key Assumptions for Each Economic Shock

This study incorporated several key assumptions and design parameters into the analysis conducted for each economic shock scenario considered. These assumptions impact the results and, thus, should be carefully considered when interpreting and drawing conclusions from the results. Assumptions are outlined in the description of the economic shock below.

A. Increase in Export Demand Assumptions

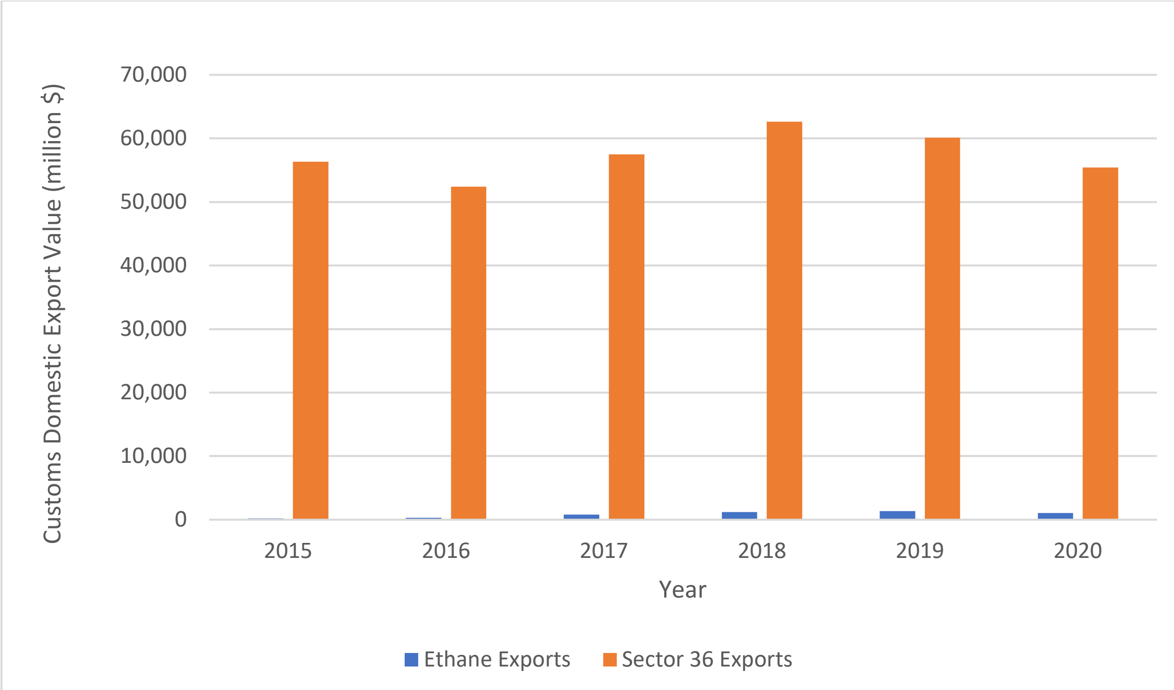
To isolate the value of the potential economic impacts associated with increased demand for ethane exports, a key assumption was that the increase in domestic production of ethane would be used solely to meet export demand. Within the 205-industrial-sector-level aggregation used by BLS, the sector identified as the most likely to be responsible for the new domestic production to be exported was industrial Sector 36 (NAICS 3251)—basic chemical manufacturing. Industries classified as basic chemical manufacturers are establishments who are primarily engaged in manufacturing chemicals using basic processes, such as thermal cracking and distillation or industries engaged in petrochemical manufacturing. Chemicals manufactured by this industry group are usually used to separate chemical elements or separate chemically defined compounds (136). Exports of ethane were assumed to increase from their base amounts, which defined as the amount of Sector 36 exports represented by ethane.

To estimate the amount of Sector 36 exports represented by ethane, data on exports of ethane between 2015 and 2020 was collected from the U.S. Census Bureau following the HTS codes. The HTS code used for ethane was 2901.10.1010 (130). Data on Sector 36 exports were also collected from the U.S. Census Bureau over the same period (130).[50] Data collected are included in Exhibit C-2.

49 Discrepancies in reported value for 2026 yielded 2024 data preferable for ratio estimates of labor income to industry output.

50 Data come from customs reports produced by the U.S. Census Bureau between 2015 and 2020 on the domestic value of exports. Prior to 2015 the U.S. did not export ethane.

Exhibit C-2. Exports of ethane and exports from Sector 36 (2015–2020) (130)



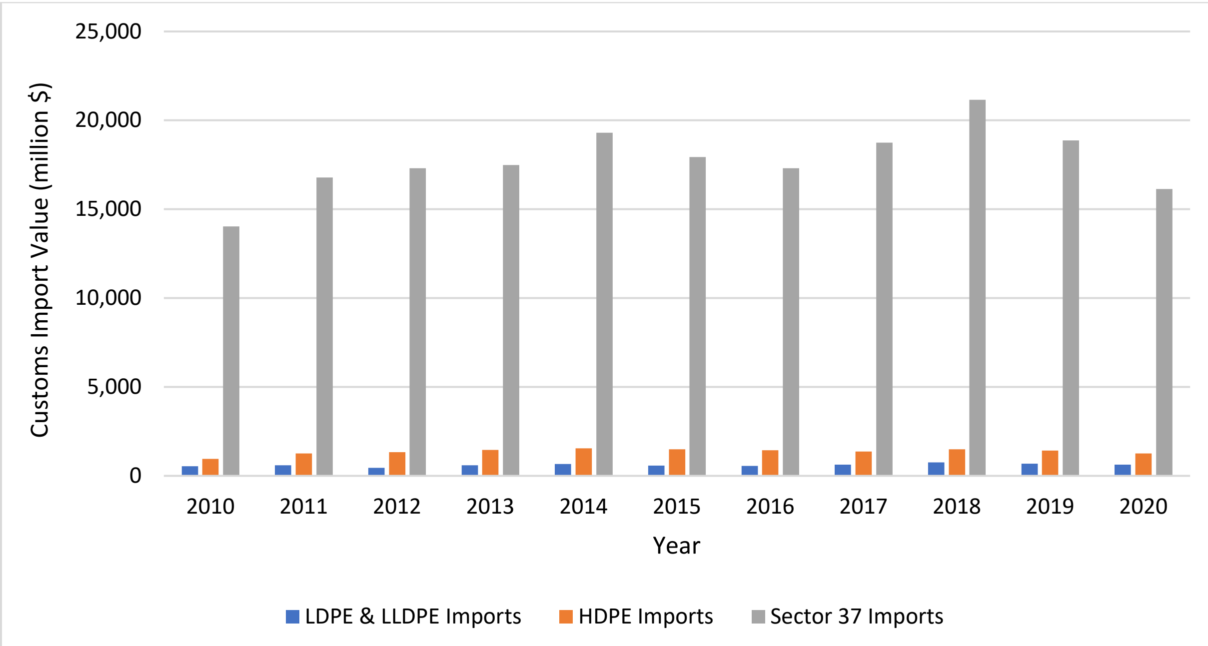
It was estimated, between 2015 and 2020, an average of 1.39 percent of Sector 36 exports were composed of ethane. Following this result, the base amount of Sector 36 exports assumed to be represented by ethane was 1.39 percent for each forecast year (2025–2029) considered. This report considered increases in ethane exports equal to 20, 30, and 40 percent from the base amount of assumed ethane exports from Sector 36 for each forecast year.

B. Increased Domestic Production of Ethylene Derivatives to Displace Imports Assumptions

To isolate the value of the potential economic impacts associated with increased domestic production of ethylene derivatives, a key assumption is that the new domestic production of ethylene derivatives would substitute for projected imports of ethylene derivatives to be used by domestic industries. Import substitution is assumed to begin in 2025 and continue throughout the remainder of the 2026–2029 forecast period. Within the 205-industrial-sector-level aggregation used by BLS, the sector responsible for the new domestic production would be industrial Sector 37 (NAICS 3252)—resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing. Sector 37 includes industries that are primarily engaged in one of the following: 1) manufacturing synthetic resins, plastics materials, and nonvulcanizable elastomers and mixing and blending resins on a custom basis; 2) manufacturing noncustomized synthetic resins; 3) manufacturing synthetic rubber; 4) manufacturing cellulosic (e.g., rayon, acetate) and noncellulosic (e.g., nylon, polyolefin, polyester) fibers and filaments in the form of monofilament, filament yarn, staple, or tow; or 5) manufacturing and texturizing cellulosic and noncellulosic fibers and filaments.

To estimate the amount of projected Sector 37 imports represented by ethylene derivates, data on imports of LDPE, LLDPE, and HDPE and imports for Sector 37 between 2010 and 2020 were collected from the U.S. Census Bureau (130).51 Data on ethylene imports were collected using the HTS codes. The HTS code used for LDPE and LLDPE was 3901.10, while the HTS code used for HDPE was 3901.20. Data on imports are included in Exhibit C-3.

Exhibit C-3. Imports of LPDE, LLPDE, and HPDE and Sector 37 Imports (2010–2020) (130)



Between 2010 and 2020, it was estimated that an average of 11.1 percent of Sector 37 imports comprised ethylene derivatives LDPE, LLDPE, and HDPE. Following this result, the maximum amount of Sector 37 imports able to be replaced by new domestic production of ethylene derivatives was assumed to be 11.1 percent of projected imports for each forecast year (2025–2029). Import substitution scenarios corresponding to 30, 60, and 90 percent of the maximum possible were assessed for each forecast year. Domestic production was assumed to replace imports following a one-to-one relationship, such that no shortages in the supply would be realized for domestic industries.

5. Economic Impact Estimation Results

Results in terms of the potential annual impacts to employment (# of direct and indirect jobs created) and labor income (thousands of chain-weighted 2012$) are presented below for each scenario considered.

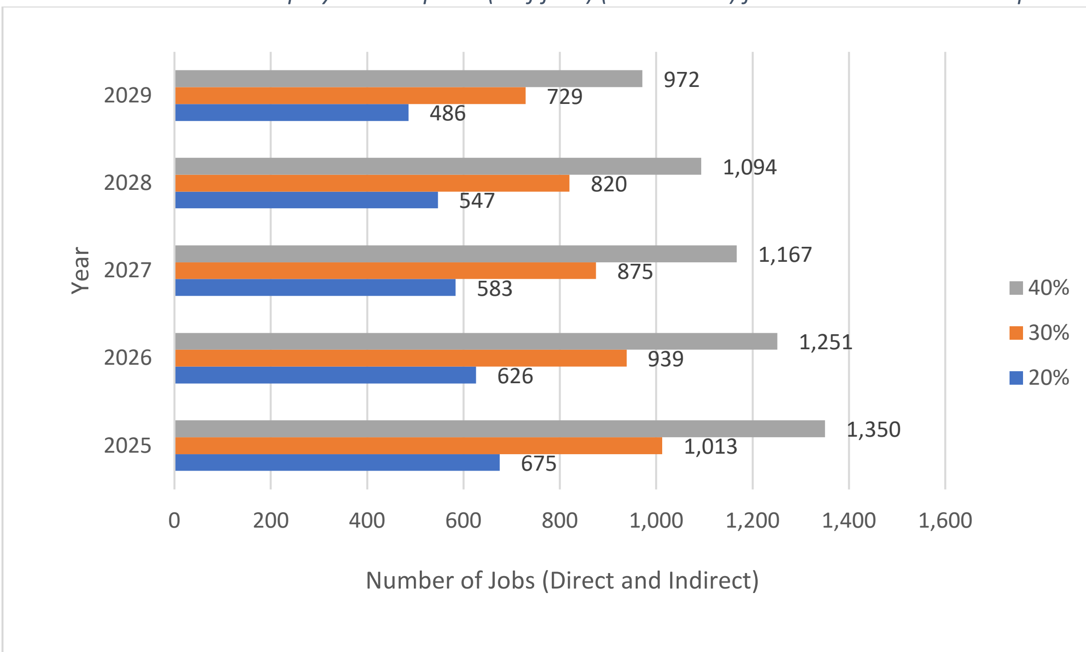
A. Increase in Export Demand Results

Exhibit C-4 reports potential annual impacts to employment resulting from new domestic production of ethane being exported beginning in 2025. Results are presented for scenarios where ethane export demand increases by 20, 30, and 40 percent from the based amount of ethane

51 Research suggests imports of EDC are not projected to occur over the forecast period considered (16). As a result, an import substitution scenario was not examined for EDC.

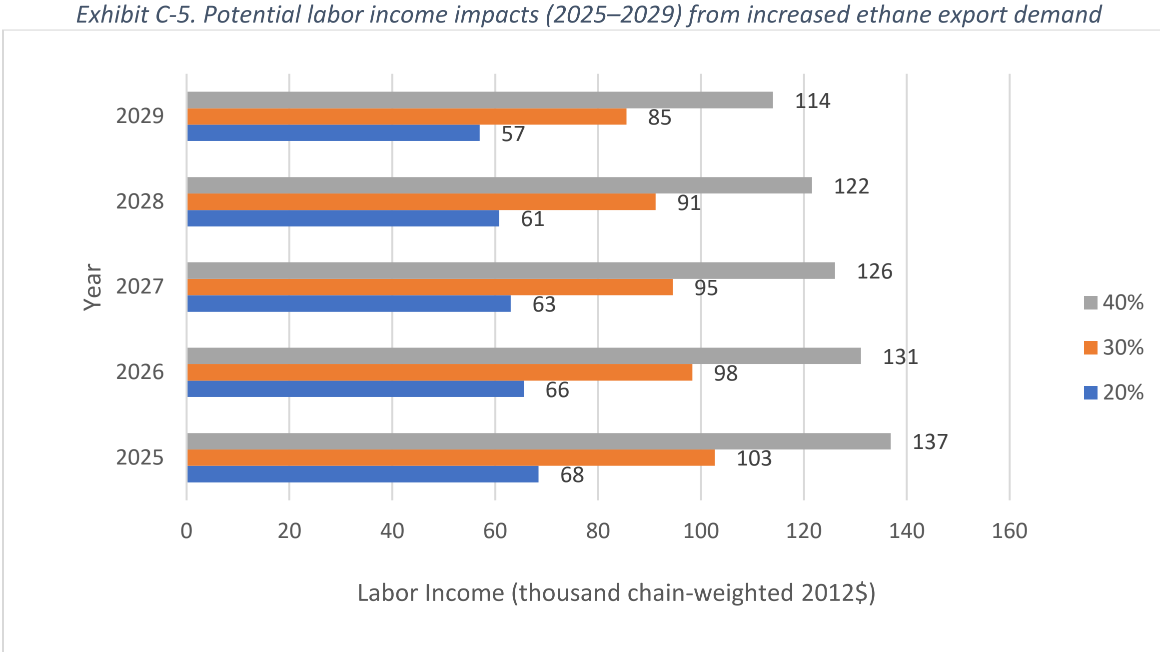
export demand assumed to already be occurring (i.e., 1.39 percent of projected export demand for Sector 36).

Exhibit C-4. Potential annual employment impacts (# of jobs) (2025–2029) from increased ethane export demand



Following the same assumptions outlined above, the potential annual impacts to labor income are presented in Exhibit C-5.

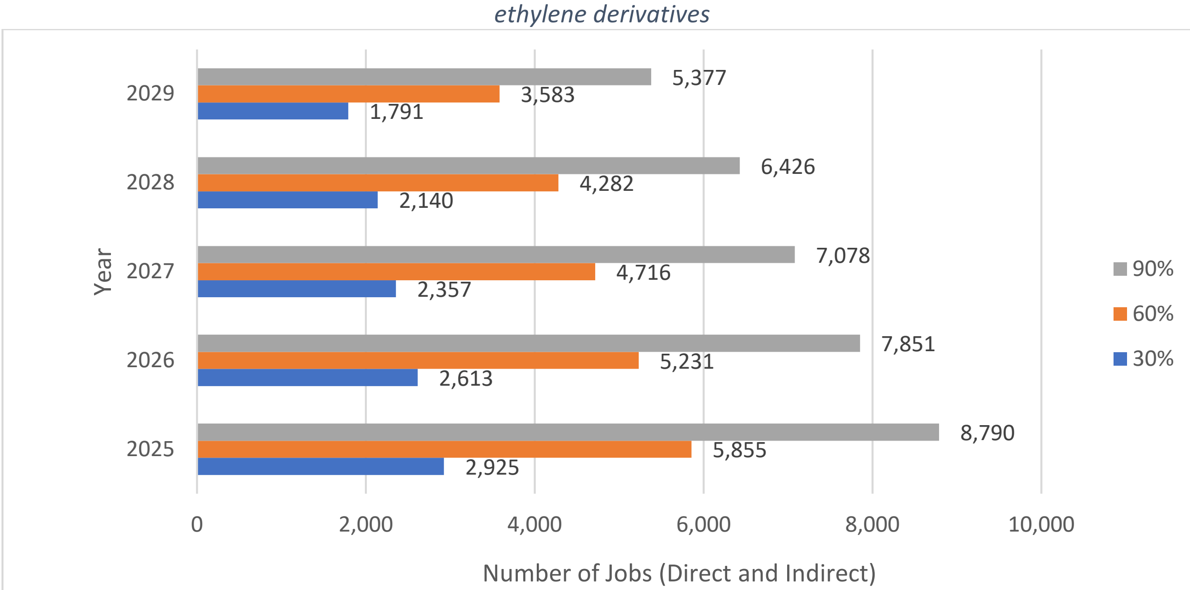
Exhibit C-5. Potential labor income impacts (2025–2029) from increased ethane export demand



B. Increased Domestic Production of Ethylene Derivatives to Displace Imports Results

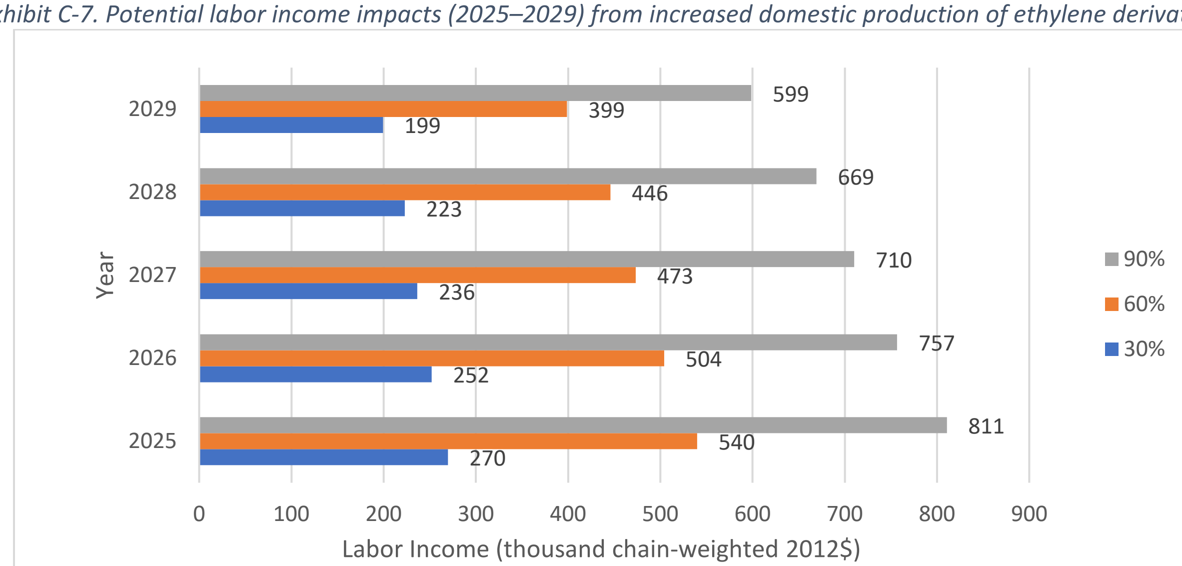
Exhibit C-6 reports the potential annual impacts to employment resulting from the production of ethylene derivatives LDPE, LLDPE, and HDPE, which will be substituted for projected imports of the same ethylene derivatives beginning in 2025 and continuing throughout the forecast period (2026–2029). Results are presented for scenarios where 30, 60, and 90 percent of ethylene derivative imports are being replaced by domestic production of the same derivatives.

Exhibit C-6. Potential annual employment impacts (# of jobs) (2025–2029) from increased domestic production of ethylene derivatives



Following the same assumptions outlined above, the potential annual impacts to labor income are presented in Exhibit C-7.

Exhibit C-7. Potential labor income impacts (2025–2029) from increased domestic production of ethylene derivatives



6. Opportunity Cost Calculations and Results

To calculate the opportunity cost of exporting domestically produced ethane in support of foreign manufacturing, the potential number of jobs created, and the amount of labor income generated were compared across the scenarios described above. Specifically, the following scenarios were compared:

1. The results from the scenario where domestically produced ethane being used to meet export demand and exports of ethane increasing by 20 percent from their base were compared to the scenario where domestically produced ethane was being used to support domestic manufacturing of three ethylene derivatives, which were substituting for 30 percent of projected derivative imports.

2. The results from the scenario where domestically produced ethane being used to meet export demand and exports of ethane increasing by 30 percent from their base were compared to the scenario where domestically produced ethane was being used to support domestic manufacturing of three ethylene derivatives, which were substituting for 60 percent of projected derivative imports.

3. The results from the scenario where domestically produced ethane being used to meet export demand and exports of ethane increasing by 40 percent from their base were compared to the scenario where domestically produced ethane was being used to support domestic manufacturing of three ethylene derivatives, which were substituting for 90 percent of projected derivative imports.

The results (see Exhibit C-7. and Exhibit C-6) indicated using domestically produced ethane to support the manufacturing of ethylene derivatives yields higher returns than exporting domestically produced ethane. Specifically, the forgone benefits of using domestically produced ethane to meet export demand instead of to support the manufacturing of ethylene derivatives is estimated to include $142,000–674,000 in labor income and 1,350–7,439 direct and indirect jobs.

Appendix D: Industries and Commodities Embedded Within the IO Accounts Used

Exhibit D-1. Industries and commodities represented in the IO accounts used (232)

Sector Number	Industry/Commodity Description	NAICS 2012
	Agriculture, forestry, fishing and hunting	11
1	Crop production	111
2	Animal production and aquaculture	112
3	Forestry	1131, 1132
4	Logging	1133
5	Fishing, hunting and trapping	114
6	Support activities for agriculture and forestry	115
	Mining	21
7	Oil and gas extraction	211
8	Coal mining	2121
9	Metal ore mining	2122
10	Nonmetallic mineral mining and quarrying	2123
11	Support activities for mining	213
	Utilities	22
12	Electric power generation, transmission and distribution	2211
13	Natural gas distribution	2212
14	Water, sewage and other systems	2213
	Construction	
15	Construction	23
	Manufacturing	31, 32, 33
16	Animal food manufacturing	3111
17	Grain and oilseed milling	3112
18	Sugar and confectionery product manufacturing	3113
19	Fruit and vegetable preserving and specialty food manufacturing	3114
20	Dairy product manufacturing	3115
21	Animal slaughtering and processing	3116
22	Seafood product preparation and packaging	3117
23	Bakeries and tortilla manufacturing	3118
24	Other food manufacturing	3119
25	Beverage manufacturing	3121
26	Tobacco manufacturing	3122
27	Textile mills and textile product mills	313,314
28	Apparel, leather and allied product manufacturing	315, 316
29	Sawmills and wood preservation	3211

Sector Number	Industry/Commodity Description	NAICS 2012
30	Veneer, plywood, and engineered wood product manufacturing	3212
31	Other wood product manufacturing, including wood tv, radio and sewing machine cabinet manufacturing	3219
32	Pulp, paper, and paperboard mills	3221
33	Converted paper product manufacturing	3222
34	Printing and related support activities	323
35	Petroleum and coal products manufacturing	324
36	Basic chemical manufacturing	3251
37	Resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing	3252
38	Pesticide, fertilizer, and other agricultural chemical manufacturing	3253
39	Pharmaceutical and medicine manufacturing	3254
40	Paint, coating, and adhesive manufacturing	3255
41	Soap, cleaning compound, and toilet preparation manufacturing	3256
42	Other chemical product and preparation manufacturing	3259
43	Plastics product manufacturing	3261
44	Rubber product manufacturing	3262
45	Clay product and refractory manufacturing	3271
46	Glass and glass product manufacturing	3272
47	Cement and concrete product manufacturing	3273
48	Lime, gypsum and other nonmetallic mineral product manufacturing	3274, 3279
49	Iron and steel mills and ferroalloy manufacturing	3311
50	Steel product manufacturing from purchased steel	3312
51	Alumina and aluminum production and processing	3313
52	Nonferrous metal (except aluminum) production and processing	3314
53	Foundries	3315
54	Forging and stamping	3321
55	Cutlery and hand tool manufacturing	3322
56	Architectural and structural metals manufacturing	3323
57	Boiler, tank, and shipping container manufacturing	3324
58	Hardware manufacturing	3325
59	Spring and wire product manufacturing	3326
60	Machine shops; turned product; and screw, nut, and bolt manufacturing	3327
61	Coating, engraving, heat treating, and allied activities	3328
62	Other fabricated metal product manufacturing	3329
63	Agriculture, construction, and mining machinery manufacturing	3331
64	Industrial machinery manufacturing	3332
65	Commercial and service industry machinery manufacturing, including digital camera manufacturing	3333
66	Ventilation, heating, air-conditioning, and commercial refrigeration equipment manufacturing	3334
67	Metalworking machinery manufacturing	3335
68	Engine, turbine, and power transmission equipment manufacturing	3336
69	Other general purpose machinery manufacturing	3339
70	Computer and peripheral equipment manufacturing, excluding digital camera manufacturing	3341
71	Communications equipment manufacturing	3342

Sector Number	Industry/Commodity Description	NAICS 2012
72	Audio and video equipment manufacturing	3343
73	Semiconductor and other electronic component manufacturing	3344
74	Navigational, measuring, electromedical, and control instruments manufacturing	3345
75	Manufacturing and reproducing magnetic and optical media	3346
76	Electric lighting equipment manufacturing	3351
77	Household appliance manufacturing	3352
78	Electrical equipment manufacturing	3353
79	Other electrical equipment and component manufacturing	3359
80	Motor vehicle manufacturing	3361
81	Motor vehicle body and trailer manufacturing	3362
82	Motor vehicle parts manufacturing	3363
83	Aerospace product and parts manufacturing	3364
84	Railroad rolling stock manufacturing	3365
85	Ship and boat building	3366
86	Other transportation equipment manufacturing	3369
87	Household and institutional furniture and kitchen cabinet manufacturing, excluding wood tv, radio and sewing machine cabinet manufacturing	3371
88	Office furniture (including fixtures) manufacturing	3372
89	Other furniture related product manufacturing	3379
90	Medical equipment and supplies manufacturing	3391
91	Other miscellaneous manufacturing	3399
	Wholesale trade	42
92	Wholesale trade	42
	Retail trade	44, 45
93	Motor vehicle and parts dealers	441
94	Food and beverage stores	445
95	General Merchandise stores	452
96	Retail, except motor vehicle and parts dealers, food and beverage stores, and general merchandise stores	442-4, 446-8, 451, 453-4
	Transportation and warehousing	48, 49
97	Air transportation	481
98	Rail transportation	482
99	Water transportation	483
100	Truck transportation	484
101	Transit and ground passenger transportation	485
102	Pipeline transportation	486
103	Scenic and sightseeing transportation and support activities for transportation	487, 488
104	Couriers and messengers	492
105	Warehousing and storage	493
	Information	
106	Newspaper, periodical, book, and directory publishers	5111
107	Software publishers	5112

Sector Number	Industry/Commodity Description	NAICS 2012
108	Motion picture, video, and sound recording industries	512
109	Radio and television broadcasting	5151
110	Cable and other subscription programming	5152
111	Wired telecommunications carriers	5171
112	Wireless telecommunications carriers (except satellite)	5172
113	Satellite, telecommunications resellers, and all other telecommunications	5174, 5179
114	Data processing, hosting, and related services	518
115	Other information services	519
	Finance and insurance	52
116	Monetary authorities, credit intermediation, and related activities	521, 522
117	Securities, commodity contracts, fund, trusts and other financial investments and vehicles and related activities	523, 525
118	Insurance carriers	5241
119	Agencies, brokerages, and other insurance related activities	5242
	Real estate and rental and leasing	53
120	Real estate	531
121	Automotive equipment rental and leasing	5321
122	Consumer goods rental and general rental centers	5322, 5323
123	Commercial and industrial machinery and equipment rental and leasing	5324
124	Lessors of nonfinancial intangible assets (except copyrighted works)	533
	Professional, scientific, and technical services	
125	Legal services	5411
126	Accounting, tax preparation, bookkeeping, and payroll services	5412
127	Architectural, engineering, and related services	5413
128	Specialized design services	5414
129	Computer systems design and related services	5415
130	Management, scientific, and technical consulting services	5416
131	Scientific research and development services	5417
132	Advertising, public relations, and related services	5418
133	Other professional, scientific, and technical services	5419
	Management of companies and enterprises	55
134	Management of companies and enterprises	55
	Administrative and support and waste management and remediation services	56
135	Office administrative services	5611
136	Facilities support services	5612
137	Employment services	5613
138	Business support services	5614
139	Travel arrangement and reservation services	5615
140	Investigation and security services	5616
141	Services to buildings and dwellings	5617
142	Other support services	5619

Sector Number	Industry/Commodity Description	NAICS 2012
143	Waste management and remediation services	562
	Educational services	61
144	Elementary and secondary schools; private	6111
145	Junior colleges, colleges, universities, and professional schools; private	6112, 6113
146	Other educational services; private	6114-7
	Health care and social assistance	62
147	Offices of physicians	6211
148	Offices of dentists	6212
149	Offices of other health practitioners	6213
150	Outpatient care centers	6214
151	Medical and diagnostic laboratories	6215
152	Home health care services	6216
153	Other ambulatory health care services	6219
154	Hospitals; private	622
155	Nursing and residential care facilities	623
156	Individual and family services	6241
157	Community and vocational rehabilitation services	6242, 6243
158	Child day care services	6244
	Arts, entertainment, and recreation	71
159	Performing arts companies	7111
160	Spectator sports	7112
161	Promoters of events, and agents and managers	7113, 7114
162	Independent artists, writers, and performers	7115
163	Museums, historical sites, and similar institutions	712
164	Amusement parks and arcades	7131
165	Gambling industries (except casino hotels)	7132
166	Other amusement and recreation industries	7139
	Accommodation and food services	72
167	Accommodation	721
168	Food services and drinking places	722
	Other services (except public administration)	81
169	Automotive repair and maintenance	8111
170	Electronic and precision equipment repair and maintenance	8112
171	Commercial and industrial machinery and equipment (except automotive and electronic) repair and maintenance	8113
172	Personal and household goods repair and maintenance	8114
173	Personal care services	8121
174	Death care services	8122
175	Dry-cleaning and laundry services	8123
176	Other personal services	8129
177	Religious organizations	8131

Sector Number	Industry/Commodity Description	NAICS 2012
178	Grantmaking and giving services and social advocacy organizations	8132, 8133
179	Civic, social, professional, and similar organizations	8134, 8139
180	Private households	814
	Government	NA
181	Postal Service	491
182	Federal electric utilities	NA
183	Federal enterprises except the Postal Service and electric utilities	NA
184	Federal defense government compensation	NA
185	Federal defense government consumption of fixed capital	NA
186	Federal defense government except compensation and consumption of fixed capital	NA
187	Federal non-defense government compensation	NA
188	Federal non-defense government consumption of fixed capital	NA
189	Federal non-defense government except compensation and consumption of fixed capital	NA
190	Local government passenger transit	NA
191	Local government enterprises except passenger transit	NA
192	Local government hospitals compensation	NA
193	Local government educational services compensation	NA
194	Local government, other compensation	NA
195	State government enterprises	NA
196	State government hospitals compensation	NA
197	State government educational services compensation	NA
198	State government, other compensation	NA
199	State and Local government consumption of fixed capital	NA
200	State and Local government except compensation and consumption of fixed capital	NA
	Special industries	NA
201	Owner-occupied dwellings	NA
202	Noncomparable imports	NA
203	Scrap	NA
204	Used and secondhand goods	NA
205	Rest of the world adjustment	NA

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