The Journal of Economic Asymmetries 20 (2019) e00132

Contents lists available at ScienceDirect

The Journal of Economic Asymmetries

journal homepage: www.elsevier.com/locate/jeca

The U.S. crude oil refining industry: Recent developments, upcoming challenges and prospects for exports

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ARTICLE INFO

Keywords:
Petroleum refining
Gasoline
Diesel
Exports
Refining industry

ABSTRACT

In 2018 the U.S. petroleum refining industry is the largest and most advanced in the world. Continuous consolidations and investments in complex refinery additions have allowed this industry to remain competitive and the shale oil revolution has contributed to the U.S. becoming a net exporter of refined petroleum products in 2008. In light of current and forecasted changes in refined petroleum product demand and worldwide refining capacity additions, the U.S. petroleum refining industry faces new challenges. This paper provides an in-depth study of this industry, presenting past trends, its current state and the effects that a changing U.S. crude oil production has on refiners. Furthermore, a scenario analysis is used to forecast future production levels and the volumes of major refined products available for exports over the years 2017–2032. The competitiveness of current U.S. gasoline and diesel exports is evaluated and forecasted gasoline and diesel demand in current export markets is compared to available export volumes. Major challenges facing refiners by changing market conditions and new regulatory rules are discussed. Finally, a set of recommendations is provided.

1. Introduction

The U.S. petroleum refining industry is the largest and most sophisticated of its kind in the world in 2019. Since the lifting of the U.S. Crude Oil Export Ban in December 2015 all international trade restrictions in this industry have been lifted and the U.S. market is fully integrated in the world market for refined products. In 2017 global petroleum refining capacity reached 98.7 million barrels per day (MMBD) and the U.S. accounted for nearly 19% of this (OECD/IEA, 2018). The International Energy Agency forecasts U.S. domestic capacity to further increase by 0.2 MMBD by 2022 (OECD/IEA, 2017a, pp. 1–147).

However, with changing regional trends in refined petroleum product demand growth, shifts in refining capacity additions, and the increased complexity of refineries around the world (Zavaleta, Walls, & Rusco, 2015), the U.S. petroleum refining industry faces new challenges. Over the years 2000–2017 global refining capacity has grown by 17 MMBD, and Asia accounted for 65% of these additions, while the Middle East accounted for 15% (Gresh, Royall, & Yu, 2017, pp. 1–106). A similar trend is expected through 2023 as world refining capacity is forecasted to increase by 7.7 MMBD from 2017 levels (OECD/IEA, 2018). The Middle East (with big projects in Kuwait, and Saudi Arabia),[1] China, and India account for more than half of all projected capacity additions from 2017 to 2023. The latter investments are driven by strong economic growth leading to an increase in the standard of living and an increased demand for transportation fuels in many non-OECD countries. In addition, new fuel specifications that have come into effect recently in Asia (Lofting, Malek, Arun, & Dsouza, 2018), and China's desire to become a prominent supplier of refined petroleum products to South East

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[1] Al-Zour in Kuwait 615 kbd; Jizan Saudi Arabia (400 kbd) (Gresh et al., 2017, pp. 1–106).

https://doi.org/10.1016/j.jeca.2019.e00132
Received 21 August 2019; Accepted 30 August 2019

Asian nations has also spurred capacity increases.

In contrast to forecasted demand increases in Asia, Latin America and Africa, demand is projected to decrease in the U.S. and Europe.[2] Fossil-fuels' share in world primary energy demand stands at 81% in 2016 and according to the World Energy Outlook's current policy scenario and new policies scenario this share is expected to decrease only slightly to respectively 79% and 75% by 2040 (OECD/IEA, 2017b). Oil represents the lion share in fossil fuel demand and total liquids demand is expected to increase from 99.9 MMBD in 2018 to 104.7 MMBD by 2023 (OECD/IEA, 2018). Although the share of refined products in total liquids demand is expected to remain around 85%, forecasts show an increase in product demand of 4.8 MMBD between 2017 and 2023 (OECD/IEA, 2018).

U.S. exports of finished petroleum products increased steadily since the onset of the shale oil revolution in 2005, and in 2008 the U.S. became a net exporter of refined products. U.S. refiners' output of gasoline, diesel, jet-fuel kerosene and residual fuel oil accounts for a combined 88% of total production in 2017 (EIA, 2018a). Gasoline, which on its own accounts for 51% of total refined product output in the same year is the most important product for refiners on the domestic market and its demand greatly influences refiners' profits. Although U.S. demand for gasoline varies with cyclical fluctuations in economic activity, a long-term historic increasing trend in demand can be observed. However, forecasts show that this trend is about to be reversed mainly due to greater fuel efficiencies in new cars and the steadily increasing share of hybrid and electric cars in the U.S. vehicle fleet. While U.S. combined demand for refined products is forecasted to decline over the coming two decades, this paper forecasts refinery output volumes to continue their long-run increasing trend. These changes as well as the observed shifts in major demand and supply centers around the world will require U.S. refiners to adjust and search for opportunities to expand sales in existing export markets and/or look for new destinations for their products. This paper's contribution to the literature is to provide an in-depth analysis of the U.S. refining industry and to identify the challenges and opportunities it faces. Therefore, the next section presents a thorough analysis of the U.S. refining sector's long-run trends, its current state and recent developments. The evolution of U.S. crude oil production and its importance to refiners is examined in section 3. Section 4 analyzes U.S. exports of finished petroleum products. Section 5 forecasts future refined product output volumes as well as available export volumes of gasoline, diesel, jet-fuel and residual fuel oil (RFO) for the years 2017–2032. Section 6 discusses the challenges and opportunities exporters face in placing additional quantities of gasoline and distillates in light of changes on both the demand and supply side of the market as well as new regulations and increased international competition. Section 7 concludes the paper by providing a set of recommendations.

2. The U.S. Petroleum refining industry

2.1. Industry development 1985–2017

The first U.S. oil refinery using atmospheric distillation started its operation in 1862 (API, 2011) soon thereafter the U.S. automotive industry started its operation in the early 1890s. In 2018 the U.S. has the world's largest and most sophisticated refining industry. Since 1985 when the U.S. had 199 refineries, the industry went through continuous consolidations leading to a drop in the number of refineries by 34% to reach 132 in 2019 (Fig. 1). Starting in the 1980s many refineries stopped operating and plant closures were mainly due to changes in market conditions that made economies of scale and refinery complexity more important. Contributing factors are changes in regulations, such as price controls, more stringent fuel specifications, and changes in local input supply or demand conditions (Meyer & Taylor, 2018). Thus exiting refineries typically are smaller, less sophisticated and process less than 50,000 barrels per day (Meyer & Taylor, 2018). For a treatment of the effect of consolidations on refined product prices see Kendix and Walls (2010). While the most recent newly built crude oil refinery dates back to 1977 many companies made substantial investments in existing units and in new technologies that would allow further treatment of crude oil distillation unit output and thus allow to increase total product output (EIA, 2018b). Investment and innovation has increased production of higher yield products and allowed to 'debottleneck' refineries. In 2019 U.S. crude oil operable distillation capacity has reached 18.8 MMBD (EIA, 2019a).

2.1.1. Utilization rates

Refinery utilization rates are driven by domestic and international liquids demand, whereby in the U.S. the demand for gasoline plays the most important role. U.S. gasoline demand fluctuates strongly in line with economic activity and co-determines refinery utilization rates which have fluctuated within a range of 85% to nearly 96% over the years 1985–2017 (Fig. 2). U.S. utilization rates are high by international comparison as the worldwide long-run average is hovering around 80%. Regional differences are big and the Middle East and Asia consistently show utilization rates above the world average while rates in Latin America and Africa typically fall well below world averages (Lofting et al., 2018). After reaching a high of 95.6%, in 1998 U.S. utilization rates hovered slightly above 90% until 2005. With the onset of the global financial crisis and the drop in gasoline demand, U.S. refinery utilization rates fell to a low of 82.9% in 2009. These developments also led to firm closures and further consolidations (Andrews, Pirog, & Sherlock, 2010). From 2010 to 2017 average annual refinery utilization rates ranged from 86.2% to 91% showing a fairly stable increasing trend (Fig. 2).

2.2. Current state

The U.S. refining industry is mature, capital intensive, very competitive but highly regulated. In 2017 industry revenue is estimated

[2] There exist some exceptions to this trend: countries with higher economic growth rates such as Turkey for example are forecasted to see an increase in the demand for refined products over the coming years.

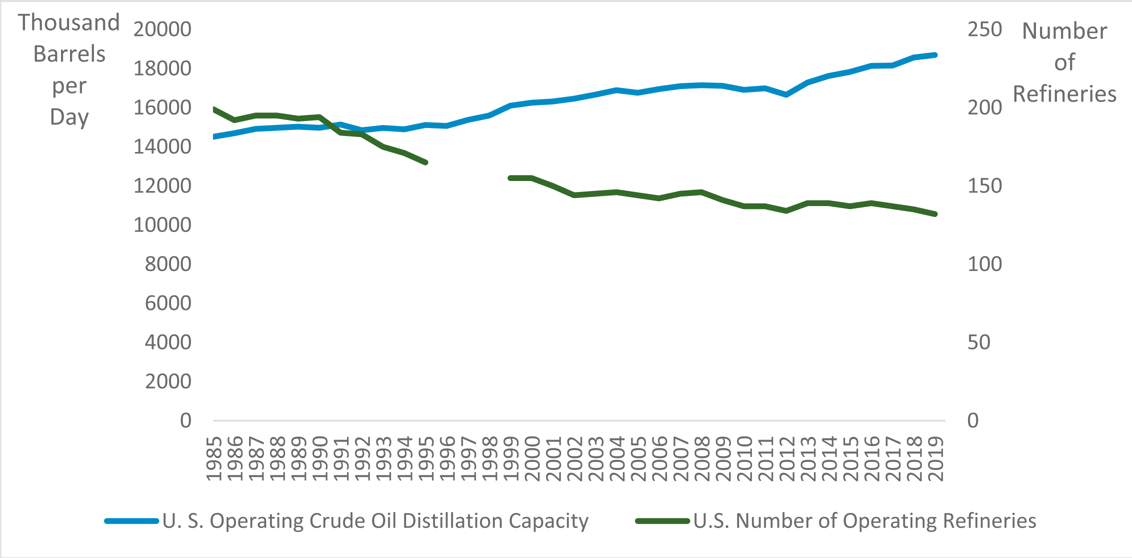

Fig. 1. U.S. number of operating refineries and refinery operating capacity
Source: author's calculations, data retrieved from http://eia.gov, July 2019.

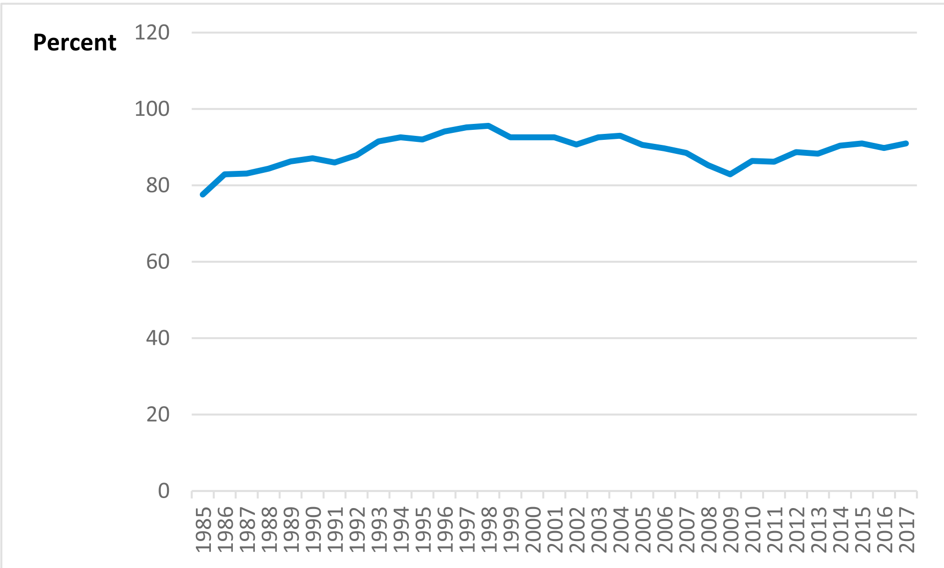

Fig. 2. U.S. percent utilization of refinery operable capacity 1985-2017
Source: author's calculations, data retrieved from http://eia.gov, April 2018.

at $ 517.8 billion with households, industry and exports contributing respectively 38.9%, 17.7%, and 15.6% to the total (IBIS, 2017). Industry key drivers include the price of crude oil, the price of refined products, the rate of economic growth in the domestic economy, globally, in big oil consuming countries and in major export markets. Further factors of importance are vehicle miles travelled, various regulations, such as for example the Renewable Fuel Standard that determines the amount of ethanol blended into gasoline and thereby reduces gasoline demand, the penetration rate of hybrid or electrical vehicles, changing market conditions due to changes in input availability, or policies affecting demand and/or supply in major U.S. export markets (examples include: changes in crude oil production, or the phasing out of diesel powered cars in Europe).

The industry is exposed to high margin volatility largely determined by the spread in crude oil and refined product prices, particularly the price of gasoline. Moreover, the spread between different types of crude oil is also important. U.S. refineries benefit from a number of advantages compared to their major competitors. These advantages include the complexity of its refineries, the rapid implementation of new technologies, low capital and operating costs, low energy costs (due to low natural gas prices) and access to a

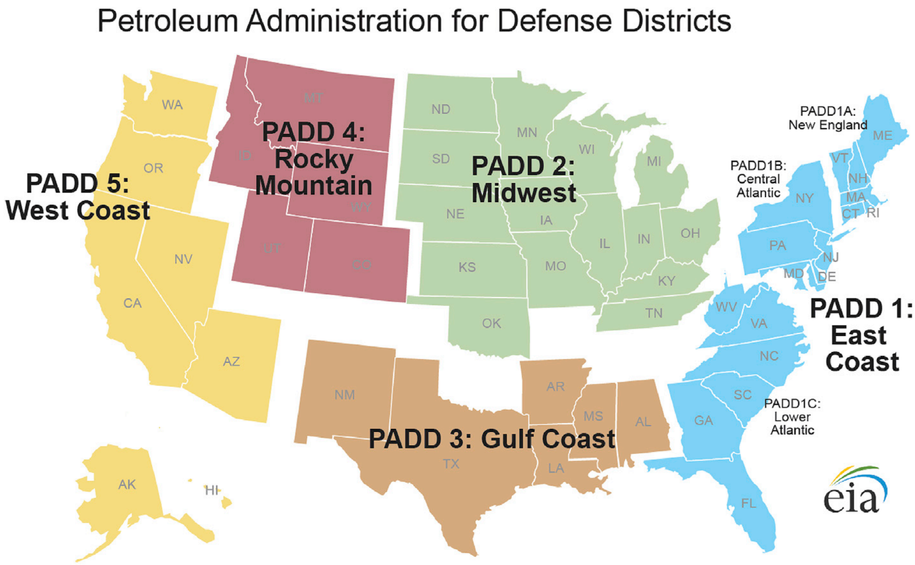

Fig. 3. Petroleum administration for defense Districts
Source: Energy Information Administration/Petroleum Supply Monthly, March 2017.

skilled workforce.

The refining sector is composed of a wide variety of firms ranging from vertically integrated multinational oil companies, that are involved in upstream, midstream and downstream operations and benefit from economies of scale, to independent refiners (that may also own pipelines) and small refineries (Difiglio, 2011). Independent refiners are generally not involved in upstream oil and gas exploration or production. As of January 2019 the U.S. refining industry is composed of 54 companies.

The simple concentration ratio (CR) for the four biggest firms shows that they hold a combined market share of 46% whereas the top ten companies hold a combined market share of 71%. The Herfindahl Hirschman Index[3] (HHI) is more informative than the simple CR as it allows to measure the extent to which firms are able to raise the price above cost. It takes into account the number of players in a market as well as their relative sizes (Viscusi, Harrington, & Vernon, 2005). The Department of Justice, and the Federal Trade Commission classify markets with an HHI of less than 1500 as not concentrated[4] (DOJ, 2010). Thus the U.S. petroleum refining industry, which in 2019 has a HHI of around 600 is considered competitive and has a low price-cost margin (see Table 1).

2.3. Industry geographic organization in Petroleum Administration for Defense Districts (PADDs)

The U.S. refining industry is organized geographically in Petroleum Administration for Defense Districts (PADDs) that were created during World War II to ration gasoline. The Defense Production Act of 1950 adopted the five established PADDs which regroup the 50 States and the District of Columbia (Fig. 3).[5] The PADDs are connected through a network of crude oil and refined product pipelines that allow for inter-PADD trade (Andrews et al., 2010). Table 2 displays the capacities and utilization rates of U.S. refineries by PADD.

Each of the Petroleum Administration for Defense Districts (PADD) has its particularities in terms of capacity, the classification of its refineries, access to various inputs, fuels and imports, and its connectivity to other regions.

- PADD 1 has a total of 8 operating refineries with a combined distillation capacity of 1.2 Million barrels per day accounting for only 6% of national refining capacity (Table 2). Although PADD 1 includes many small independent refiners, major players such as Philadelphia Energy Solutions, Philipps 66 Company and Monroe Energy LLC hold the bulk of crude oil distillation capacity (EIA, 2019b).
- PADD 2 accounts for 21% of U.S. refining capacity with 26 refineries. Many of the majors such as BP Products North America Inc., WRB Refining LP, Exxon Mobil Refining and Supply, are present in this market benefitting from economies of scale and vertical integration. PADD 2 uses mainly heavy Canadian crude and the share might increase along with an increasing Western Canadian

[3] HHI= $(100s_1)^2 + (100s_2)^2 + \ldots + (100s_n)^2$; the HHI is equal to 10,000 in the case of a monopoly and decreases with the number of sellers while it increases with more inequality between a given number of players (see Viscusi et al., 2005 for a full treatment).

[4] "Based on their experience, the Agencies generally classify markets into three types:Unconcentrated Markets: HHI below 1500; Moderately Concentrated Markets: HHI between 1500 and 2500; Highly Concentrated Markets: HHI above 2500″

[5] "PADD 1 is further divided into sub-PADDs, with PADD 1A as New England, PADD 1B the Central Atlantic States, and PADD 1C comprising the Lower Atlantic States. There are two additional PADDs (PADDs VI and VII) that encompass U.S. Territories" EIA, 2018 available at https://www.eia.gov/todayinenergy/detail.php?id=4890.

Table 1
U.S. top ten refining companies and market shares, 2019[a].

	Major Companies	Market share (percent)	Capacity Barrels per Calendar Day
1	Marathon Petroleum Corp.	16	3,024,715
2	Valero Energy Corp	12	2,181,300
3	Exxon Mobil Corp.	9	1,732,124
4	Philipps 66 Company	9	1,668,300
5	Chevron Corp.	5	925,431
6	PBF Energy Co LLC	5	865,000
7	Royal Dutch Shell Group	4	829,545
8	PDV America Inc.	4	754,765
9	BP PLC	4	678,500
10	Koch Industries Inc	3	640,000

Source: EIA, 2019b.
[a] Calculations are based on U.S. Total operable atmospheric crude oil distillation capacity as of January 1, 2019 of 18,802,435 barrels per calendar day.

Table 2
U.S. refineries, capacity and utilization rates in 2017.

Petroleum Administration for Defense Districts	Number of Operating Refineries (Idle refineries)	Operable Crude Oil Distillation Capacity (Thousand Barrels per Day)	Operating Crude Oil Distillation Capacity (Thousand Barrels per Day)	Percentage of total refining capacity	Refinery utilization rate (Percentage)
1 East Coast	8 (1)	1206	1187	7%	88.8
2 Midwest	26 (1)	3939	3873	21%	93.7
3 Gulf Coast	57 (1)	9758	9528	53%	90.9
4 Rocky Mountain	16	693	673	4%	89.5
5 West Coast	30 (1)	2904	2799	16%	88.8
Total U.S.	137	18460	18060	100%	

Source: data retrieved from http://www.eia.gov, April 2018.

Select-West Texas Intermediate (WCS-WTI) spread. PADD 2's average utilization rate of 93% is the highest in the U.S. in 2017 (EIA, 2019b).

- PADD 3 accounts for a bit more than half (53%) of total U.S. refining capacity and has the largest number of refineries. The refining capacity and major hubs are mainly located on the Gulf Coast of Texas and Louisiana. Refineries in this area account not only for the around 85% of total PADD 3 capacity, but these are also the biggest and most sophisticated refineries in the U.S., and thus benefit from economies of scale (EIA, 2019b).
- PADD 4 is the smallest refining market in the U.S. accounting for only 4% of refining capacity and 16 refineries (Table 2) with comparatively low conversion factors (EIA, 2019b).
- PADD 5 has 30 refineries and a capacity share of 16%. PADD 5's market is not very connected to the major tight oil regions that experienced a substantial boom in recent years. Inner PADD 5 heavy oil production is slowly declining and replaced by domestic crude, without major changes in the crude slate. The three major players in this market are Chevron USA Inc., Tesoro Refining and Marketing Company, BP West Coast Products LLC (EIA, 2019b).

2.4. Refined product inter-PADD trade

The supply of refined products is dominated by PADD 3 while major refined product consumption areas by PADD are, in order of importance, the PADD 1 (31%), PADD 2 (27%), the PADD 3 (21%), the PADD 5 (17%), and the PADD 4 (4%) (Fig. 4).

Table 3 shows that inter-PADD trade of refined products (mostly gasoline) is dominated by shipments from PADD III to PADD I and to some extent still to PADD II. The latter have however dropped dramatically in recent years as gasoline production in PADD II caught up with demand.

3. U.S. crude oil production and consumption

3.1. U.S. field production of crude oil

U.S. field production of crude oil gradually increased from nearly 174 MBD in 1900 to a first peak of 9.6 MMBD in 1970 (Fig. 5). Fluctuations in oil production in the 1970s were followed by a gradual decline in conventional oil production starting in the mid-1980s until 2008 when output reached a low of 5 MMBD. The onset of the shale oil revolution brought a reversal to this trend and the U.S. is now the world's biggest crude oil producer with nearly 11 MMBD in 2018 (EIA, 2019c). The EIA's 2018 Annual Energy Outlook further forecasts domestic crude production to reach close to 12 MMBD by 2032 while net imports will decline to 5.45 MMBD (EIA, 2018c).

Accessed in July 2018.

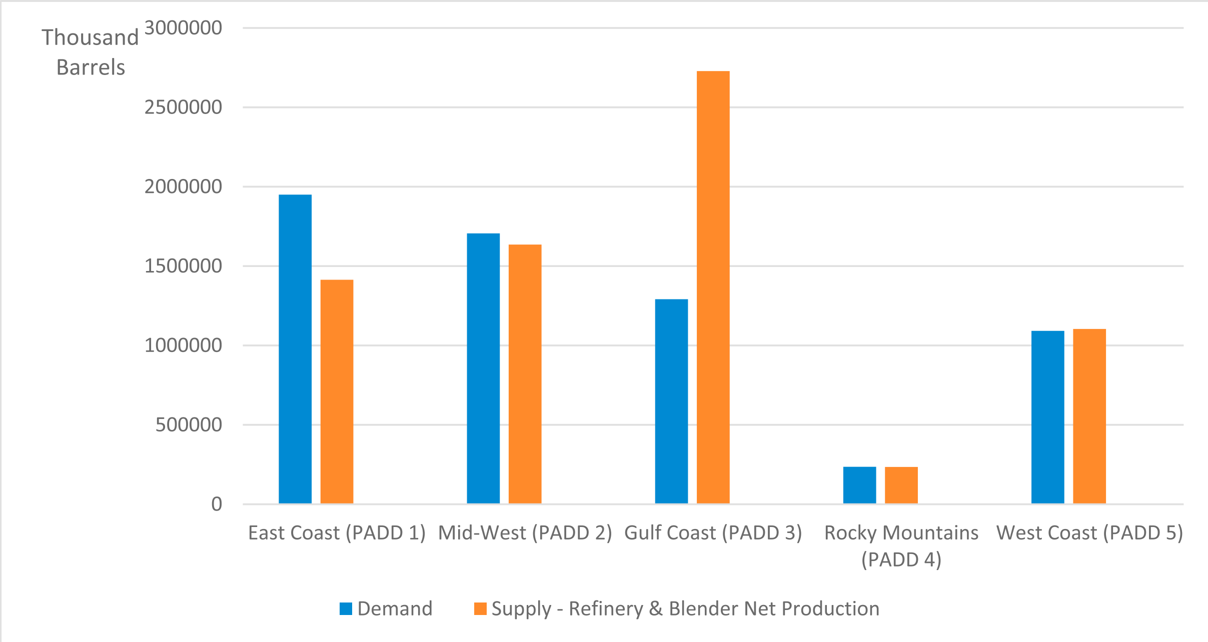

Fig. 4. Refined product demand and supply by PADD 2016.
Source: author's calculations, data retrieved from http://eia.gov, November 2017.

Table 3
U.S. petroleum product inter-PADD trade in 2016 (million barrels annually).

PADD	From 1	From 2	From 3	From 4	From 5	Total receipts
To 1	–	27	953	0	0	980
To 2	159	–	239	86	0	484
To 3	0	239	–	69	0	308
To 4	0	76	0	0	0	76
To 5	0	0	60	22	–	82
Total shipments	159	342	1252	177	0	

Source: http://www.eia.gov, September 2017.

The exploration and production (E&P) of tight oil is different from E&P of conventional reservoirs as it allows the industry to adjust production volumes more swiftly to changes in the price of oil. Hence the larger the share of tight oil in total U.S. oil production, the more elastic supply will be in reaction to changes in the price of crude oil. In 2019 tight oil accounts for 59% of total U.S. crude oil production (Table 4).

3.2. *Technical background*

About 85% of refiner and blender net input is crude oil. Other components include: fuel ethanol (5%), motor gasoline blending components (3%), hydrocarbon gas liquids (3%) and other liquids (4%). Total U.S. refinery input (including these components) reached 7 billion barrels or 19.2 MMBD in 2017 (EIA, 2018d). The quality of crude oil is generally assessed based on two criteria. Its density as measured by the American Petroleum Institute (API) gravity formula[6] resulting in light versus heavy crude,[7] and its sulfur content usually described as sweet versus sour crude. For example, through the process of simple distillation light sweet crudes will yield a higher share of lighter, higher value products such as gasoline, diesel or jet fuel. To reach a similar result with heavier crudes requires further refining processes. In general, this would make the same output from a heavy crude more costly and require a high price differential between light sweet and heavy sour crude oil to offset higher processing costs. Similarly, crudes with very high sulfur content affect both processing and output quality negatively (API, 2011).

[6] The API gravity formula was developed by Porter (1965). It is an arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of degrees API; it is calculated as follows: Degrees API = (141.5/(specific gravity) - 131.5).

[7] The higher the API gravity, the lighter the compound. Light crudes generally exceed 38° API and heavy crudes are commonly labeled as all crudes with an API gravity of 22° or below. Intermediate crudes fall in the range of 22°–38° API gravity.

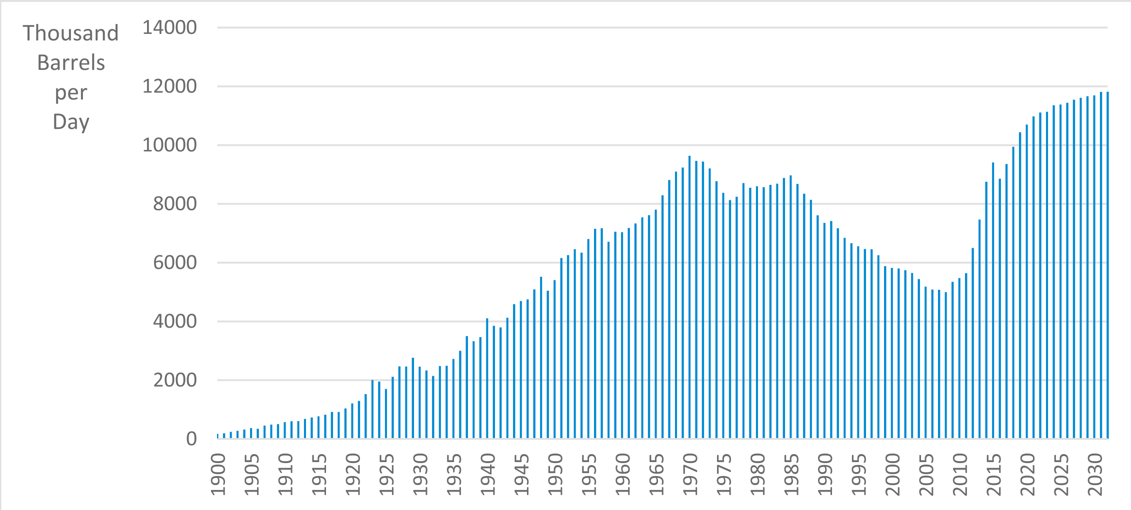

Fig. 5. U.S. crude oil field production 1900-2032
Source: data retrieved from EIA 2018. Available at: https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm.

Table 4
U.S. crude oil field production, imports and exports, 2018

Crude oil	Thousand Barrels per Day	Thousand Barrels
Refiner & Blender net input	16,962	6,191,008
U.S. Total production	10,957	3,999,609
- Tight oil	6,436	2,349,286
- Conventional	4,521	1,650,262
Imports	7,757	2,831,274
Exports	2,002	730,882
Net Imports	5,755	2,100,575

Source: data retrieved from http://www.eia.gov (EIA, 2019c).

Refineries are not homogenous and are characterized by different configurations and a range of processes that will determine the type of crude oil inputs that can be used. According to Nelson's Complexity Index refineries are categorized as *simple*, *complex* or *deep conversion*.[8] The technological complexity of refineries is a function of capital investment and refineries that possess complex secondary units can process any type of crude oil whereas simpler refineries are limited to sweet crudes that are less sulfurous and less corrosive.

3.3. The U.S. crude oil export ban

U.S. oil trade restrictions exist since the early twentieth century. Examples include the 1920 Jones Act, President Eisenhower's restrictions on the import of crude oil that were imposed in the 1960s, the 1973 Emergency Petroleum Allocation Act (EPAA), the 1975 Energy Policy and Conservation Act, and the 1975 crude oil export ban that was enacted in response to the first oil price shock (Colgan & Van de Graaf, 2017). The lifting of the crude oil export ban in December 2015 allowed for a fuller integration of the U.S. oil sector into the global market.

In 2010 the shale oil boom in combination with the oil export ban led to a fragmentation of the domestic market for crude oil (Borenstein & Kellogg, 2014; Kaminski, 2014; Kilian, 2016). Shale oil, a light sweet crude was abundantly available in the Cushing, Oklahoma hub, however, transportation constraints prevented it from travelling to refineries on the East Coast that could have absorbed additional quantities (Kilian, 2016). The supply glut in Cushing was exacerbated by a growing supply of Canadian crudes and to some extent by the relative scarcity of crude in the global market, and by 2011 the Brent-WTI spread increased with Brent selling at a premium of $20 per barrel at times (Colgan & Van de Graaf, 2017). Similarly, transportation constraints also led to a spread between WTI and Louisiana Light Sweet (LLS) in the years 2010–2013. For a full discussion of the factors leading to the lifting of the U.S. crude oil export ban see Colgan and Van de Graaf (2017).

[8] "Simple: composed of Crude Distillation Column, Vacuum Distillation Column and Reforming.Complex: the addition of conversion units such as cracking processes (i.e. Fluid Catalytic Crackers, Hydrocrackers) to a simple scheme, resulting in a complex configuration. Deep Conversion: the addition of conversion units such as Cokers to simple or complex configurations." (API, 2011).

Table 5
Top 12 countries of U.S. crude oil imports in 2016.

	Country	Thousand Barrels per Day
1	Canada	3,227
2	Saudi Arabia	1,099
3	Venezuela	741
4	Mexico	582
5	Colombia	442
6	Iraq	419
7	Ecuador	237
8	Kuwait	209
9	Nigeria	207
10	Angola	159
11	Brazil	145
12	Chad	67

Source: Energy Information Administration, US crude oil imports 2016, released October 31, 2017.

3.4. Refiner and blender crude oil input volumes and imports

U.S. refiner and blender net input of crude oil shows an overall increase from 15.1 MMBD in 2000 to almost 17 MMBD in 2018 with the exception of a brief decline in input during the years of the great recession, particularly in 2009. Increased U.S. field production however led to a gradual decrease in crude oil net imports from 10.1 MMBD in 2005 to 5.8 MMBD in 2018 (Table 4). Table 5 displays the top 12 crude oil exporters to the U.S.; Canada is leading the list with around 3.2 MMBD and is followed by Saudi Arabia, Venezuela, Mexico and Iraq. Together these top five exporters account for nearly 79% of U.S. imports, while the top ten exporters provide 93% of total U.S. crude oil imports (Table 5).

In 2017 U.S. crude oil imports account for an average of 50% of refinery total crude oil inputs. Fig. 6 shows that the relevance of crude imports varies across PADDs. In PADD 1 imports account for 88% of total crude oil input with substantial shares coming from Nigeria (34%) and Canada (30%), and minor supplies coming from Saudi Arabia (13%), Brazil (7%), Columbia (6%), and Iraq (4%) (Fig. 7). East coast refineries are predominantly configured to process light and sweet crude oil inputs. PADD 2 imports account for 65% of total crude input and are almost exclusively from Canada (98%) (Fig. 7). The bulk of Midwestern refineries is configured to process heavy crude oil. West Coast (PADD 5) refineries rely on imports for 52% of crude oil inputs coming predominantly from 4 countries: Saudi Arabia (30%), Canada (20%), Ecuador (20%) and Columbia (11%) (Fig. 7).

3.5. U.S. finished petroleum product supply and demand

In 2017 U.S. net production of finished petroleum products amounted to 19.7 million barrels per day while U.S. consumption[9] reached 17 million barrels per day. Finished gasoline and distillates account for a combined 74% of U.S. refiner and blender net production (Fig. 8). Gasoline, diesel, jet fuel and RFO account for the largest shares of products consumed in the domestic market with respectively 54% (10 MMBD), 23% (or 5.1 MMBD), 9% (or 1.8 MMBD) and 2% (0.5 MMBD) of total refined product consumption in 2017 (Fig. 8). U.S. production of finished petroleum products in 2017 exceeds or is equal to domestic consumption for all products with the exception of petrochemical feedstocks (Fig. 8).

The U.S. transportation sector relies on petroleum products for 92% of its total energy consumption and is dominated by gasoline accounting for 60%[10] of this total. Around 90% of gasoline sold in the U.S. is consumed by light duty vehicles (EIA, 2018f).

Despite the occurrence of economic downturns which led to minor fluctuations, U.S. finished petroleum product output shows a steady increasing trend over the past three decades (Fig. 9). Domestic demand for refined products however, shows stronger cyclical fluctuations than product output. For example, demand was strongly affected by the 2008 recession when a drop in vehicle miles travelled, as well as in new vehicle purchases, could be observed. Demand picked up again starting in 2011 without reaching pre-2008 levels until the end of 2016 (Fig. 9). The sluggish demand recovery is also partly due to increased vehicle fleet efficiency which improved by 5% from 2006 to 2016. Refineries have responded to domestic demand fluctuations by adjusting their utilization rates and the quantities of imports or exports.

4. U.S. exports of finished petroleum products

After three decades U.S. trade in finished petroleum products experienced a strong reversal in the second half of the last decade. The U.S. shale oil production boom allowed U.S. production of finished petroleum products to continue its long-run increasing trend while at

[9] Consumption was approximated: total refiner and blender production – exports + imports.

[10] Gasoline includes aviation gasoline and motor gasoline, which includes fuel ethanol. Estimates from the Annual Energy Outlook 2017, Reference case, Table 37, January 2017.

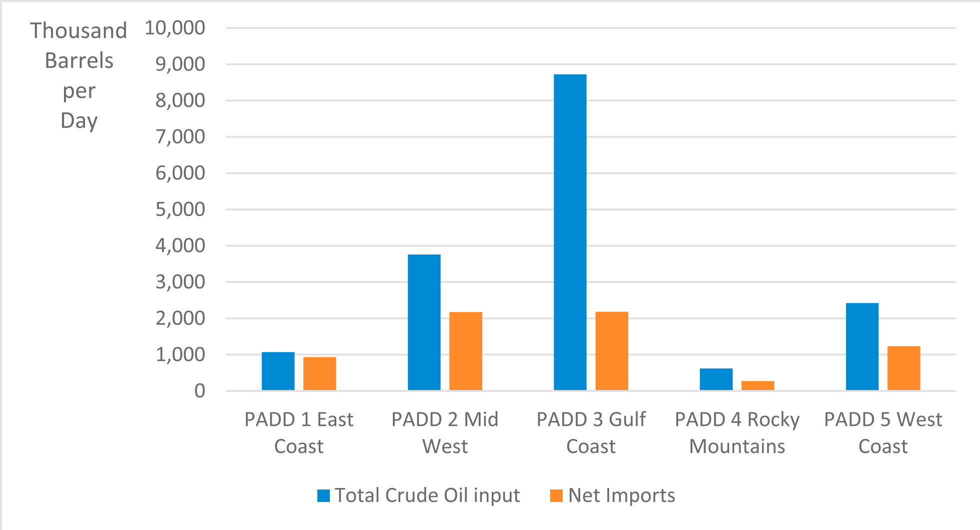

Fig. 6. Refinery total crude oil input and net imports by PADD in 2017
Source: author's calculations, data retrieved from http://eia.gov, April 2018.

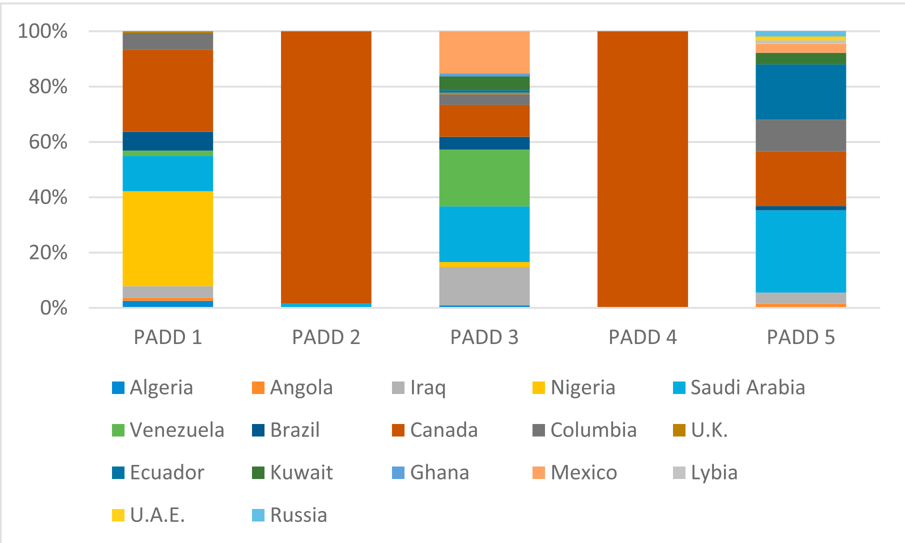

Fig. 7. U.S. imports of processing crude by source of origin for PADD 1 through 5 in March 2017
Source: author's calculations, data retrieved from http://www.eia.gov, April 2018.

the same time domestic consumption of these products experienced a sharp drop. Hence, U.S. exports of finished petroleum products increased steadily starting in 2005 to reach over 3.3 MMBD in 2017. Over the same period imports decreased and in 2008 the U.S. transitioned from net importer to net exporter of finished petroleum products (Fig. 10).

4.1. Major product categories and export destinations

In 2017 net exports of total finished petroleum products reached over 3 MMBD and net exports of gasoline and diesel accounted for respectively 27% and 46% of this total while heavy fuel oil and jet fuel accounted for respectively 4% and 1% (Fig. 11).

U.S. refiner's prime export markets are located in Latin America, Europe and Asia, but Fig. 12 shows that U.S. exports reach countries in four continents.

4.1.1. Gasoline

Mexico is the number one destination for U.S. gasoline exports, accounting for 52% of the total, corresponding to 421,000 barrels per

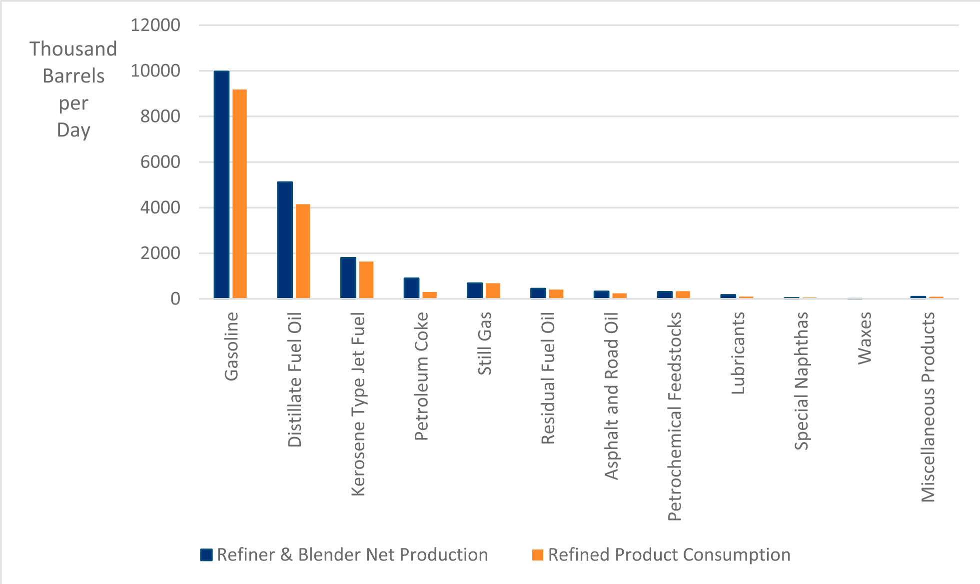

Fig. 8. U.S. production and consumption of finished petroleum products in 2017
Source: author's calculations, data retrieved from http://www.eia.gov, April 2018.

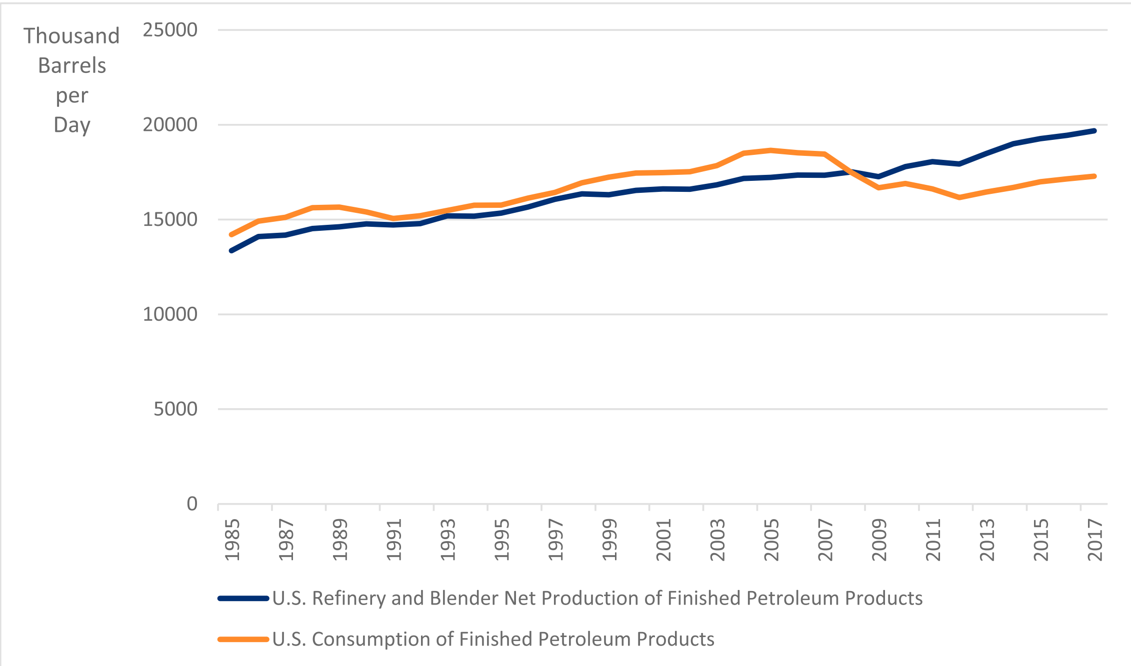

Fig. 9. U.S. finished petroleum products consumption vs. total net production 1985-2017
Source: data retrieved from http://eia.gov, April 2018.

day in 2017. With just a few exceptions, remaining gasoline exports are shipped to other destinations in Latin America (Fig. 13).

4.1.2. Distillate fuel oil

Major U.S. export markets for distillate fuel oil are located in Latin America and Europe accounting for respectively around 65% and 24% of total exports (Fig. 14). Mexico is the number 1 destination for U.S. distillate fuel oil, accounting for 16% of exports or 250,000 barrels per day in 2017. Other important markets in the Americas are Brazil, Chile, Peru, Colombia, Argentina, Ecuador, Panama, Guatemala and Costa Rica. Major export destinations in Europe include the Netherlands, France, Belgium and Spain (Fig. 14). In

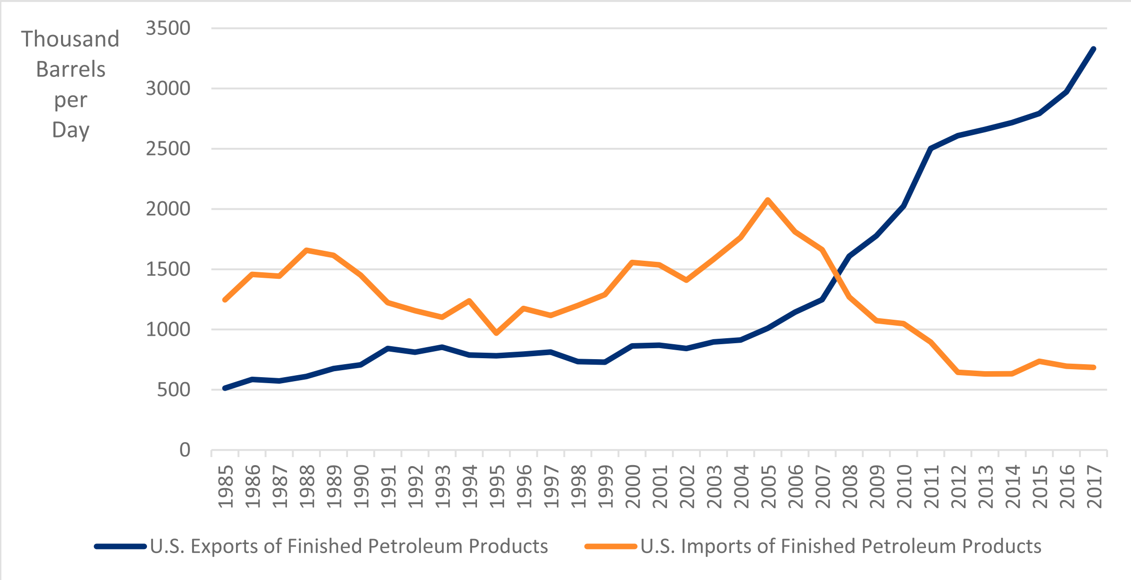

Fig. 10. U.S. exports & imports of finished petroleum products 1985-2017
Source: data retrieved from http://eia.gov, April 2018.

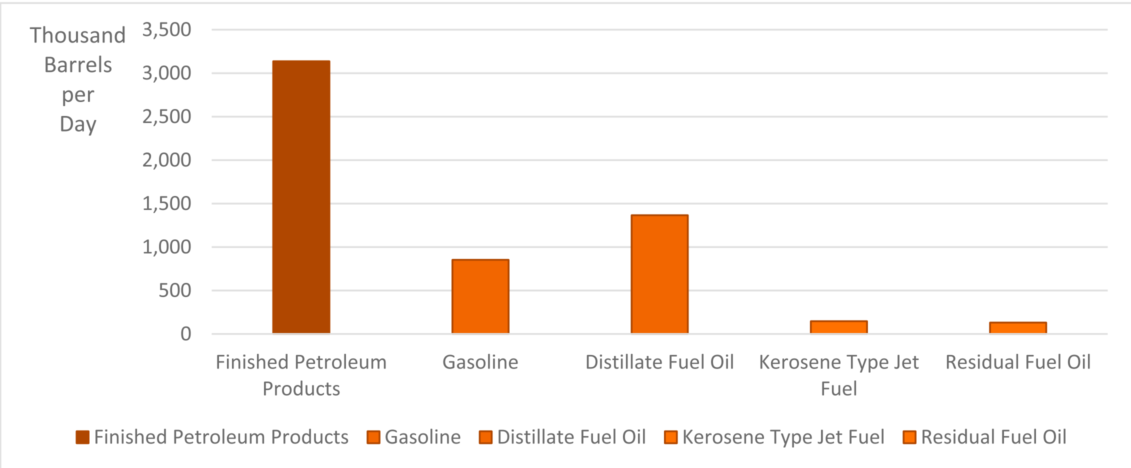

Fig. 11. U.S. net exports of total finished petroleum products and gasoline, distillate fuel oil, kerosene type jet fuel and residual fuel oil in 2017
Source: data retrieved from http://www.eia.gov, April 2018.

comparison to gasoline exports, U.S. distillate fuel oil export destinations are much more diversified. This reduces producers' risks of high exposure to sudden changes in demand in primary export markets.

4.1.3. Kerosene-type jet fuel

Canada and Mexico are the most important export destinations for jet fuel. U.S. Jet fuel exports to Canada continuously increased since 2008 and reached 38,000 barrels per day in 2017 while imports only amounted to 20,000 barrels per day. Mexico is the second most important export market for jet fuel with over 40,000 barrels per day delivered in 2017 (Fig. 15); this represents 19% of total U.S. kerosene exports. Other important destinations include several countries in the Americas, Europe as well as West Africa and Israel.

4.1.4. Residual fuel oil

Singapore was the number 1 destination for U.S. exports of RFO in 2017 and, with over 75,000 barrels per day it accounted for 26% of total U.S. RFO exports. The second and third most important export markets were Canada and Mexico accounting for respectively 38,000 and 37,000 barrels per day and a share of 13% of total U.S. RFO exports each (Fig. 16).

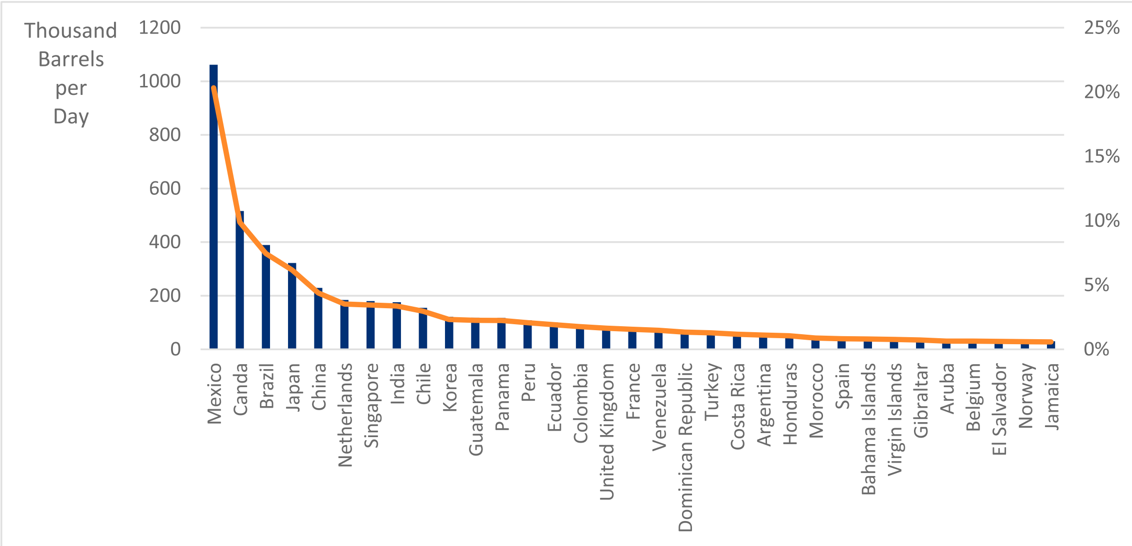

Fig. 12. U.S. exports of finished petroleum products by destination, 2017[11]
Source: data retrieved from http://www.eia.gov, April 2018.

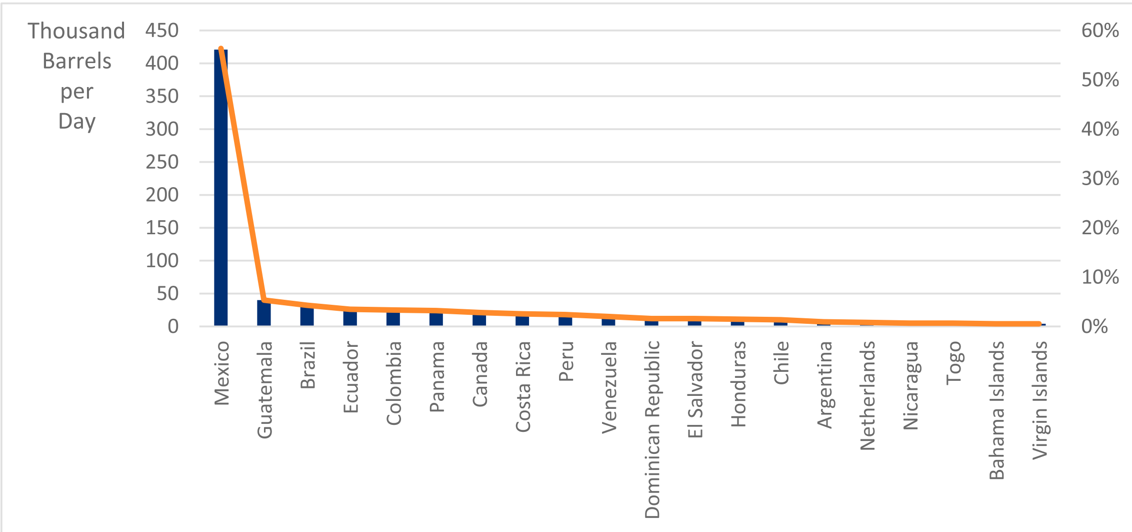

Fig. 13. U.S. exports of finished motor gasoline by destination country in 2017
Source: data retrieved from http://www.eia.gov, April 2018.

5. Scenario analysis

5.1. Forecasting production of refined petroleum products 2017–2032

In order to forecast potential future output levels of finished petroleum products for the years 2017–2032 a scenario analysis was developed. This forecasting exercise will allow us to determine export volumes that need to find markets in light of the forecasted decline in gasoline demand in the U.S. market. A baseline scenario (BS), scenario 1 (S1) and scenario 2 (S2) were constructed by extrapolation of historic growth rates of refiner and blender net production of finished petroleum products. The historic average annual growth rates for three different time periods are provided in Table 6.

Hence, based on these assumptions the production of finished petroleum products in the BS, S1 and S2 over the years 2017–2032

[11] Positive values for exports to countries that account for less than 1% of total U.S. finished petroleum products have been omitted in this graph.

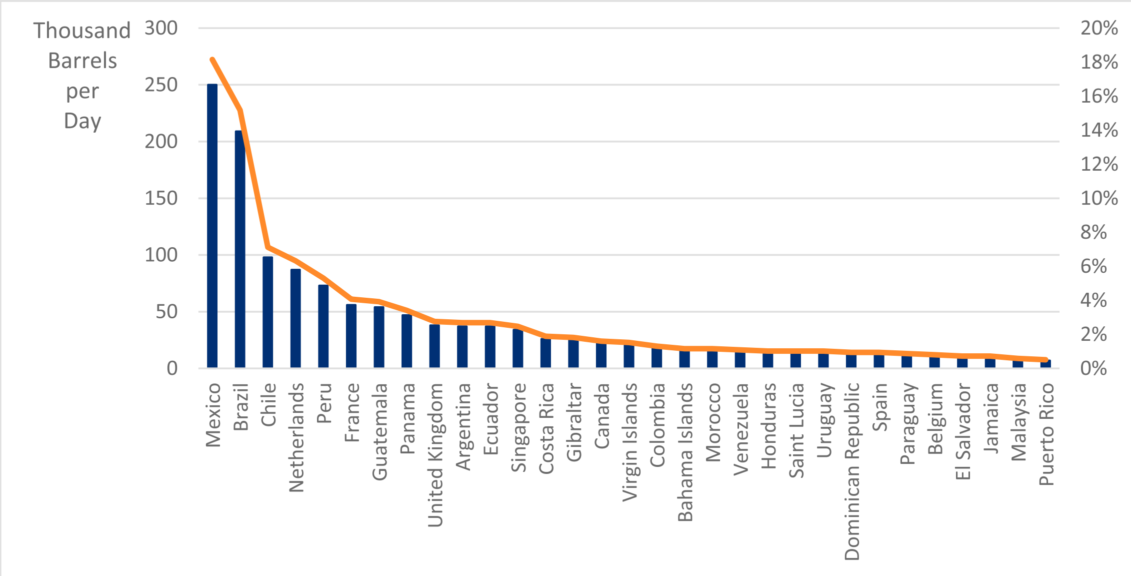

Fig. 14. Top 25 destinations[12] for U.S. distillate exports in 2017
Source: data retrieved from http://www.eia.gov, April 2018.

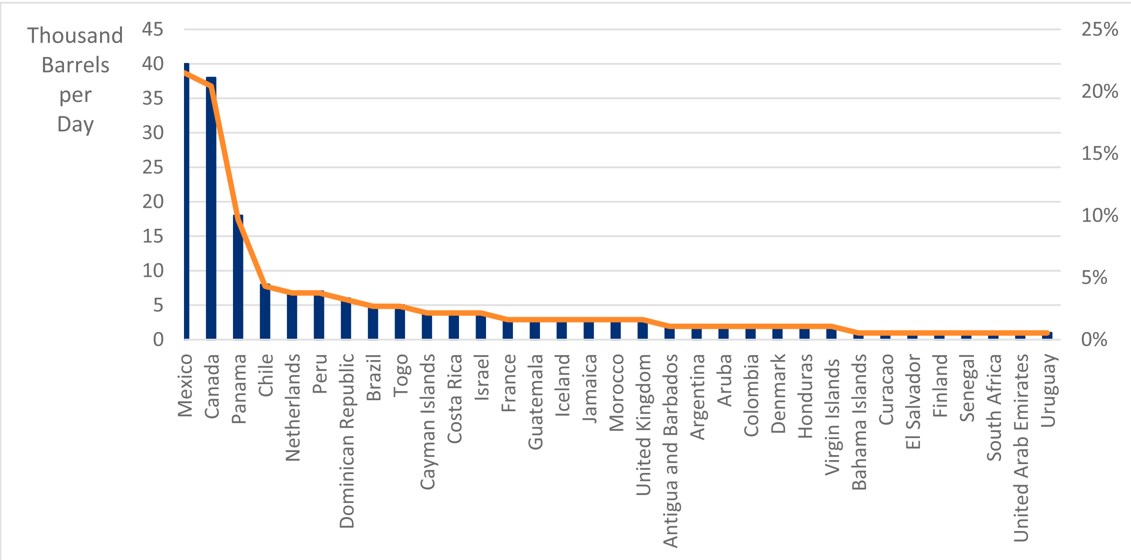

Fig. 15. U.S. exports of kerosene type jet fuel by destination country in 2017
Source: data retrieved from http://www.eia.gov, April 2018.

increases at respectively 1, 2%, 1% and 1.4%. All three scenarios lead to substantial increases in U.S. refiner and blender net production volumes. By 2032 production of finished petroleum products in BS, S1, and S2 will reach respectively 22.9, 23.5 and 24.2 MMBD.

5.2. Gasoline, diesel, jet-fuel and RFO production forecasts through 2032

Based on forecasted output levels of total finished petroleum products presented in Fig. 17, U.S. refiner and blender net production of gasoline, diesel, jet fuel and RFO through 2032 has been calculated. The base year for these forecasts is 2017 and it is assumed that the four fuels will continue accounting for their respective 2017 shares in total refined petroleum product as follows: gasoline 51%, diesel

[12] U.S. export destinations for distillate fuel that accounted for less than 1% of total exports were omitted in this graph.

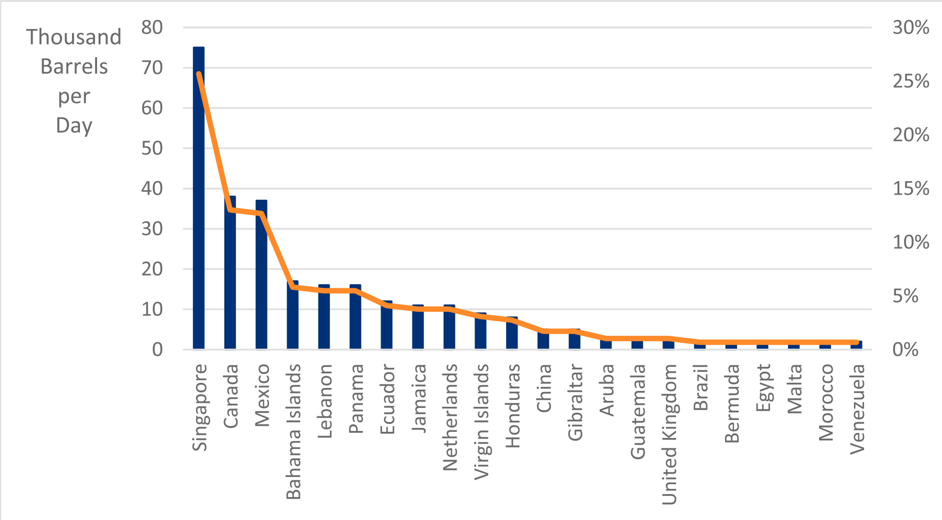

Fig. 16. U.S. exports of residual fuel oil by destination in 2017
Source: data retrieved from http://www.eia.gov, April 2018.

Table 6
Historic average annual growth rates of refiner and blender net production.

Years	Average annual growth rate[a]	Scenario
1985–2017	1.2%	Baseline (BS)
2000–2017	1%	Scenario 1 (S1)
2010–2017	1.4%	Scenario 2 (S2)

[a] Average annual growth rate = [1/(n-1)] ln (end-year value/first-year value).

26%, jet-fuel 9% and RFO 2%.

Forecasted gasoline and diesel production reaches respectively 5.9 MMBD and 2.1 MMBD by 2032 (Fig. 18). Net production of jet fuel and RFO is forecasted to amount to respectively 2.1 MMBD and 0.457 MMBD by 2032 (Fig. 18).

5.3. U.S. demand for gasoline, diesel, jet-fuel and RFO through 2032

U.S. forecasted demand for the four major refined product categories under consideration reaches a peak in 2018 after which it is expected to decline throughout the year 2032. This decline is primarily driven by a steady drop in gasoline demand (Fig. 19). U.S. domestic production of RFO exceeds demand. In 2017 about 2/3 of RFO consumed in the U.S. is used in the bunker sector while the remaining share is used by industry and for power production. The use of natural gas in industry and the power sector is expected to further increase in the coming years, gradually reducing demand for RFO.

5.4. Refined product export forecasts through 2032

Assuming that U.S. producers entirely satisfy U.S. demand for the selected four fuels over the years 2017–2032 the volumes available for exports have been calculated (Fig. 20). The forecast shows that quantities available for export of gasoline, diesel, jet fuel and RFO will increase from respectively 0.9 MMBD, 1.2 MMBD, 0.2 MMBD and 0.065 MMBD in 2017 to 4.7 MMBD, 2.1 MMBD, 0.08 MMBD, and 0.12 MMBD in 2032. The technical complexity of the U.S. refining industry make exports of high end products such as gasoline and distillates the more profitable than exports of lower end products such as RFO which can more easily be produced by simple refineries.

6. Results & discussion

6.1. Competitiveness of U.S. exports

The forecasts in the previous section show that over the years 2017–2032 U.S. refiners will produce increasingly larger quantities of gasoline and diesel for exports. These exports could be directed to markets where U.S. refiners already have a strong presence, provided that demand growth in these markets is sufficiently strong, and/or alternatively, refiners can seek to develop sales in markets in which they currently either have a weak or no presence at all. The choice of export destinations for additional volumes of refined products will depend on local market conditions and shipping costs. The remainder of this section provides an analysis of the competitiveness of U.S.

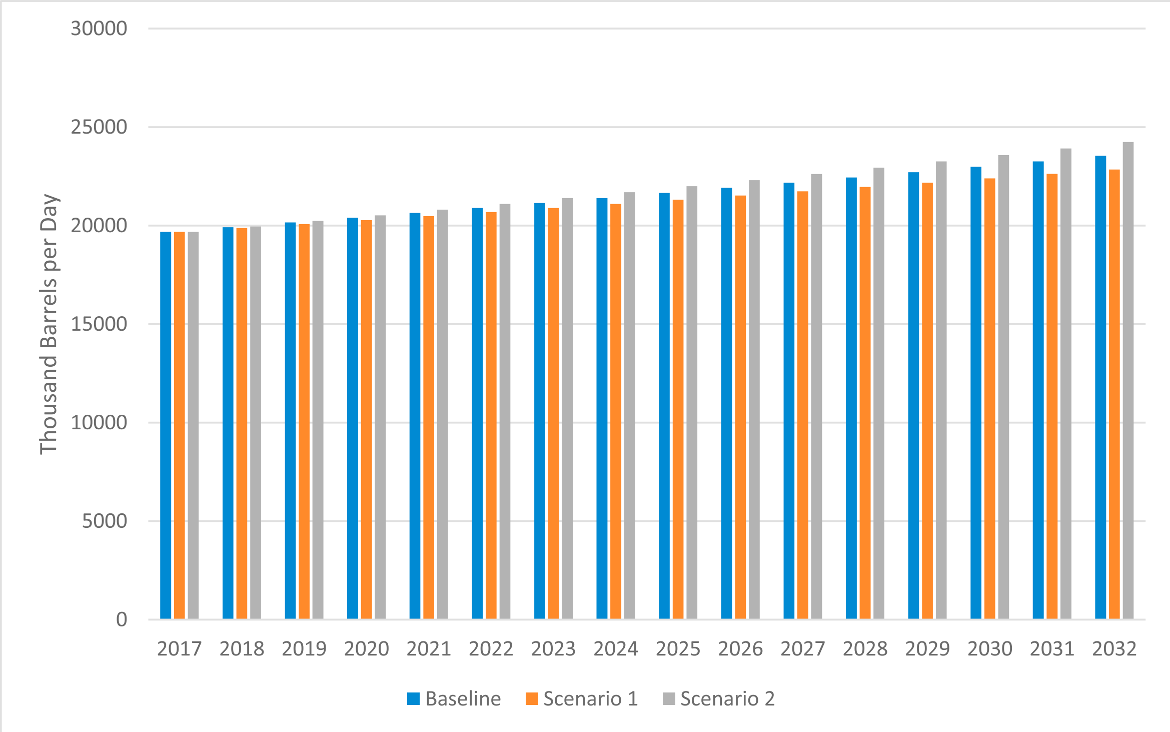

Fig. 17. U.S. refiner & blender forecasted net production of total finished petroleum products 2017-2032
Source: author's calculations, base year data retrieved from http://www.eia.gov.

gasoline and diesel exports to a selection of export destinations and a brief characterization of current and potential export markets.

To determine the competitiveness of U.S. gasoline and diesel exports the delivered price to various worldwide destinations is calculated and compared to Cost Insurance Freight (CIF) prices. To estimate the shipping costs for unleaded regular gasoline and for diesel we consider a clean tanker transporting 38,000 metric tons (MT) (or 321,100 barrels) of product and density conversion factors of 8.45 bbl/MT and 7.45 bbl/MT for gasoline and diesel respectively. The estimated shipping costs are calculated based on World Scale (WS)[13] shipping rates for June 5th, 2018 (PLATTS, 2018), take into account the distance travelled and include the transportation costs as well as port fees and unloading or loading charges as well as any other handling dues when applicable. Using forecasted 2018 U.S. Gulf Coast FOB prices[14] for unleaded regular gasoline and diesel that average respectively $76.75 and $73.08 per barrel, Table 7 presents the shipping cost as well as the delivered price of gasoline and diesel in US dollars per barrel at various worldwide destinations. Table 8 shows forecasted Cost Insurance and Freight (CIF) prices at various major trading hubs and potential export destinations around the world. The comparison of the estimated delivered prices to CIF prices shows that U.S. exports to North West Europe, the Mediterranean, Latin America and Asia are profitable (Tables 7 and 8).

6.2. Future challenges and opportunities

6.2.1. U.S. export availability vs. net import demand in major current export markets

Projections of gasoline demand growth in current U.S. export markets show that U.S. refiners cannot depend on these destinations alone to place forecasted available export volumes (Table 9). For diesel the situation is better, as forecasted demand exceeds the volumes of available U.S. exports in current export markets through 2025. Typically, refineries have some ability to shift production between gasoline and distillates. However, the percentage share for distillate production of 35% (for diesel and jet-fuel combined) assumed in this study represents the maximum possible. Hence product output variations within high value products would solely be possible by increasing the share of gasoline while reducing distillate output. However, the opposite would be required in order to place larger amounts of product (Table 9). Furthermore, in 2032 vol of U.S. gasoline and diesel available for exports largely exceed forecasted demand in current markets.

[13] New Worldwide Tanker Nominal Freight Scale "Worldscale" as revised effective 1st January 2016. Worldscale Association (London) Limited and Worldscale Association (NYC) Inc. Copyright reserved. Printed and bound in Great Britain by: Polestar Wheatons Ltd, Exeter.
[14] These prices were retrieved from the IHS Data browser available at: http://www.ihs.com.

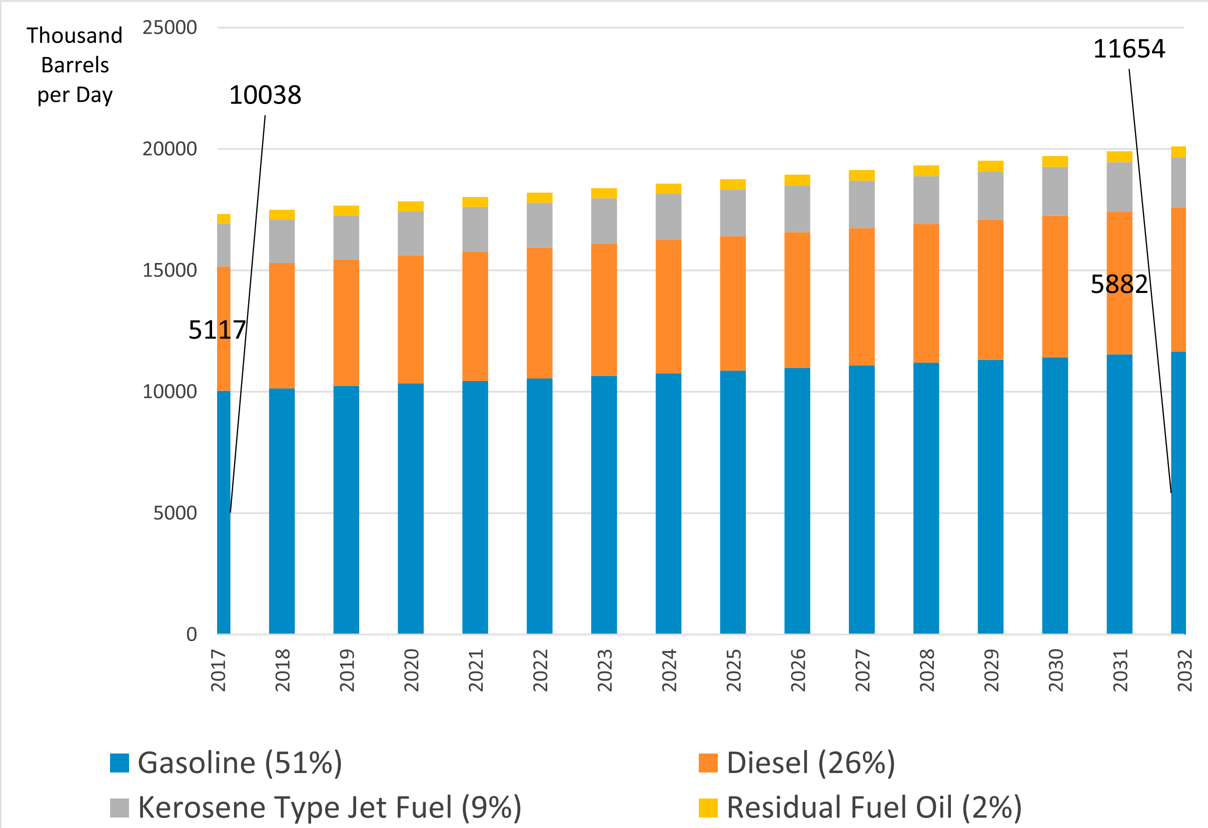

Fig. 18. U.S. production forecasts for gasoline, diesel, jet fuel and residual fuel oil 2017-2032
Source: author's calculation – base year data retrieved from http://www.eia.gov.

6.2.2. Regional trends in current and potential export markets

6.2.2.1. Mexico, Brazil, Europe, North Africa and West Africa

6.2.2.1.1. Mexico. Mexico and Brazil are the major U.S. refined petroleum product export markets in Latin America. U.S. energy exports to Mexico reached $25.8 billion in 2017 of which $23.2 billion were petroleum products. This makes Mexico the second most important energy export market for the U.S. Mexican demand growth for gasoline and diesel is forecasted to remain strong, driven by economic and population growth. Mexico has made great progress in implementing many of the goals formulated in its 2013 Energy Sector Reform. However, for structural and political reasons implementation in the refining sector has lagged behind. This market presents a good opportunity for U.S. refiners to place additional volumes of product. The proximity and sophistication of U.S. refiners and their strong presence in this market are big advantages compared to potential competitors.

Mexican gasoline demand is growing at 1.4% (CAGR) between 2017 and 2025 and at 0.9% (CAGR) through 2040; while the demand for diesel is growing at 1.5% through 2040 (IHS, 2018a). Gasoline demand amounted to 796,100 barrels per day in 2017 of which 71% were satisfied with imports and forecasts show an increase in demand to nearly 965,000 b/d by 2035 (IHS, 2018a). Similarly, diesel demand stood at 365,500 b/d in 2017 (Pemex, 2018) and is forecasted to reach 477,800 b/d in 2035 (IHS, 2018a). Mexico's import dependence for diesel neared 65% in 2017 and the U.S. provided nearly all of it. While import dependence is expected to decrease slightly for both fuels, the imbalance between domestic production and demand will remain important and Mexico will require imports in the amount of 530,000 b/d and 176,400 b/d for gasoline and diesel respectively in 2035.

6.2.2.1.2. Brazil. Brazil is the third largest energy producer in the Americas and while the country is self-sufficient in crude oil supplies, it relies on gasoline and diesel imports for respectively 40% and 20% of domestic consumption. Diesel is the most important refined product in Brazil accounting for over half of total oil product consumption (Soares et al., 2017). In 2017, 70% of imported diesel and 27% of imported gasoline came from U.S. refineries. Forecasts show that import demand for both fuels will remain strong over the coming decades. To cover domestic demand Brazil will need to increase its imports of gasoline from 88,500 b/d in 2017 to 178,200 b/d in 2035 (IHS, 2018b). The import demand for diesel while remaining important will slightly decrease from 272,500 b/d in 2017 to 206, 800 b/d in 2035 (IHS, 2018b).

6.2.2.1.3. Europe. Europe is traditionally long on gasoline and short on distillates. It is the world's third largest region in terms of refined petroleum product demand and its five biggest economies account for around 56% of demand in 2017 (IHS, 2018c). European

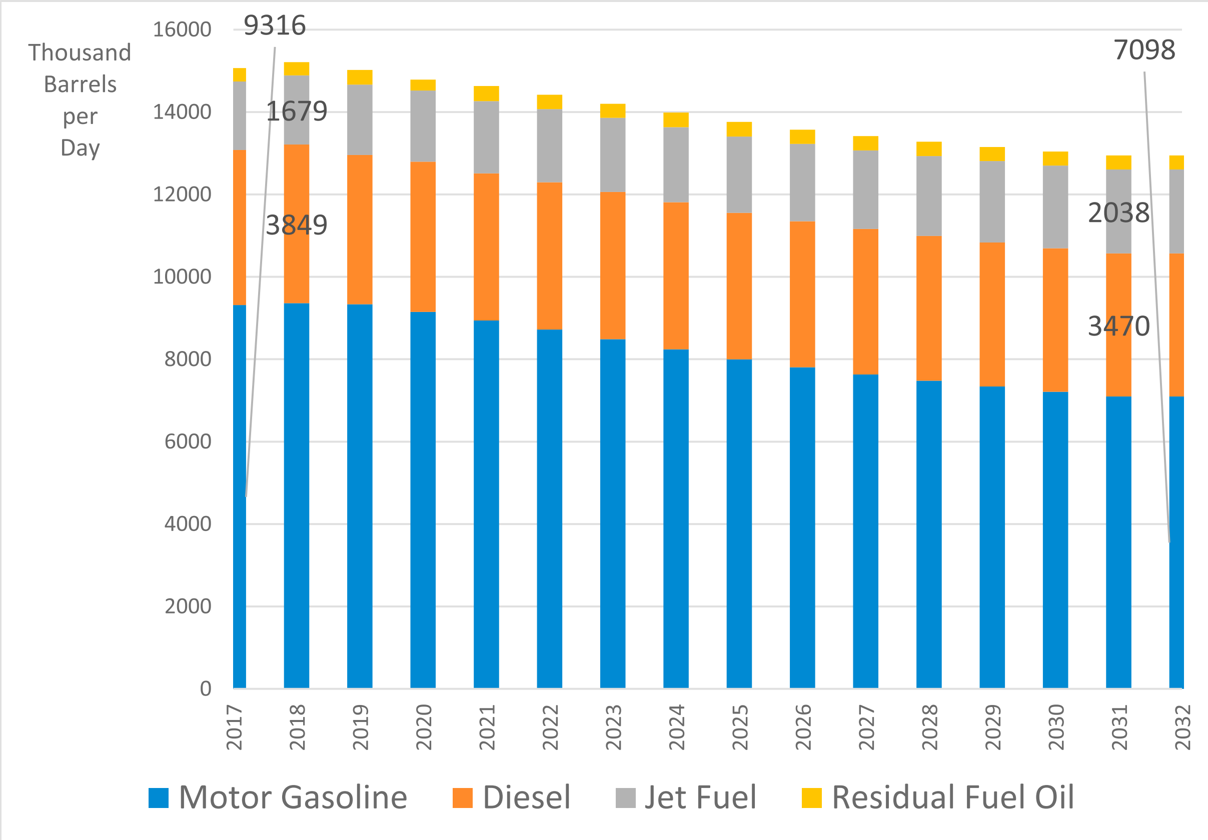

Fig. 19. U.S. forecasted demand for gasoline, diesel, jet fuel, and residual fuel oil 2017-2032
Source: data retrieved from EIA, 2018. AEO, Accessed February 2018. Available at: https://www.eia.gov/dnav/pet/pet_cons_psup_dc_nus_mbblpd_a.htm.

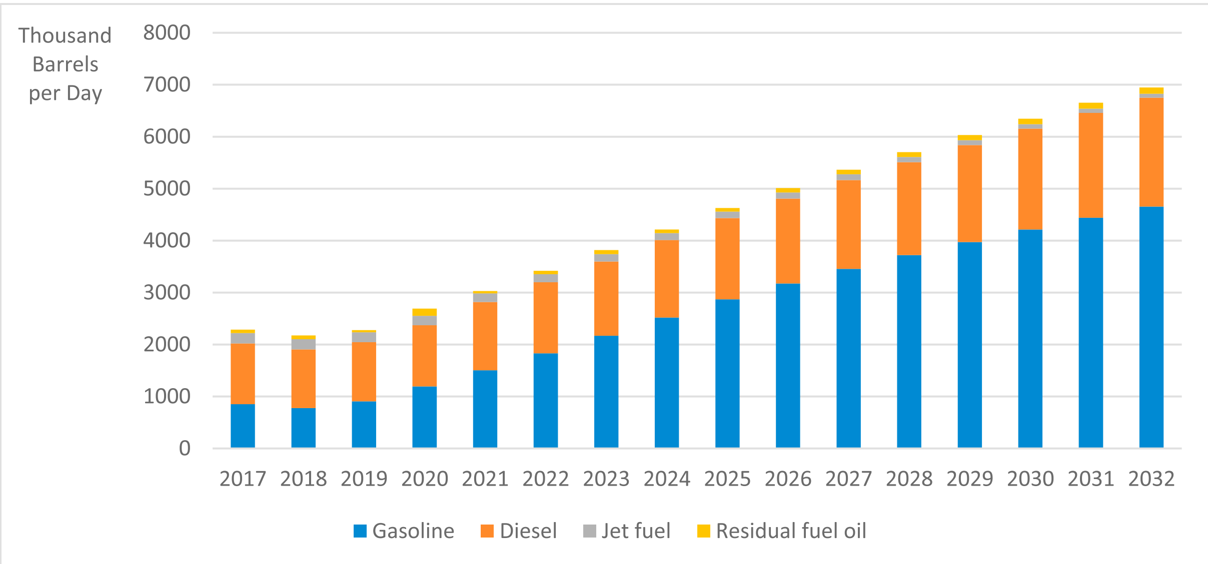

Fig. 20. U.S. refinery product volumes of gasoline, diesel, jet fuel and residual fuel oil available for exports 2017-2032
Source: author's calculations based on estimates and base year data retrieved from EIA, 2018.

Table 7
US Gulf Coast delivered price of unleaded gasoline and diesel at select worldwide destinations (dollars per barrel).

From Houston to:	Delivered price of gasoline	Delivered price of diesel
Salina Cruz (Mexico-West coast)	78.39	74.95
Coatzacoalcos (Mexico-East coast)	77.26	73.66
North Brazil	78.56	75.14
Brazil	79.14	75.79
Argentina	79.70	76.42
Peru	79.19	75.85
Puerto La Cruz (Venezuela)	77.95	74.45
Ecuador	78.88	75.5
Chile	79.82	76.56
Antwerp (Belgium)	79.37	76.06
Rotterdam (Netherlands)	79.34	76.02
United Kingdom	78.02	74.52
Mediterranean	78.13	74.64
Lagos (Nigeria)	79.52	76.48
Cap Limboh (Cameroun)	79.75	76.48
Abidjan (Ivory Coast)	79.51	76.22
Fujairah via Suez (UAE)	80.75	77.62
Singapore via Cape	81.99	79.03
Singapore via Suez	81.66	78.65
Japan & South Korea	80.02	76.79

Source: author's calculations.

Table 8
Estimated 2018 CIF prices at major worldwide trading points.

	Premium Unleaded Gasoline	Diesel
North West Europe	81.18	85.23
Mediterranean	81.42	85.64
Japan C&F	82.83	86.21
Singapore	83.40	82.82
Arab Gulf	83.39	81.64
Mexico East Coast	84	84.42

Source: IHS Data Browser, http://www.ihs.com.

Table 9
Gasoline and diesel net import demand vs. U.S. export volumes available through 2032 (Thousand Barrels per Day).

	2017		2025		2032*	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
Latin America[a]	888	891	876	821	945	976
Caribbean[b]	58	64	71	98	85	127
North & West Africa[c]	312	167	371	223	472	264
Europe[d]	0	855	0	802	0	449
Total	1258	1977	1318	1944	1502	1814
U.S. export availability	856	1168	2876	1563	4656	2093
Excess demand	402	808	−1558	381	−3154	−279

Source: author's calculations based on data retrieved from IHS; available at http://www.ihs.com; accessed in June 2018.
*Author's estimates.
[a] Select Latin American countries: Mexico, Brazil, Chile, Ecuador, Colombia, Peru, Venezuela, Argentina, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama.
[b] Select Caribbean countries: Cuba, Dominican Republic, Jamaica, Puerto Rico, Trinidad and Tobago and others.
[c] Africa: Morocco, Nigeria, Togo, Cameroon.
[d] Europe: EU28.

demand for distillates is expected to peak around 2020–2022 and enter a period of gradual long-run decline after that,[15] which will decrease import demand (IHS, 2018c). The near-future peak is due mainly to the IMO MARPOL VI regulation which presents an opportunity for U.S. refiners as it will require Europe to increase its diesel imports in the coming years. The decline in the reliance on diesel

[15] Distillate demand is expected to decrease in the five big EU economies while it remains strong in eastern European countries where economic growth will be relatively stronger.

in the long run, driven by the phasing out of diesel powered vehicles, will however require U.S. exporters to eventually direct potential additional volumes of product to other markets.

Gasoline demand will remain strong through 2032, as governments continue to gradually remove incentives for diesel powered cars. Gasoline demand will gradually decline starting in the mid-2020s (IHS, 2018c).

6.2.2.1.4. North and West Africa. U.S. refiners currently provide relatively small quantities of gasoline and diesel to Morocco and some West African Nations such as Nigeria, Togo and Cameroon. In 2017 Morocco does not possess a single working refinery and imports all its refined petroleum products. In Nigeria where gasoline accounts for 73% of oil product consumption, 94% of gasoline consumed in 2017 was imported. Nigeria's Dangote Refinery which is expected to be completed in 2019 and will have a name plate capacity of 650,000 barrels per day aims to eliminate Nigeria's import needs (Vanguard, 2017). Nevertheless, in Morocco and West Africa refined product demand growth is forecasted to remain substantial through 2035 (IHS, 2018d) and hence provides an excellent opportunity for U.S. refiners to place additional export volumes.

6.2.2.1.5. De-carbonization policies. De-carbonization policies around the world are at the forefront of the public policy agenda.

6.2.2.1.6. MARPOL ANNEX VI regulations. On January 1st' 2020 the International Maritime Organization's MARPOL ANNEX VI regulation will come into effect and require the global shipping industry to comply with a sulfur cap of 0.5% instead of 3.5% as is currently the case. To comply with this new requirement shipping companies can switch to fuels that have a lower sulfur content than RFO (such as low sulfur fuel oil or diesel), switch to Liquefied Natural Gas (LNG), or use scrubbers (OECD/IEA, 2017b). In 2016 worldwide crude oil based fuel used by shippers reached 3.9 million barrels per day of which about 70% is RFO while gasoil accounts for 30% and the International Transport Forum expects a reversal of these percentages by 2020 (PLATTS, 2016; OECD/IEA, 2017b). While the overall crude oil based fuel demand in shipping is expected to stay constant, the drop in demand for RFO will change product trade flows of RFO and other distillates as well as the price spread between RFO and low-sulfur products, which is expected to increase. Most regions in the world with the exception of Asia and the Middle-East will become importers of low sulfur (0.5%) fuel blends (PLATTS, 2016). MARPOL ANNEX VI will adversely affect major RFO exporters, such as for example Russia, Venezuela and Malaysia, while it works to the advantage of technologically advanced refineries in the U.S. and elsewhere in the world (PLATTS, 2016). The implementation of MARPOL ANNEX VI is challenging for both shippers and refiners, who faced with uncertainty about implementation and enforcement, delayed necessary investments. There are concerted international efforts through the MARPOL ANNEX VI Marine Environment Protection Committee to ensure and harmonize enforcement on open seas, and to foster the supply of sufficient quantities of compliant bunker fuels. Although at the time of writing IMO MARPOL ANNEX VI regulations are scheduled to come into effect on January 1st' 2020, and enforcement of the high sulfur carriage ban will start on March 1st' 2020 challenges remain. For example, it was noted that 'fuel oil non availability' could lead to operational constraints and could be a justification for non-compliance. Furthermore, in the medium-run LNG use as bunker fuel is expected to increase substantially and this can be another challenge refiners have to face.

6.2.2.1.7. Electric vehicles (EVs). Oil companies predict that EVs will account for 10%–20% of the vehicle fleet while car producers forecast a much higher percent range of 30%–40% (WRA, 2018). To date, EVs still cost more than Internal Combustion Engine cars. Insufficient recharging infrastructure and the need for frequent recharging are major hurdles for fast deployment (WRA, 2018). Hybrid fuels can be used for a larger variety of vehicles and can be distributed through existing infrastructure. Although hybrid vehicles still require a share of refined petroleum products they do represent another threat to refiners (WRA, 2018).

6.2.2.1.8. Overcoming challenges. To overcome some of the challenges highlighted through this analysis U.S. refiners can aim at increasing their exports to Latin America and West Africa where vehicle ownership rates are still low and where economic growth and transport fuel demand are forecasted to remain strong through 2035. Another option for refiners is to increase the share of capacity devoted to petrochemicals from currently about 30%–50%. Also, companies that possesses various assets along the downstream supply chain can leverage these in the transition to other fuels or possibly EVs (WRA, 2018). A sufficiently large Brent-WTI spread which is anticipated to average $5 in 2019 also works to the advantage of U.S. refiners (EIA, 2018f). Lastly, the newly imposed Iran oil export embargo will make fewer quantities of lighter feedstocks available to countries around the world, leading to incremental benefits for complex refineries.

7. Conclusion

Changes in the demand for refined products are affecting the industry worldwide. The U.S. refining sector is the most complex of its kind in the world in 2019 and, vis-à-vis its competitors, it benefits from a series of advantages, ranging from low capital and operating costs to a highly skilled labor force and low energy costs. The decreasing U.S. crude oil import dependency, tighter fuel specifications in some existing and new export markets, and the new IMO MARPOL VI specifications as well as a recovering crude oil price, all work to the advantage of U.S. refiners. However, based on the assumptions in this study export dependency of U.S. refiners is increasing through 2032. Furthermore, forecasted available export volumes of gasoline and eventually diesel fuel will exceed demand in current U.S. export markets. Unless product demand growth reveals itself to be higher than forecasted, exporters will have to look for new export markets where they will face increasing competition from Middle Eastern, Russian, Indian and Chinese refiners. Lastly, geopolitical factors and the looming U.S. trade war are important factors that could influence the industry's success in the future.

Acknowledgement

This research was supported in part by the Department of Energy (DOE) Office of Policy (OP) administered by the Oak Ridge Institute for Science and Education (ORISE) for the DOE. ORISE is managed by Oak Ridge Associated Universities (ORAU) under DOE contract number DE-SC0014664. All opinions expressed in this paper are the author's and do not necessarily reflect the policies and views of DOE, ORAU, or ORISE.

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Further reading

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