Overview to the Petroleum Refining Industry

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Topics

Energy consumption & petroleum's place

- Size of U.S. industry
- Major refiners

Petroleum products

Basic petroleum economics

- Trends for crude oil & gasoline prices
- When do refiners make money?

Generalized Petroleum Refinery

Energy consumption in the U.S. & petroleum's contribution

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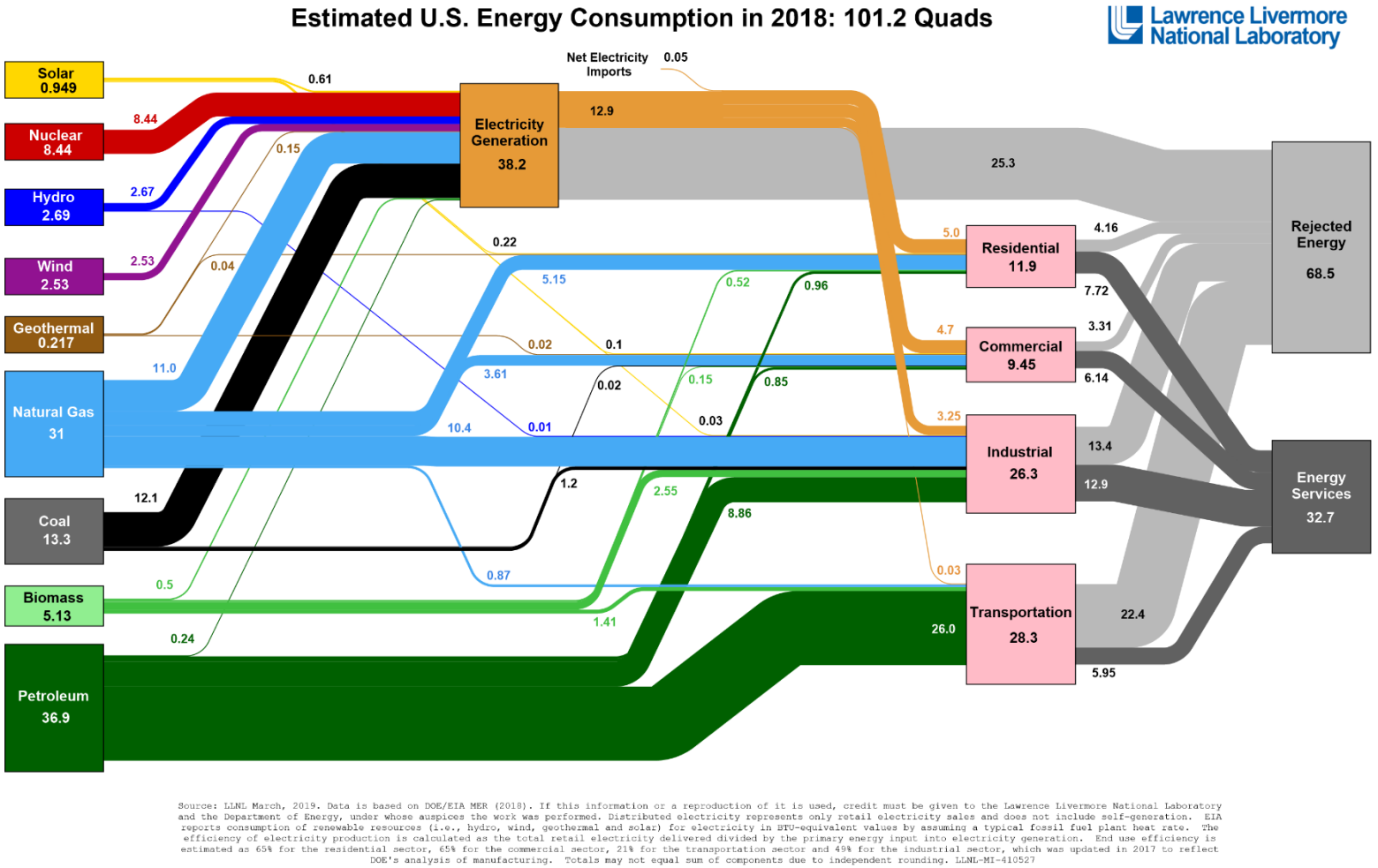
Energy Markets Are Interconnected



https://flowcharts.llnl.gov/commodities/energy

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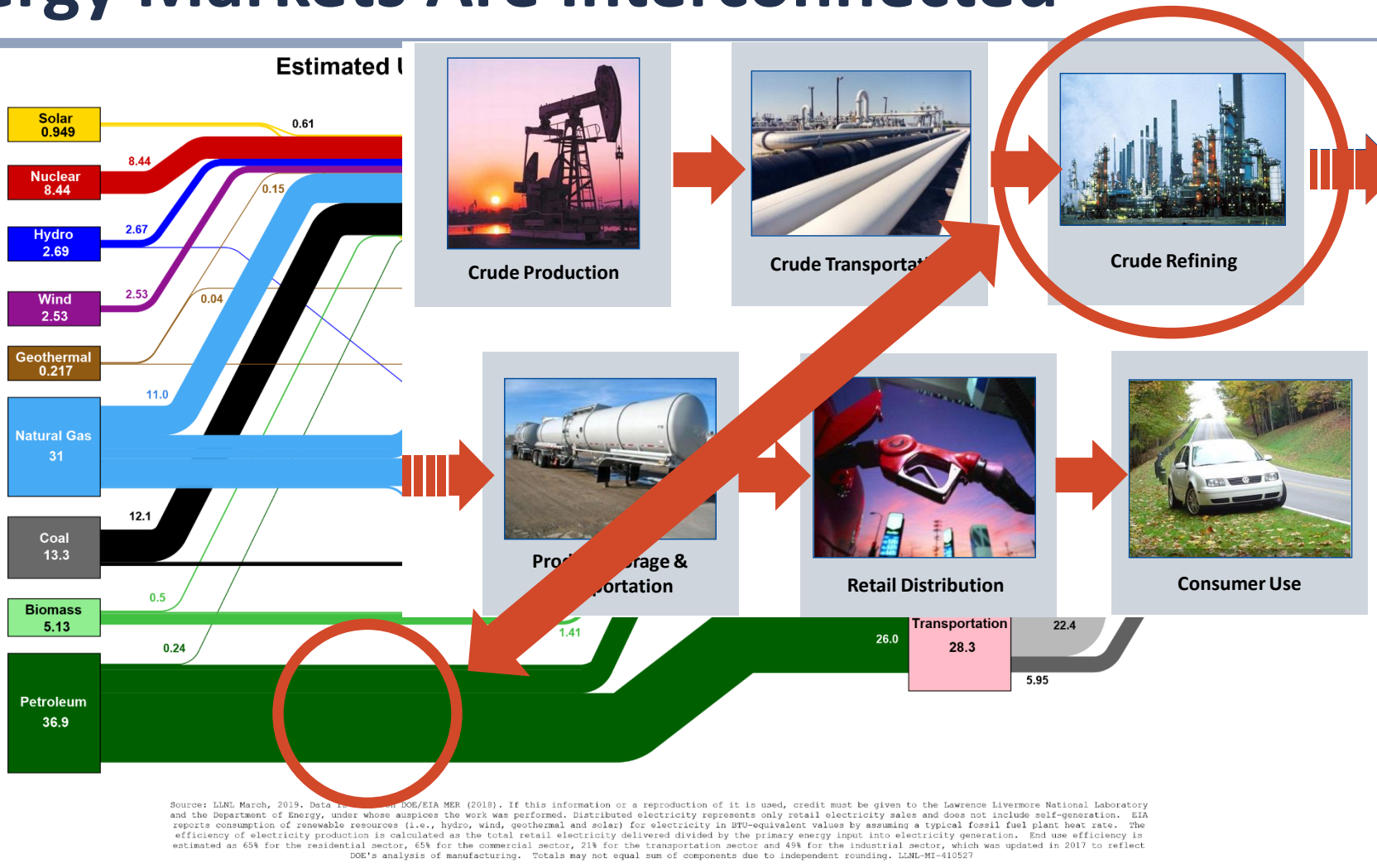
Energy Markets Are Interconnected



Source: LLNL March, 2019. Data [illegible] DOE/EIA MER (2018). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

https://flowcharts.llnl.gov/commodities/energy

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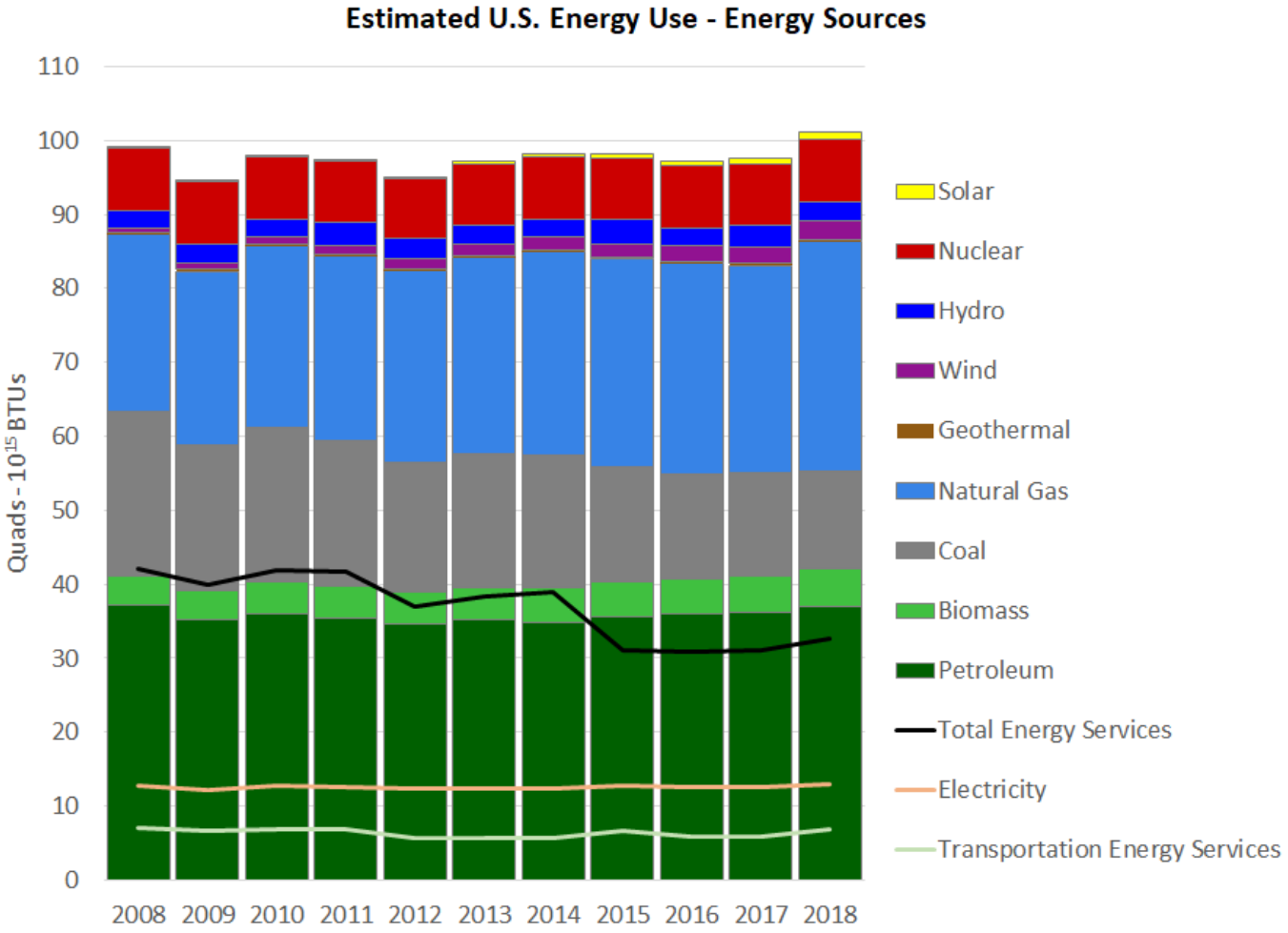
Energy Markets Over the Last Decade



https://flowcharts.llnl.gov/commodities/energy

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World & U.S. Refining Capacity

HOW THE WORLD'S LARGEST REFINERS RANK

Table 1

Rank Jan. 1, 2015	Rank Jan. 1, 2014	Company	Crude capacity, b/cd[1]
1	1	ExxonMobil Corp.	5,465,500
2	2	Royal Dutch Shell PLC	4,184,600
3	3	Sinopec	3,971,000
4	4	BP PLC	2,858,964
5	5	Saudi Aramco	2,835,500
6	6	Valero Energy Corp.	2,769,500
7	7	Petroleos de Venezuela SA	2,678,000
8	8	China National Petroleum Corp.	2,675,000
9	10	Phillips 66	2,523,200
10	9	Chevron Corp.[2]	2,463,600
11	11	Total SA	2,304,326
12	12	Petroleo Brasileiro SA	1,997,000
13	13	Marathon Petroleum Co. LP	1,731,000
14	14	Petroleos Mexicanos	1,703,000
15	15	National Iranian Oil Co.	1,451,000
16	16	JX Nippon Oil & Energy Corp.	1,423,200
17	17	Rosneft	1,293,000
18	18	OAO Lukoil	1,217,000
19	19	SK Innovation	1,115,000
20	20	Repsol YPF SA	1,105,500
21	21	Kuwait National Petroleum Co.	1,085,000
22	22	Pertamina	988,250
23	23	Agip Petroli SPA	904,000
24	24	Flint Hills Resources	582,350
25	—	Formosa Petrochemical Co.	540,000

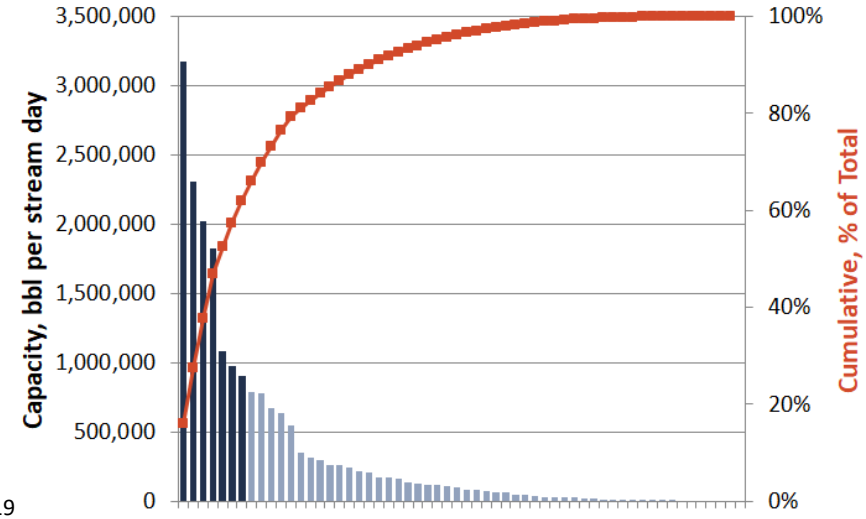
[1]Includes partial interests in refineries not wholly owned by the company. [2]Includes holdings in Caltex Oil and GS Caltex.

"Asia-Pacific refining primed for capacity growth", *Oil & Gas Journal*, pp 34-45, Dec. 1, 2014

Corporations with U.S. Capacities Near 1 Million bbl per stream day

Corporation	Capacity Barrels per Stream Day	Capacity Barrels per Calendar Day	Availability
Marathon Petroleum Corp	3,174,200	3,024,715	95%
Valero Energy Corp	2,307,500	2,181,300	95%
Phillips 66 Company	2,026,033	1,919,300	95%
ExxonMobil Corp	1,829,500	1,732,124	95%
Royal Dutch/Shell Group	1,082,500	967,045	89%
Chevron Corp	980,500	925,431	94%
PBF Energy Co LLC	907,400	865,000	95%
Total	19,866,258	18,723,935	94%

Capacities for LLC refineries split among the partner companies



EIA, Jan. 1, 2019database, published June 2019
http://www.eia.gov/petroleum/refinerycapacity/

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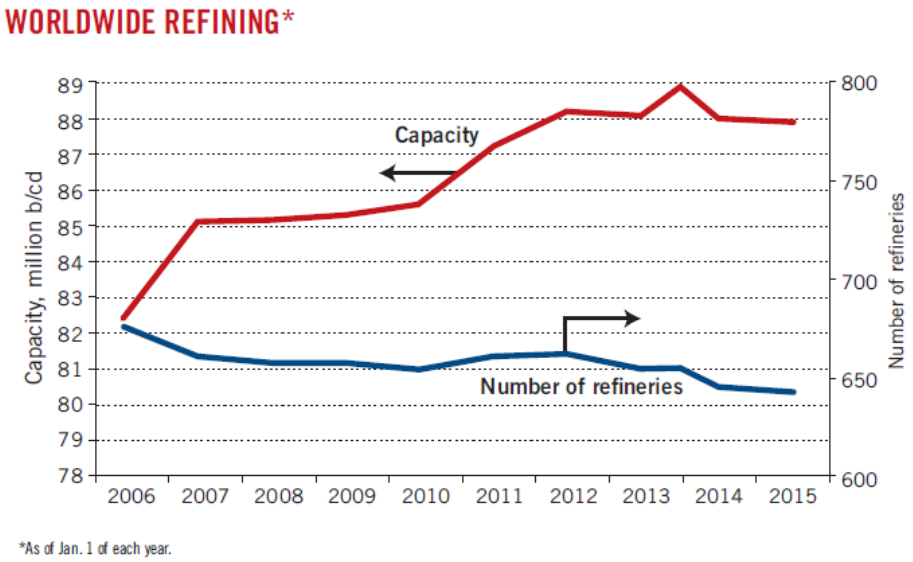
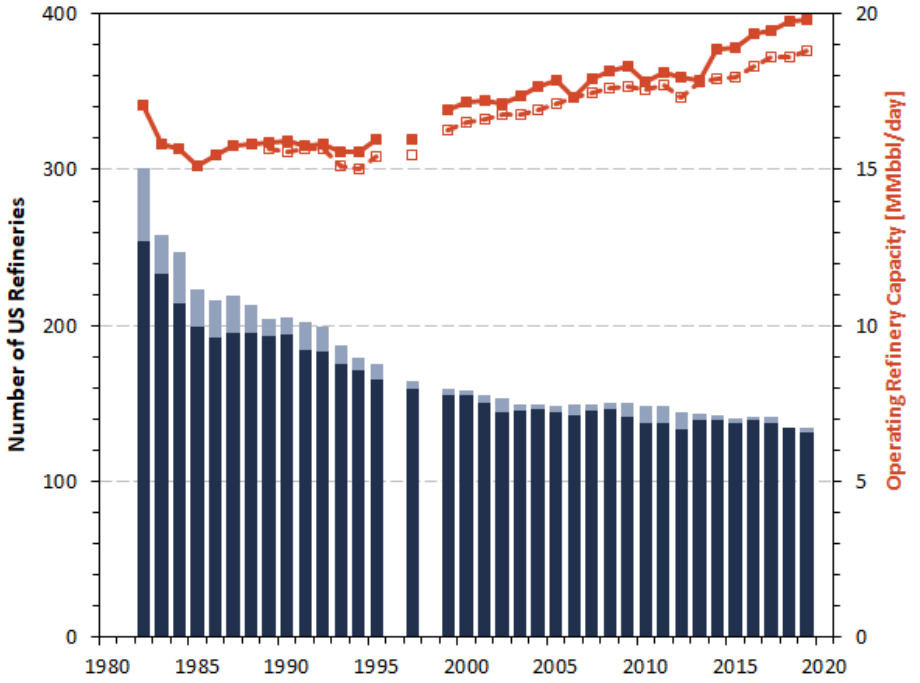
Number & Capacity of World & U.S. Refineries



"Asia-Pacific refining primed for capacity growth", *Oil & Gas Journal*, pp 34-45, Dec. 1, 2014



Source:
EIA, Jan. 1, 2019 database, published June 2019
http://tonto.eia.doe.gov/dnav/pet/pet_pnp_cap1_dcu_nus_a.htm

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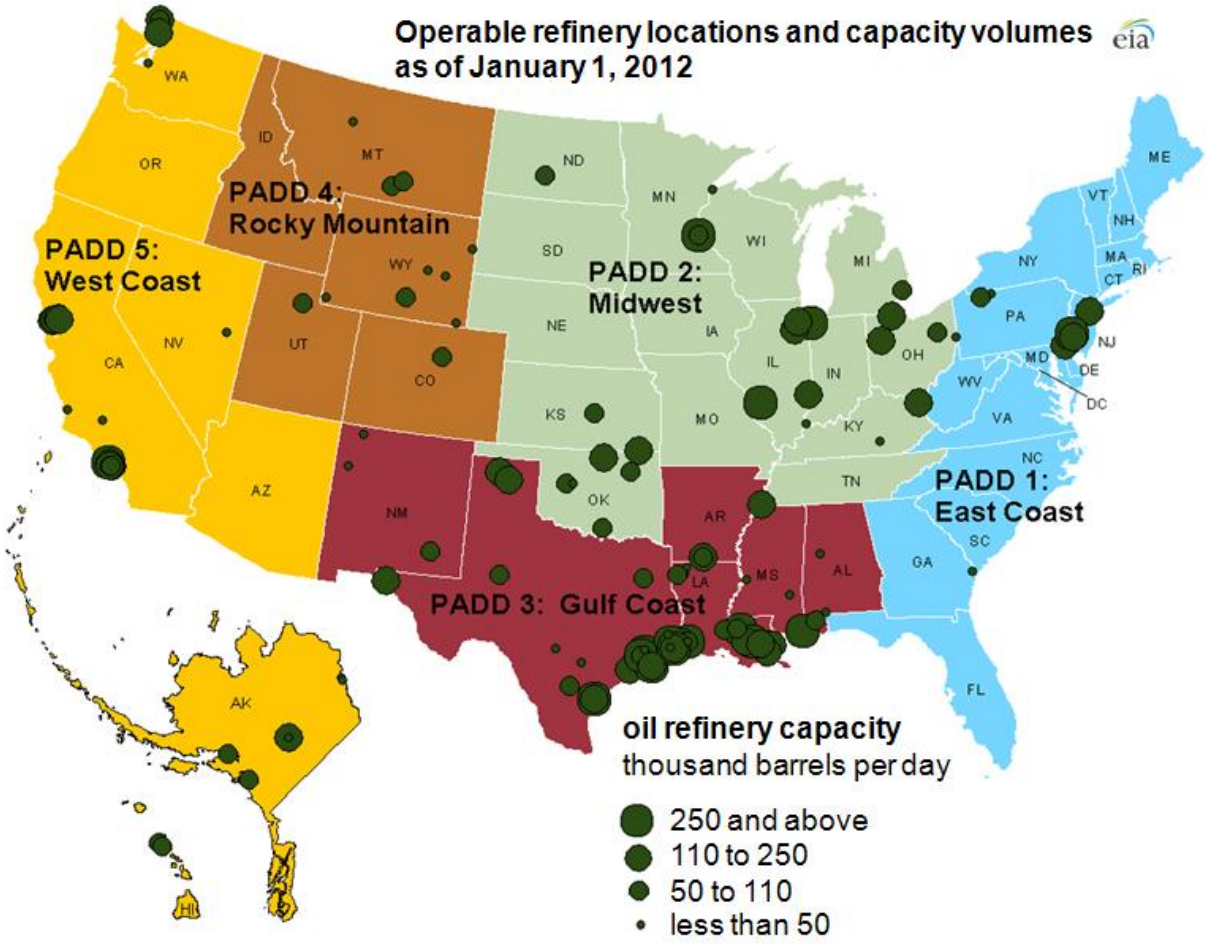
Locations of U.S. Refineries



http://www.eia.gov/todayinenergy/detail.cfm?id=7170

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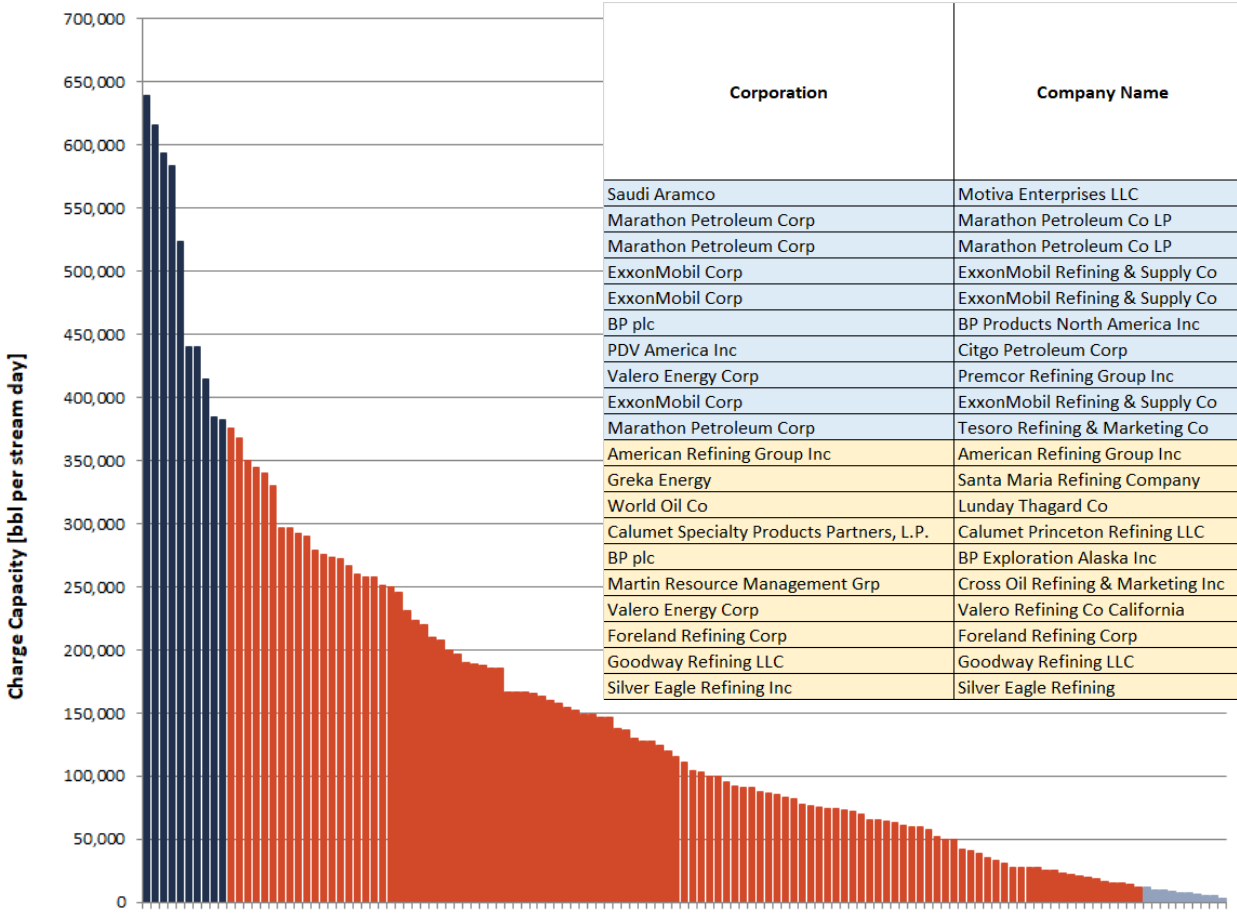
Individual U.S. Refinery Sizes – 10 Largest & 10 Smallest



Corporation	Company Name	State	Site	Atmospheric Crude Distillation Capacity (barrels per calendar day)	Atmospheric Crude Distillation Capacity (barrels per stream day)
Saudi Aramco	Motiva Enterprises LLC	Texas	Port Arthur	607,000	639,700
Marathon Petroleum Corp	Marathon Petroleum Co LP	Texas	Galveston Bay	585,000	616,000
Marathon Petroleum Corp	Marathon Petroleum Co LP	Louisiana	Garyville	564,000	594,000
ExxonMobil Corp	ExxonMobil Refining & Supply Co	Texas	Baytown	560,500	584,000
ExxonMobil Corp	ExxonMobil Refining & Supply Co	Louisiana	Baton Rouge	502,500	523,200
BP plc	BP Products North America Inc	Indiana	Whiting	430,000	440,000
PDV America Inc	Citgo Petroleum Corp	Louisiana	Lake Charles	418,000	440,000
Valero Energy Corp	Premcor Refining Group Inc	Texas	Port Arthur	335,000	415,000
ExxonMobil Corp	ExxonMobil Refining & Supply Co	Texas	Beaumont	369,024	384,400
Marathon Petroleum Corp	Tesoro Refining & Marketing Co	California	Carson	363,000	382,000
American Refining Group Inc	American Refining Group Inc	Pennsylvania	Bradford	11,000	11,800
Greka Energy	Santa Maria Refining Company	California	Santa Maria	9,500	10,000
World Oil Co	Lunday Thagard Co	California	South Gate	8,500	10,000
Calumet Specialty Products Partners, L.P.	Calumet Princeton Refining LLC	Louisiana	Princeton	8,300	8,655
BP plc	BP Exploration Alaska Inc	Alaska	Prudhoe Bay	6,500	8,000
Martin Resource Management Grp	Cross Oil Refining & Marketing Inc	Arkansas	Smackover	7,500	7,700
Valero Energy Corp	Valero Refining Co California	California	Wilmington Asphalt Plant	6,300	6,500
Foreland Refining Corp	Foreland Refining Corp	Nevada	Ely	2,000	5,000
Goodway Refining LLC	Goodway Refining LLC	Alabama	Atmore	4,100	5,000
Silver Eagle Refining Inc	Silver Eagle Refining	Wyoming	Evanston	3,000	3,400

EIA, Jan. 1, 2019 database, published June 2019
http://www.eia.gov/petroleum/refinerycapacity/

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World's Largest Refineries

WORLD'S LARGEST REFINERIES

Table 3

	Company	Location	Crude capacity, b/cd
1	Paraguana Refining Center	Cardon/Judibana, Falcon, Venezuela	940,000
2	SK Innovation	Ulsan, South Korea	840,000
3	GS Caltex Corp.	Yeosu, South Korea	785,000
4	S-Oil Corp.	Onsan, South Korea	669,000
5	Reliance Petroleum Ltd.	Jamnagar, India	660,000
6	ExxonMobil Refining & Supply Co.	Jurong/Pulau Ayer Chawan, Singapore	592,500
7	Reliance Industries Ltd.	Jamnagar, India	580,000
8	ExxonMobil Refining & Supply Co.	Baytown, Tex.	560,500
9	Saudi Arabian Oil Co. (Saudi Aramco)	Ras Tanura, Saudi Arabia	550,000
10	Formosa Petrochemical Co.	Mailiao, Taiwan	540,000
11	Marathon Petroleum Co. LLC	Garyville, La.	522,000
12	ExxonMobil Refining & Supply Co.	Baton Rouge, La.	502,500
13	Kuwait National Petroleum Co.	Mina Al-Ahmadi, Kuwait	466,000
14	Shell Eastern Petroleum (Pte.) Ltd.	Pulau Bukom, Singapore	462,000
15	Marathon Petroleum Co. LLC	Galveston Bay, Tex.	451,000
16	Citgo Petroleum Corp.	Lake Charles, La.	440,000
17	Shell Nederland Raffinaderij BV	Pernis, Netherlands	404,000
18	Sinopec	Zhenhai, China	403,000
19	Saudi Arabian Oil Co. (Saudi Aramco)	Rabigh, Saudi Arabia	400,000
20	Saudi Aramco-Mobil	Yanbu, Saudi Arabia	400,000
21	Saudi Aramco Total Refinery & Petrochemicals Co.	Jubail	400,000

"Asia-Pacific refining primed for capacity growth", *Oil & Gas Journal*, pp 34-45, Dec. 1, 2014

Recent changes to the slate of US refineries

Existing refineries getting larger

- Marathon Petroleum expanding Galveston Bay to incorporate Texas City refinery & increase capacity
  - STAR program scheduled for full commissioning in 2022

Changes in operations

- Superior Refining (Husky Energy) rebuilding Superior, WI, refinery after fire in 2018
- Philadelphia Energy Solutions will close refinery after explosion in June 2019
  - 13th largest refinery in U.S. based on bbl per stream day, 350,000 bpd
- ExxonMobil to expand Beaumont, TX, refinery, including new 250,000 bpd crude unit

Changes in ownership

- Marathon Petroleum Company purchased Andeavor (2018)
  - Tesoro purchased Dakota Prairie Refining (June 2016)
  - Tesoro bought Western Refining (June 2017) & changed name to Andeavor (August 2017)
- Shell selling Martinez Refinery (CA) to PBF Holding Company LLC

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Newest Grass-Roots Refineries in U.S.?

Year Built	First Operated	Location	Original Owner	Original Capacity bbl/cd	Current Owner	2019 Capacity bbl/cd
2018	2019	Channelview, Texas	Targa Resources	35,000	Targa Resources	35,000
2016	2017	Corpus Christi, Texas	Magellan Midstream Partners	42,500	Magellan Midstream Partners	42,500
2015	2015	Corpus Christi, Texas	Buckeye Partners	46,250	Buckeye Partners	60,000
2015	2015	Houston, Texas	Petromax Refining	25,000	Petromax Refining	25,000
2014	2015	Dickinson, North Dakota	Dakota Prairie Refining	19,000	Marathon	19,000
2014	2015	Galena Park, Texas	Kinder Morgan	42,000	Kinder Morgan	84,000
1998	1998	Atmore, Alabama	Goodway	4,100	Goodway	4,100
1993	1993	Valdez, Alaska	Petro Star	26,300	Petro Star	55,000
1991	1992	Ely, Nevada	Petro Source	7,000	Foreland	2,000
1986	1987	North Pole, Alaska	Petro Star	6,700	Petro Star	19,700
1985	1986	Prudhoe Bay, Alaska	ARCO	12,000	ConocoPhillips	15,000
1979	1980	Wilmington, California	Huntway	5,400	Valero	6,300
1978	1979	Vicksburg, Mississippi	Ergon	10,000	Ergon	26,500
1978	1979	North Slope, Alaska	ARCO	13,000	BP Exploration, Alaska	6,500
1977	1978	Lake Charles, Louisiana	Calcasieu	6,500	Calcasieu	128,000
1976	1977	Garyville, Louisiana	Marathon	200,000	Marathon	564,000
1976	1977	Krotz Springs, Louisiana	Gold King	5,000	Delek	80,000
1975	1975	Corpus Christi, Texas	Saber	15,000	Valero	290,000

http://www.eia.gov/tools/faqs/faq.cfm?id=29&t=6, page last updated June 23, 2019

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New Grass-Roots Refineries in U.S.?

Simple refineries usually near oil production

- Dakota Prairie Refinery – 20,000 bpd Bakken crude topping unit with diesel hydrotreating (2015 start up)
- Targa Resources –38,000 bpd, Channelview, TX
- Meridian Energy Group – 49,500 bpd near Belfield, ND
  - Originally expected 2018 startup – now 2020
- Unknown status
  - MHA Clean Fuels Refinery, 15,000 bpd refinery on the Fort Berthold Indian Reservation near Makoti, ND
    - Ground broken May 2013. No report of completion
  - Quantum Energy? History of announcing refineries & not proceeding

Complex refineries – 2 planned in mid 2000s no longer active projects

- Hyperion Energy Center, $10 billion, 400,000 bpd refinery near Union County, SD
  - Would have included Petcoke IGCC for power & hydrogen
  - Air permit applications expired March 2013 & released options on land May 2013
- Arizona Clean Fuels Yuma, LLC, 150,000 bpd refinery near Yuma, AZ
  - No press releases since March 2009

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Nelson's Complexity Factor

EDC: Equivalent Distillation Capacity

- Measure of downstream conversion capacity to the initial distillation
- Developed by Nelson (1960) to quantify relative costs of refining processes
  - Reflects complexity of ISBL, no OSBL considerations

Refineries to process heavy sour crudes typically have higher complexity factors

Unit	Index	Unit	Index
Distillation Capacity	1.0	Lubes	60.0
Vacuum Distillation	2.0	Asphalt	1.5
Thermal Processes	5.0	Hydrogen (Mcfd)	1.0
Catalytic Cracking	6.0	Oxygenates (MTBE / TAME)	10.0
Catalytic Reforming	5.0	Thermal Cracking	3.0
Catalytic Hydrocracking	6.0	Visbreaking	2.5
Catalytic Hydrorefining	3.0	Fluid Coking	6.0
Alkylation / Polymerization	10.0	Delayed Coking	6.0
Aromatics / Isomerisation	15.0	Others	6.0

Ref: http://www.ril.com/downloads/pdf/business_petroleum_refiningmktg_lc_ncf.pdf

Petroleum products

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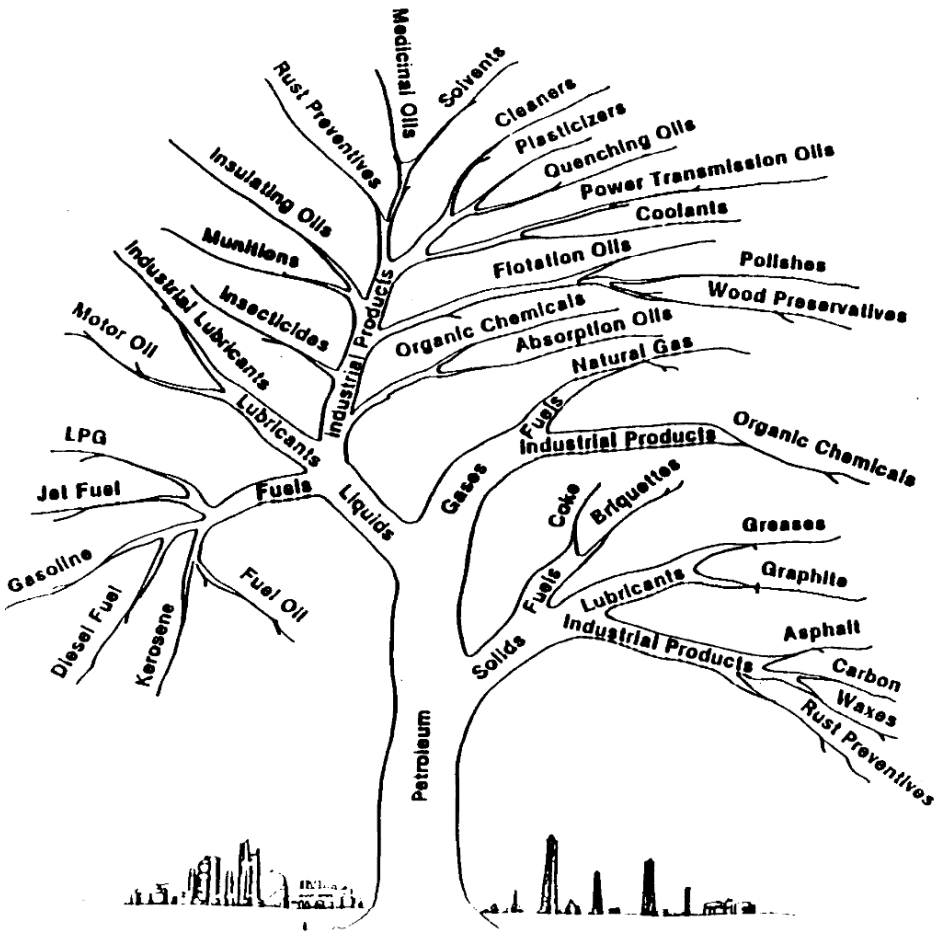
Petroleum Products

- There are specifications for over 2,000 individual refinery products
- Intermediate feedstocks can be routed to various units to produce different blend stocks
  - Highly dependent on economics specific to that refinery & contractual limitations



Ref: Unknown origin. Possibly Socony-Vacuum Oil Company, Inc. (1943)

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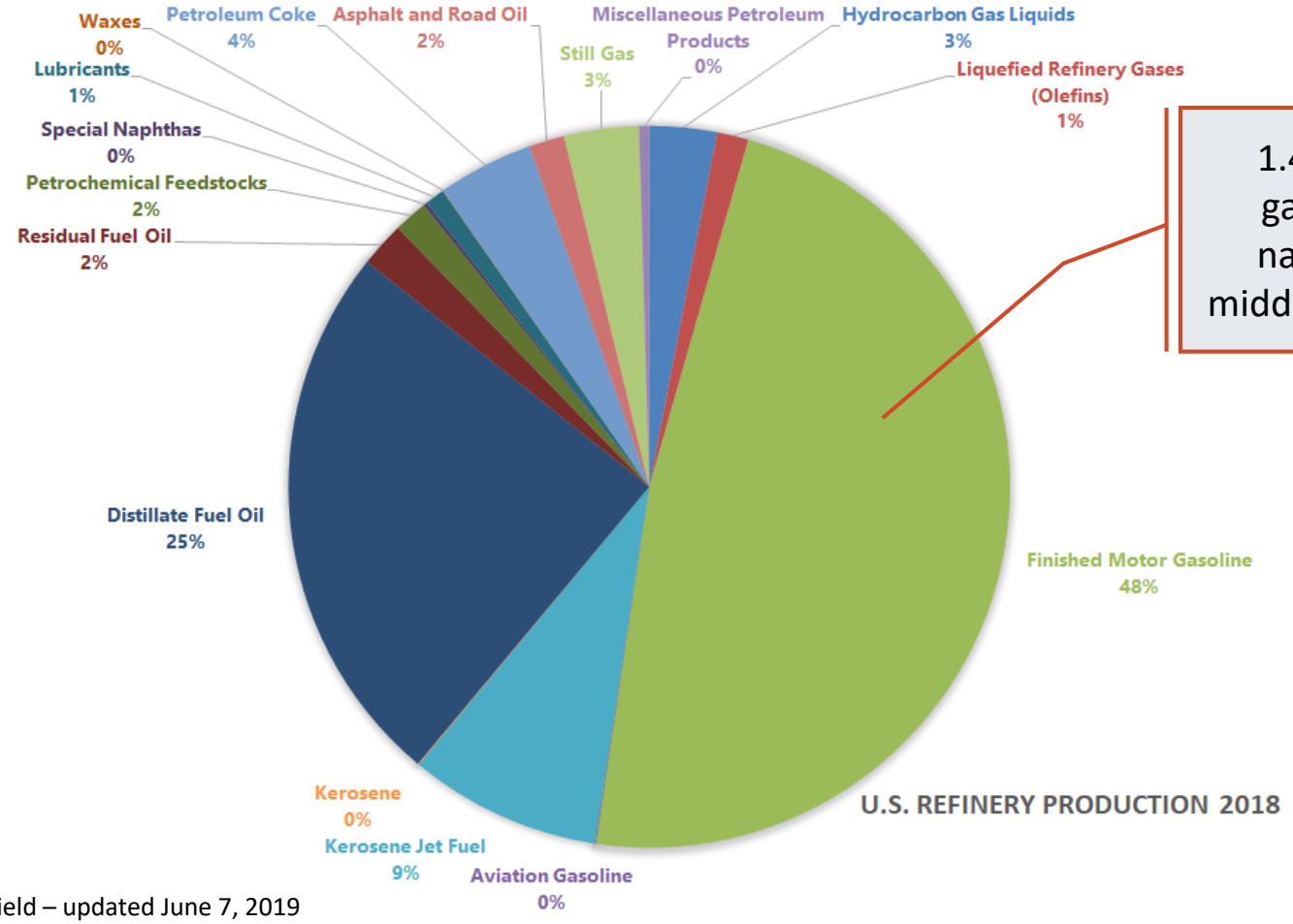
U.S. Refinery & Blender Net Production



EIA, refinery yield – updated June 7, 2019
http://tonto.eia.doe.gov/dnav/pet/pet_pnp_pct_dc_nus_pct_m.htm

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Basic petroleum economics

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Refinery Economics

When do refiners make money?

- High crude oil prices?
- Low crude oil prices?

It depends!

- **Difference between the sale price of the products & purchase price of the crude oil**
- **Operating costs cut into this spread**

Typical prices

- What is the price of crude oil?
  - Depends on location, quality, …
- What are the product prices?

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Product Economics — Crack Spread

Estimates the value added by refining (as an industry)

4 standard spreads

- 5-3-2
  - 5 bbl crude → 3 bbls gasoline + 2 bbls heating oil/diesel
- 3-2-1
  - 3 bbl crude → 2 bbls gasoline + 1 bbls heating oil/diesel
- 2-1-1
  - 2 bbl crude → 1 bbls gasoline + 1 bbls heating oil/diesel
- 6-3-2-1
  - 6 bbl crude → 3 bbls gasoline + 2 bbls heating oil/diesel + 1 bbl residual fuel oil

Rule of thumb for profitable operating environment

- Long held view – greater than $4 per bbl as strongly profitable
- Current view – should be greater than $9 per bbl to be profitable

Crack Spread Calculation

Example — Bloomberg, 6/25/2019

- Prices
  - WTI Cushing Spot $57.81 per bbl
  - Brent $65.00 per bbl
  - RBOB Gasoline $1.8773 per gal
  - Heating Oil $1.9226 per gal
- 5-3-2 Spreads
  - WTI:

$$\frac{42\times(3\times1.8773+2\times1.9226)}{5}-57.81=\$21.78\,\text{per bbl}$$

  - Brent:

$$\frac{42\times(3\times1.8773+2\times1.9226)}{5}-65.00=\$14.61\,\text{per bbl}$$

Crude Oil & Natural Gas

INDEX	UNITS	PRICE
CL1:COM **WTI Crude Oil (Nymex)**	USD/bbl.	57.81
CO1:COM **Brent Crude (ICE)**	USD/bbl.	65.00
CP1:COM **Crude Oil (Tokyo)**	JPY/kl	40,510.00
NG1:COM **Natural Gas (Nymex)**	USD/MMBtu	2.29

Refined Products

INDEX	UNITS	PRICE
XB1:COM **RBOB Gasoline (Nymex)**	USd/gal.	187.73
HO1:COM **Heating Oil (Nymex)**	USd/gal.	192.26
QS1:COM **Gasoil (Nymex)**	USD/MT	588.50
JX1:COM **Kerosene (Tokyo)**	JPY/kl	57,430.00

http://www.bloomberg.com/energy/

Prices Are Crude Specific

US CRUDE PRICES

	5-24-19 $/bbl*
Alaska-North Slope 27°	61.34
Light Louisiana Sweet	54.00
California-Midway Sunset 13°	59.40
California-Buena Vista Hills 26°	70.43
Southwest Wyoming Sweet	54.88
East Texas Sweet	52.00
West Texas Sour 34°	50.25
West Texas Intermediate	55.25
Oklahoma Sweet	55.25
Texas Upper Gulf Coast	49.00
Michigan Sour	47.25
Kansas Common	54.25
North Dakota Sweet	47.25

*Current major refiner's posted prices except N. Slope lags 2 months. 40° gravity crude unless differing gravity is shown. Source: Oil & Gas Journal. Data available at PennEnergy Research Center.

WORLD CRUDE PRICES

OPEC reference basket Wkly. avg.	5-24-19 $/bbl 70.23	
	— Mo. avg., $/bbl — Mar.-19	Apr.-19
OPEC reference basket	66.37	70.78
Arab light-Saudi Arabia	67.40	71.88
Basrah light-Iraq	66.05	70.45
Bonny light 37°-Nigeria	67.71	72.81
Es Sider-Libya	65.38	70.45
Girassol-Angola	67.16	72.88
Iran heavy-Iran	64.17	68.52
Kuwait export-Kuwait	66.78	71.20
Merey - Venezuela	57.75	58.95
Murban - UAE	68.01	71.51
Oriente - Ecuador	63.66	67.61
Saharan blend 44 - Algeria	66.38	71.15
Zafiro - Equatorial Guinea	67.15	72.65
Other crudes		
Fateh 32°-Dubai	66.91	70.93
Minas 34°-Indonesia	59.63	67.64
Isthmus 33°-Mexico	66.53	70.34
Brent 38°-UK	66.08	71.15
Urals-Russia	66.21	71.90
Differentials		
WTI/Brent	(7.92)	(7.28)
Brent/Dubai	(0.83)	0.22

Source: OPEC Monthly Oil Market Report. Data available at PennEnergy Research Center.

Ref: Statistics, *Oil & Gas Journal*, June 3, 2019

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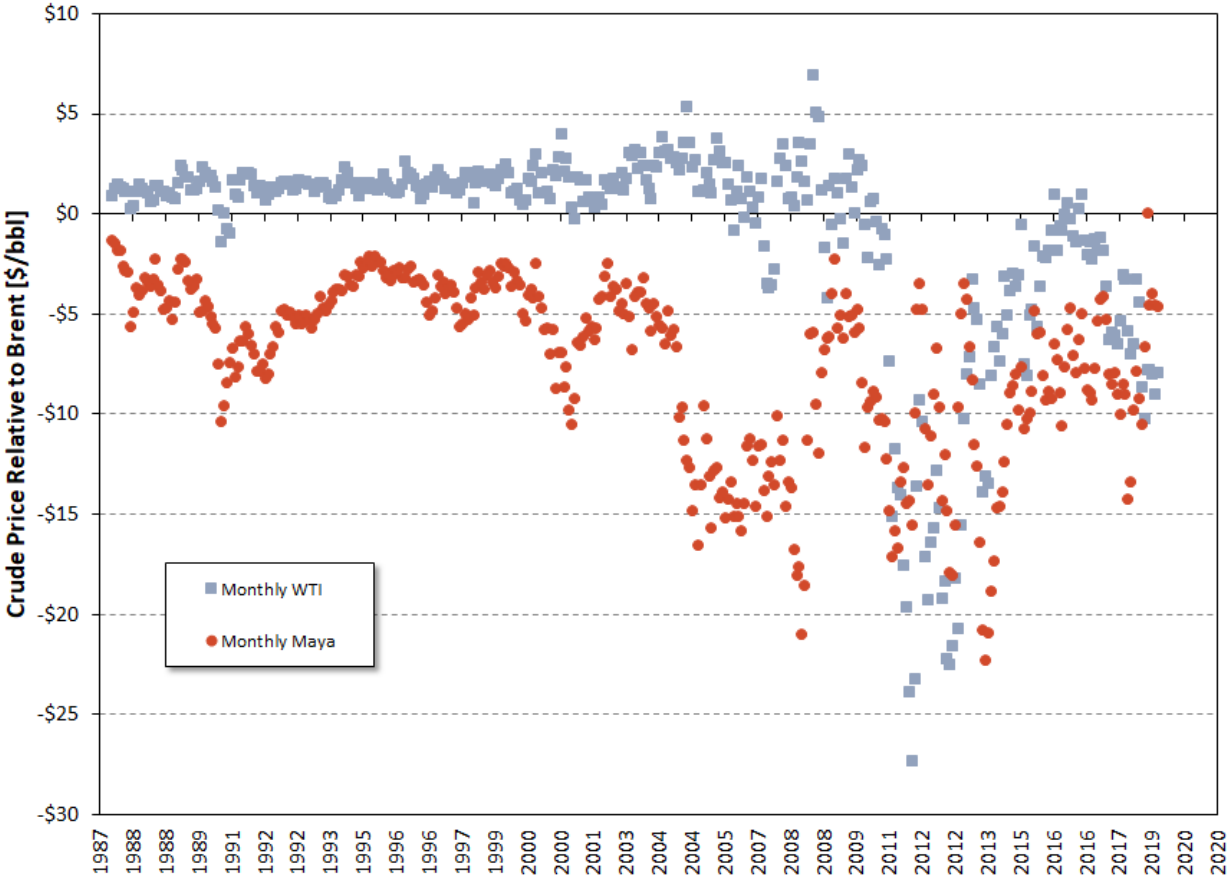
Prices Are Crude Specific



EIA published monthly production data – updated June 25, 2019
http://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm
http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=IMX2810004&f=M

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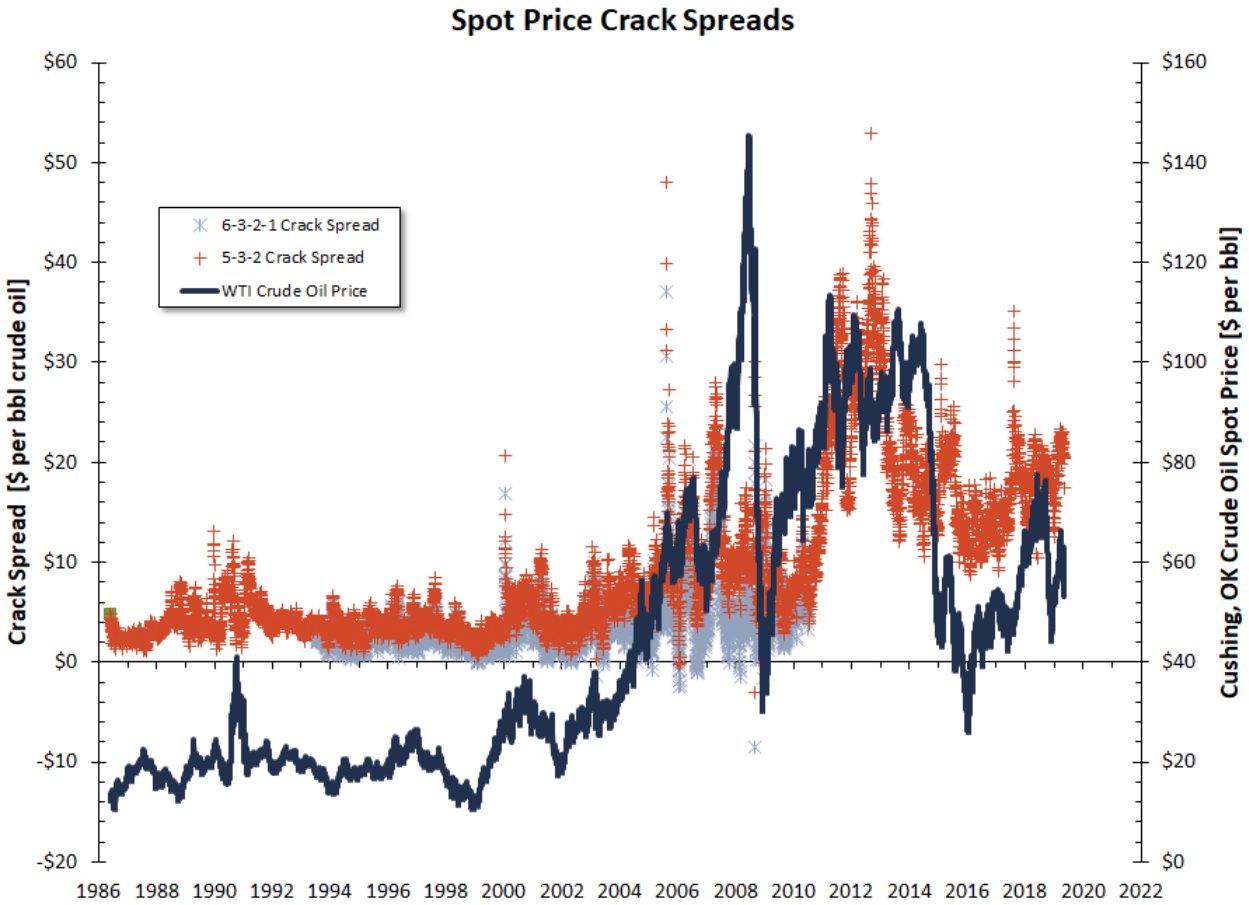
Historical Crude Prices & Crack Spreads



Updated July 12, 2018
Source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm

Price shocks?

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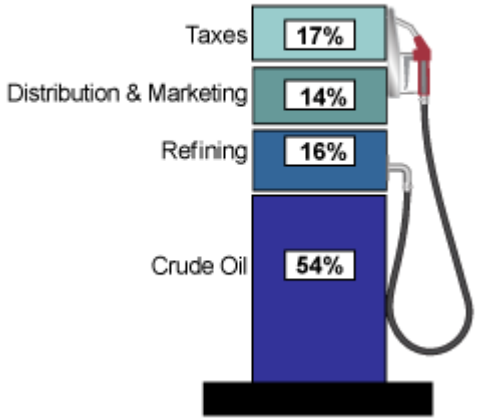
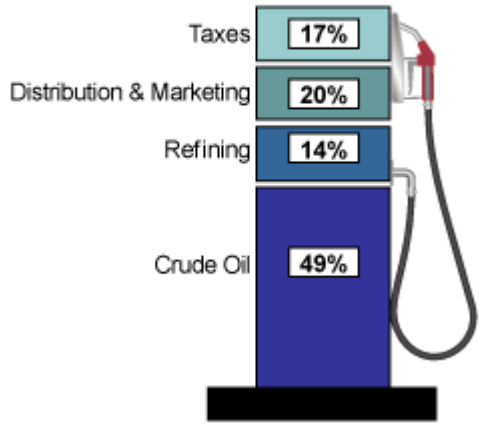
Gasoline & Diesel Retail vs. Wholesale Prices

Regular Gasoline (May 2019)
Retail Price: $2.86/gallon



Diesel (May 2019)
Retail Price: $3.16/gallon



Gasoline Retail Cost Contributions

		Per Gallon	Per Barrel
Retail Price		$2.86	$120.12
Taxes	17%	$0.49	$20.42
Distribution & Marketing	14%	$0.40	$16.82
Refining	*16%*	*$0.46*	*$19.22*
Crude Oil	*54%*	*$1.54*	*$64.86*
Refinery Costs / Wholesale Price		*$2.00*	*$84.08*

Diesel Retail Cost Contributions

		Per Gallon	Per Barrel
Retail Price		$3.16	$132.72
Taxes	17%	$0.54	$22.56
Distribution & Marketing	20%	$0.63	$26.54
Refining	*14%*	*$0.44*	*$18.58*
Crude Oil	*49%*	*$1.55*	*$65.03*
Refinery Costs / Wholesale Price		*$1.99*	*$83.61*

Source: http://www.eia.gov/petroleum/gasdiesel/
Updated June 25, 2019

Updated: August 5, 2019

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How do energy prices compare?

	Given Price		Heating Value			Price [$/MWh]	Price [$/MMBtu]	Relative to Natural Gas
RBOB Gasoline - wholesale	1.9149	$ per gallon	115,000	Btu/gal	LHV	56.82	16.65	7.4
Heating Oil - wholesale	1.9392	$ per gallon	130,500	Btu/gal	LHV	50.70	14.86	6.6
WTI Crude Oil	58.58	$ per bbl	5.8	MMBtu/bbl	HHV	34.46	10.10	4.5
Brent Crude Oil	64.448	$ per bbl	5.8	MMBtu/bbl	HHV	37.91	11.11	4.9
Ethanol - Chicago	1.4930	$ per gallon	75,700	Btu/gal	LHV	67.30	19.72	8.7
Natural Gas - Henry Hub	2.256	$ per MMBtu			HHV	7.70	2.26	1.0
Propane - Mt.Belvieu	0.40250	$ per gallon	90,905	Btu/gal	HHV	15.11	4.43	2.0
Powder River Basin Coal (low sulfur)	12.25	$ per ton	8,800	Btu/lb	HHV	2.37	0.70	0.3
Illinois Basin (high sulfur)	39.10	$ per ton	11,800	Btu/lb	HHV	5.65	1.66	0.7
Electricity (Residential, winter season)	5.461	¢ per kWh				54.61	16.00	7.1
Electricity (Residential, summer, over 500 kWh)	9.902	¢ per kWh				99.02	29.02	12.9
Electricity (Small Commercial, winter season)	4.256	¢ per kWh				42.56	12.47	5.5
Electricity (Small Commercial, summer season)	8.512	¢ per kWh				85.12	24.95	11.1
Hydrogen dispensed cost	13.99	$ per kg	324.2	Btu/scf	HHV	354.77	103.97	46.1

References:

Gasoline, Heating Oil, Crude Oil, Natural Gas from Blomberg (7/1/2019, Aug contract)
http://www.bloomberg.com/energy/

Natural Gas, Propane, & Ethanol prices from NYMEX via barchart.com (7/1/2019)
https://www.barchart.com/my/watchlist?viewName=main

Coal from US EIA Coal News & Markets (week ending 6/28/19).
http://www.eia.gov/coal/news_markets/

Xcel Energy electric tariff book (retrieved 4/12/2018)
http://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/CO-Rates-&-Regulations-Entire-Electric-Book.pdf

Ave. hydrogen cost, CA, from "Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California," Dec. 2015 (page 7)
http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf

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Generalized Petroleum Refinery

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Early History

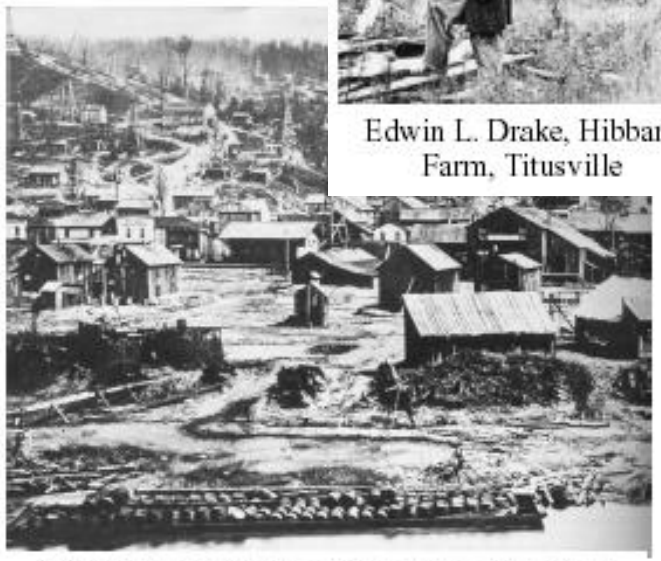
Commercial oil well of "Colonel" Edwin L. Drake

- August 1859, Oil Creek in northwestern Pennsylvania
- First refineries built up around Pennsylvania oil wells. Batch distillation to recover kerosene.
  - First U.S. refinery in Pittsburgh, PA, in 1853
  - Kerosene viewed as a superior replacement to whale oil for lamp oil.

Edwin L. Drake, Hibbard Farm, Titusville

Standard Oil Trust

- John D. Rockefeller acquired petroleum interests during the late 1800s. Organized as the Standard Oil Trust in 1882.
- U.S. Supreme Court dissolved in 1911. 34 companies spun off.



Oil Fields and Shipping Barges Along Oil Creek Pennsylvania, circa 1865

Change in product demand

- In 1911, nation's kerosene output eclipsed for the 1st time by a discarded byproduct - gasoline

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Implementation of Technologies

Year	Process name	Purpose	By-products, etc.
1862	Atmospheric distillation	Produce kerosene	Naphtha, tar, etc.
1870	Vacuum distillation	Lubricants (original) Cracking feedstocks (1930's)	Asphalt, residual coker feedstocks
1913	Thermal cracking	Increase gasoline	Residual, bunker fuel
1916	Sweetening	Reduce sulfur & odor	Sulfur
1930	Thermal reforming	Improve octane number	Residual
1932	Hydrogenation	Remove sulfur	Sulfur
1932	Coking	Produce gasoline basestocks	Coke
1933	Solvent extraction	Improve lubricant viscosity index	Aromatics
1935	Solvent dewaxing	Improve pour point	Waxes
1935	Cat. polymerization	Improve gasoline yield & octane number	Petrochemical feedstocks
1937	Catalytic cracking	Higher octane gasoline	Petrochemical feedstocks
1939	Visbreaking	Reduce viscosity	Increased distillate, tar
1940	Alkylation	Increase gasoline octane & yield	High-octane aviation gasoline
1940	Isomerization	Produce alkylation feedstock	Naphtha
1942	Fluid catalytic cracking	Increase gasoline yield & octane	Petrochemical feedstocks
1950	Deasphalting	Increase cracking feedstock	Asphalt
1952	Catalytic reforming	Convert low-quality naphtha	Aromatics
1954	Hydrodesulfurization	Remove sulfur	Sulfur
1956	Inhibitor sweetening	Remove mercaptan	Disulfides
1957	Catalytic isomerization	Convert to molecules with high octane number	Alkylation feedstocks
1960	Hydrocracking	Improve quality and reduce sulfur	Alkylation feedstocks
1974	Catalytic dewaxing	Improve pour point	Wax
1975	Residual hydrocracking	Increase gasoline yield from residual	Heavy residuals

Ref: http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html

Description of Petroleum Refinery

Manages hydrocarbon molecules

Organized & coordinated arrangement of manufacturing processes

- Provide physical & chemical change of crude oil
- Salable products with specifications & volumes as demanded by the marketplace

Complete refinery will include:

- Conversion units
- Tankage for storage
  - Typically 28 to 32 days of storage
- Dependable source for electric power
- Waste disposal & treatment facilities
- Product blending facilities
- Around the clock operations

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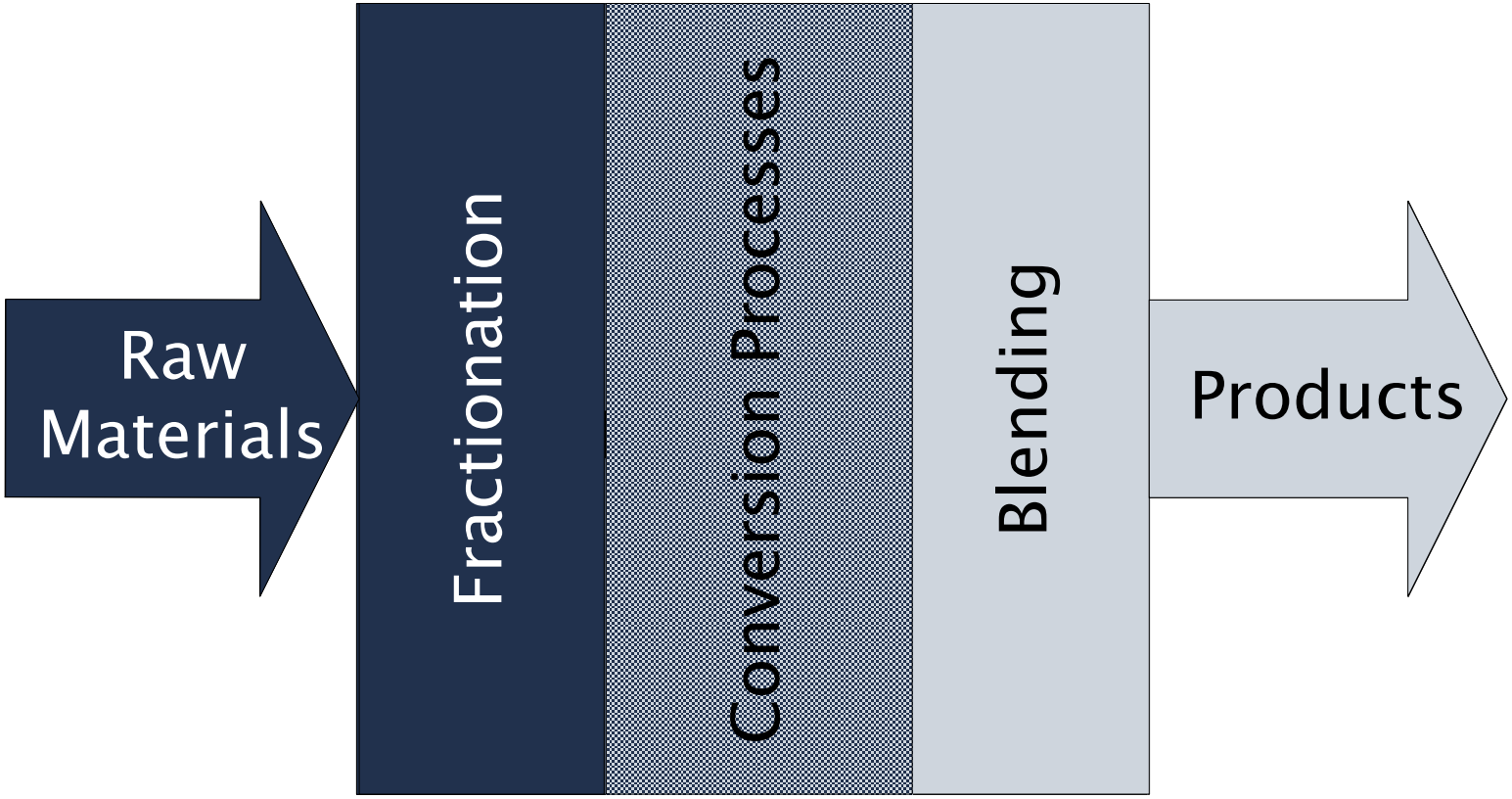
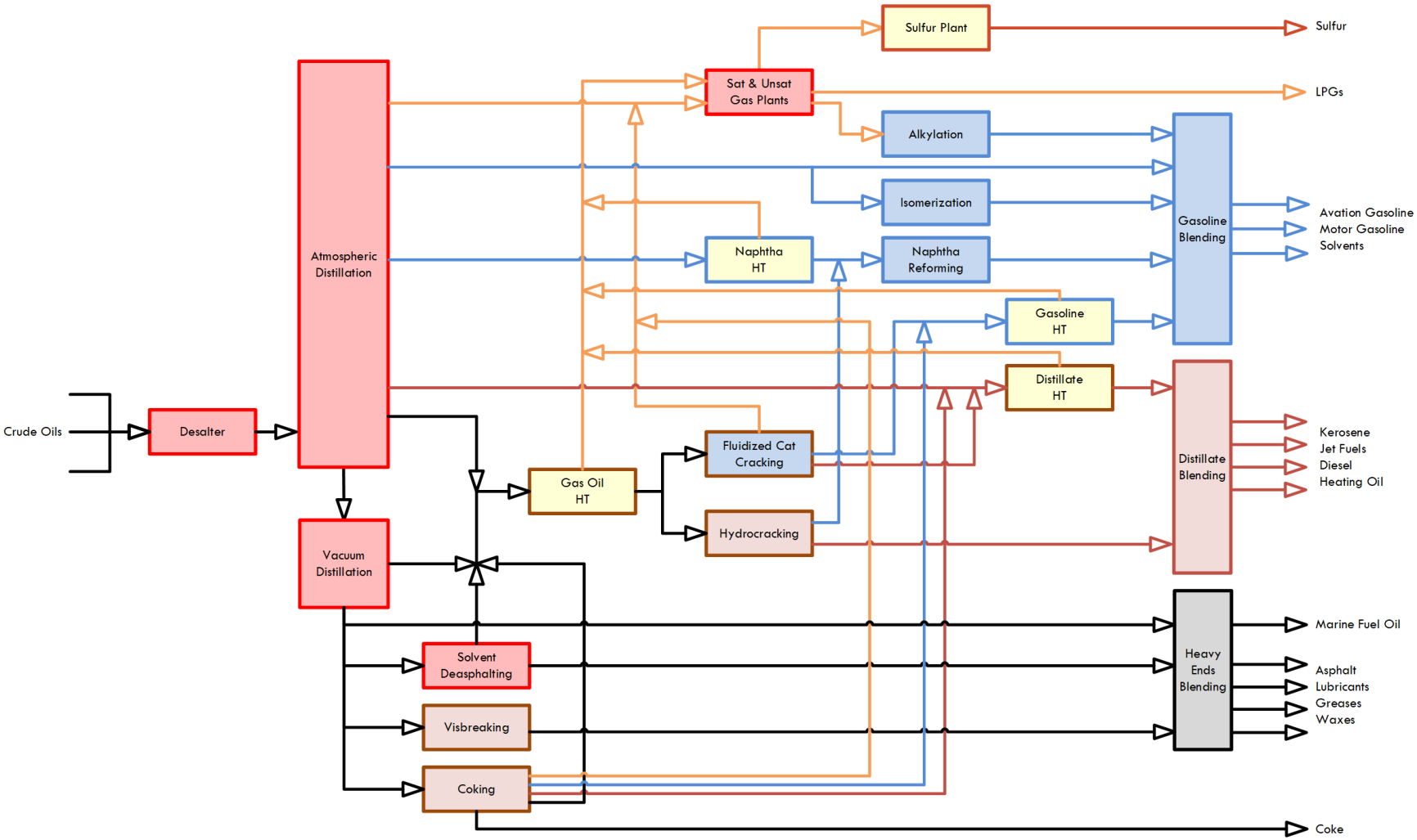
Petroleum Refinery Block Flow Diagram



Petroleum Refinery Block Flow Diagram



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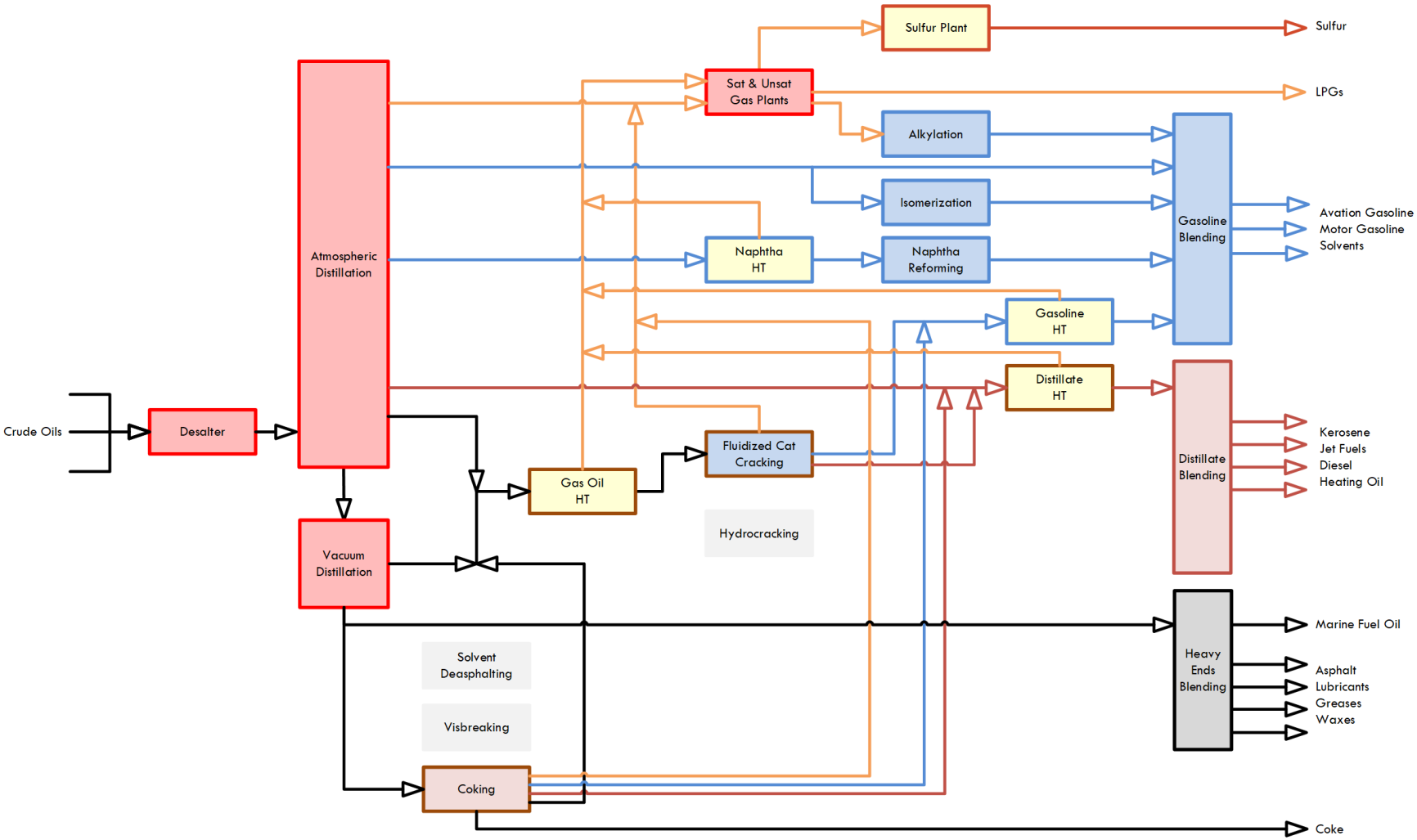
1990s Heavy Oil Refinery



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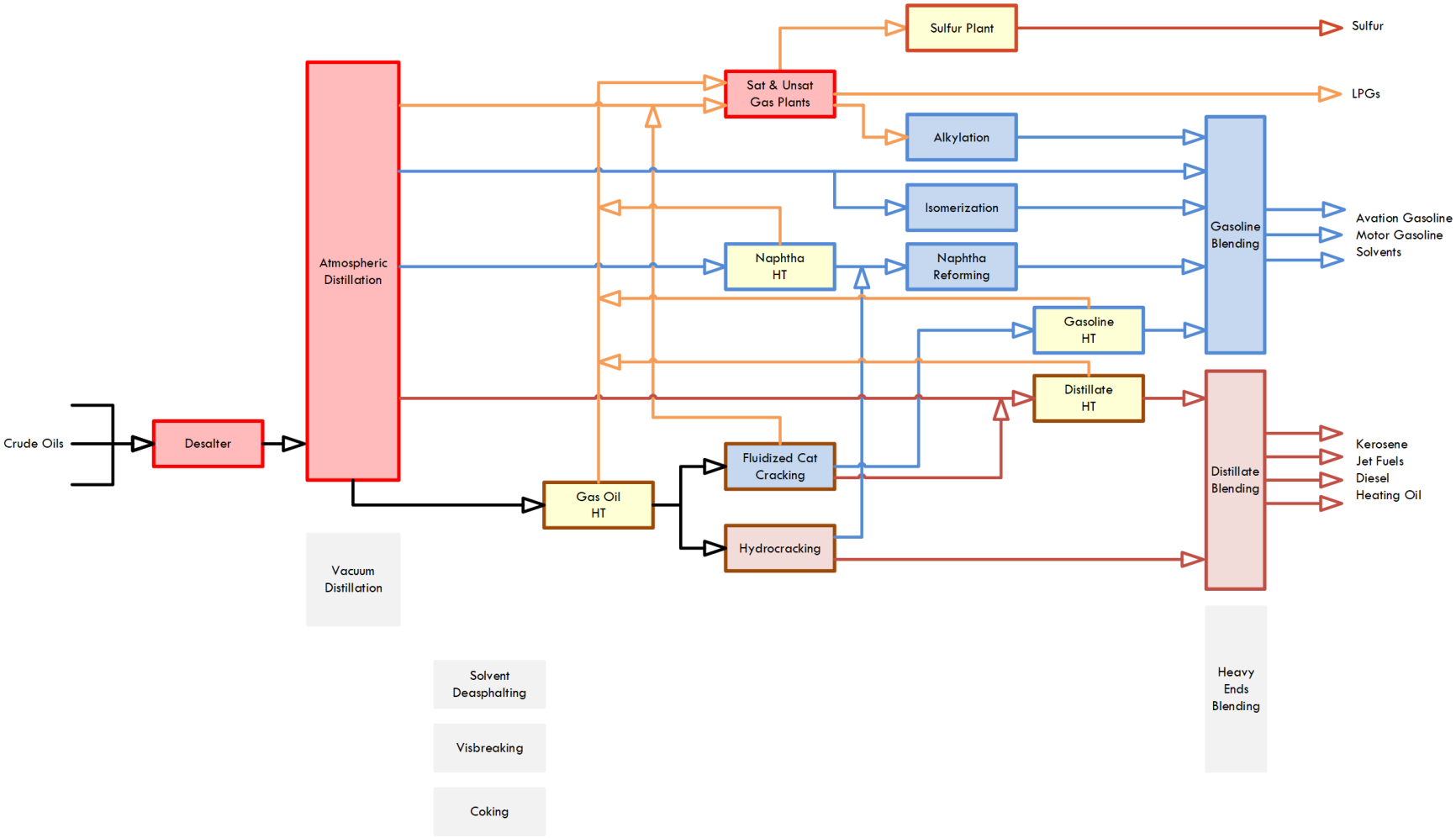
Light Crudes, no Vacuum Processing



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Summary

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Summary

Energy consumption in the U.S. & petroleum's contribution

- In the U.S. petroleum accounts for just over 35% of the nation's energy source
- Over 70% of petroleum is directed toward the transportation sector & accounts for 90% of the energy used in this sector
- Currently about 150 refineries in the U.S. & ownership changes to meet strategic needs of the companies' portfolios
- About 50% of the output of U.S. refineries is gasoline

Basic refining economics

- Refinery profits are based on the spread between product prices & crude oil costs

Generalized Petroleum Refinery

- Refineries may be simple or complex depending on the strategy of product production from particular crude oils

Supplemental Slides

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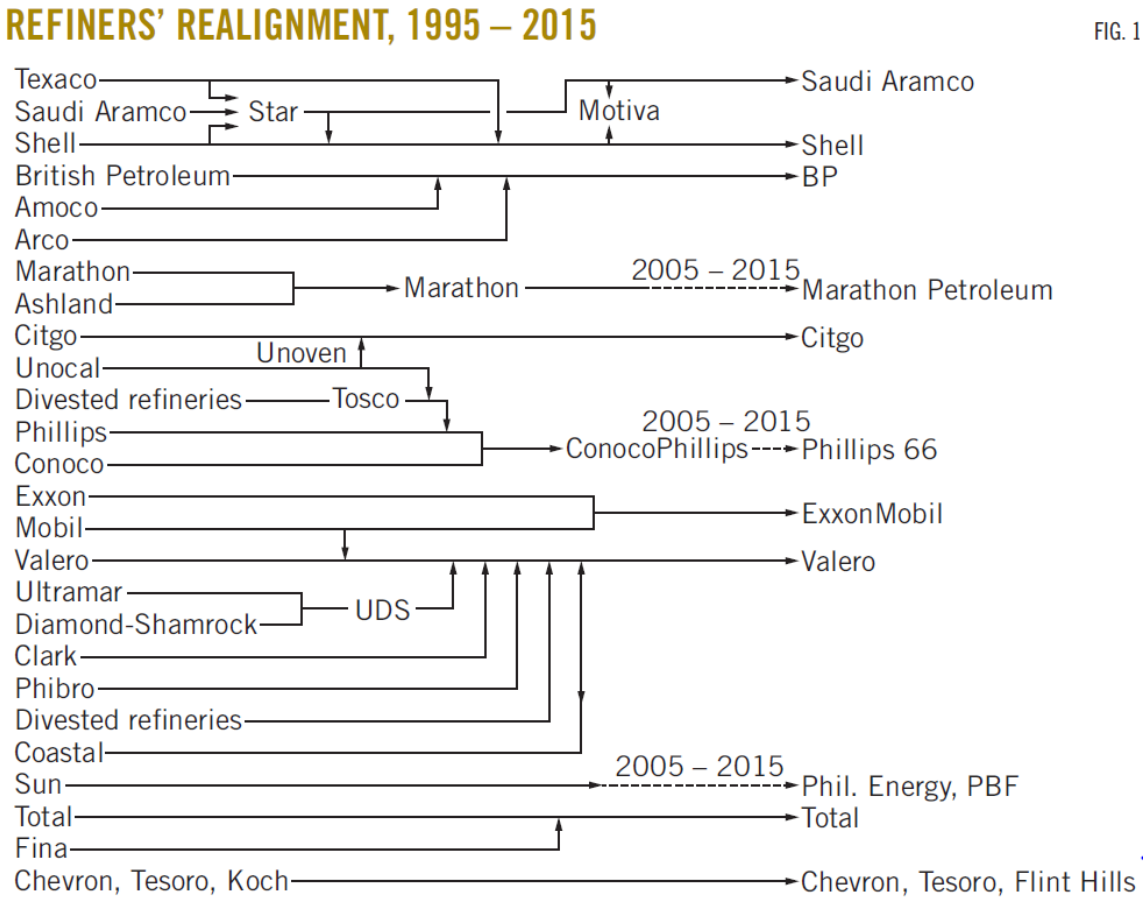
Refiner's Realignment



"US refiners continue consolidation, restructuring efforts", Leffler, *Oil & Gas Journal*, Aug. 3, 2015

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Recent Refinery Closures

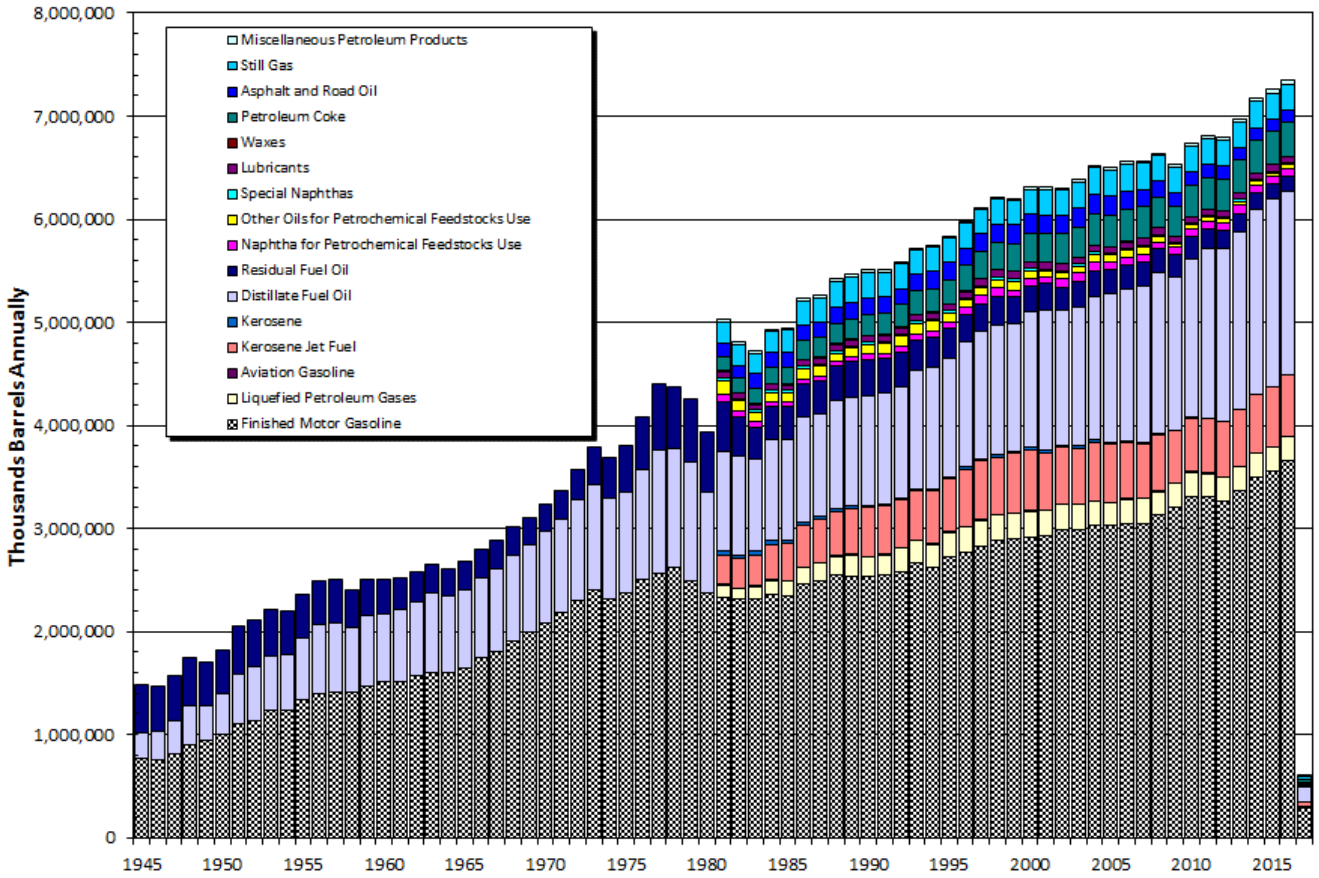
Location	Owner	CDU Capacity Closed (MBPD)	Year Closed
Perth Amboy, NJ	Chevron	80	2008
Bakersfield,CA	Big West	65	2008
Westville, NJ	Sunoco	145	2009
Bloomfield, NM	Western	17	2009
Teesside, UK	Petroplus	117	2009
Gonfreville, France*	Total	100	2009
Dunkirk, France	Total	140	2009
Japan*	Nippon Oil	205	2009
Toyama, Japan	Nihonkai Oil	57	2009
Arpechim, Romania *	Petrom	70	2009
Cartagena*	REPSOL	100	2009
Bilboa*	REPSOL	100	2009
Arpechim, Romania	OMV	70	2010
Japan*	Cosmo	94	2010
Nadvornaja, Ukraine	Privat Group	50	2010
Montreal, Canada[1]	Shell	130	2010
Yorktown, Virginia	Western	65	2010
Reichstett, France	Petroplus	85	2010
Wilhemshaven, Germany	Phillips 66	260	2010
Ingolstadt, Germany	Bayernoil	90	2010
Cremona, Italy	Tamoil	94	2011
St. Croix, U.S.V.I,*	Hovensa	150	2011
Funshun, China	PetroChina	70	2011

Location	Owner	CDU Capacity Closed (MBPD)	Year Closed
Keihin Ohgimachi, Japan	Showa Shell	120	2011
Clyde, Australia	Shell	75	2011
Porto Marghera, Italy	ENI	70	2011
Marcus Hook, PA	Sunoco	175	2011
Harburg, Germany	Shell	107	2012
Berre, France	LyondellBassel	105	2012
Coryton, U.K.	Petroplus	220	2012
Petit Couronne, France[1]	Petroplus	160	2012
St. Croix, U.S.V.I	Hovensa	350	2012
Aruba	Valero	235	2012
Rome, Italy	TotalErg	82	2012
Fawley, U.K.*	ExxonMobil	80	2012
Trecate, Italy*	ExxonMobil	70	2012
Paramo, Czech Republic	Unipetrol	20	2012
Lisichansk, Ukraine	TNK-BP	175	2012
Bakersfield/Paramount, CA	Alon	90	2012
Ewa Beach, Hawaii	Tesoro	94	2013
Port Reading, NJ	Hess	N/A	2013
Venice, Italy	ENI	80	2013
Sakaide, Japan	Cosmo Oil	140	2013
Japan	Indemitsu Kosan	100	2014
Japan	Nippon	200	2014
Kurnell, Australia	Caltex	135	2014
Kawasaki, Japan	Tonen- General	105	2014

*Partial closure of refinery captured in capacity Note: This data represents refineries currently closed, ownership may choose to restart or sell listed refinery
Sources: Industry and Consultant reports and Valero estimates
[1]The Petit Couronne refinery has shut completely when processing deal with Shell ended in December 2012
[2]Alon announced the closure of these refineries for economic reasons, may restart

Ref: Valero, *UBS Global Oil and Gas Conference*, May 21-22, 2013

U.S. Refinery & Blender Net Production



Includes production to January 2017 – updated April 7, 2017
Source: http://tonto.eia.doe.gov/dnav/pet/pet_pnp_refp_dc_nus_mbbl_m.htm

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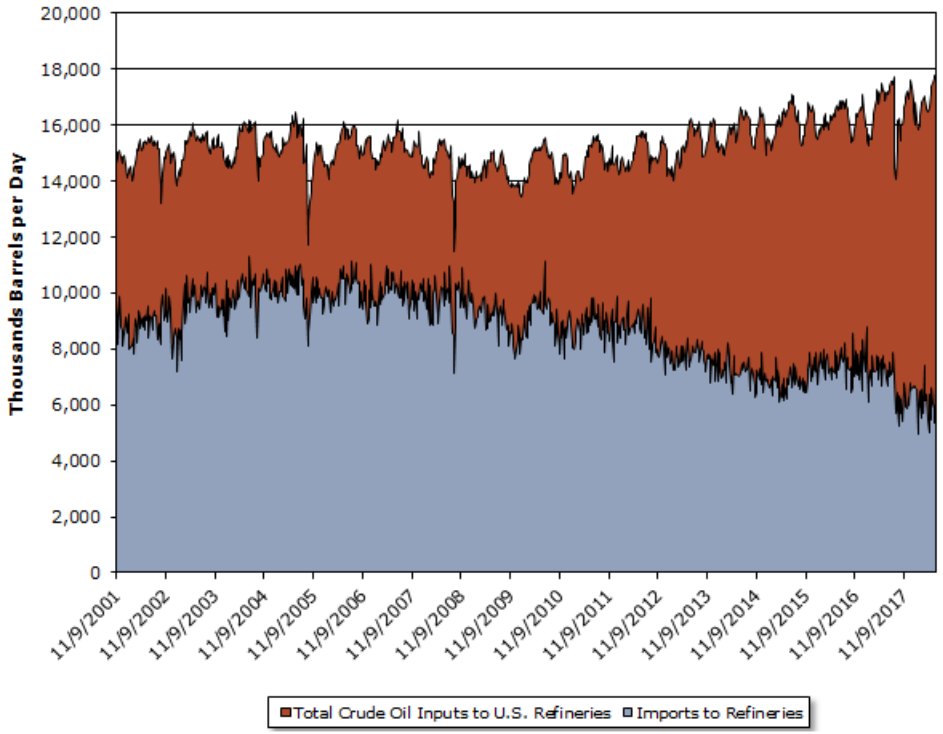
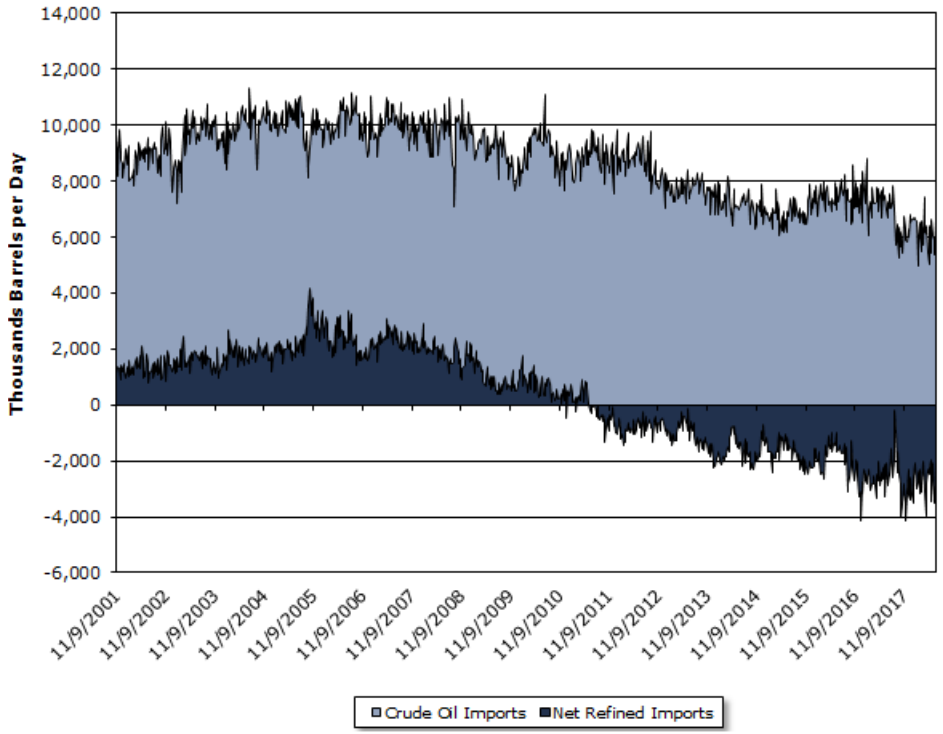
U.S. Oil from Imports





EIA published data used for charts – updated July 12, 2018
http://www.eia.gov/dnav/pet/pet_move_wkly_dc_nus-z00_mbblpd_w.htm
http://www.eia.gov/dnav/pet/pet_pnp_wiup_dcu_nus_w.htm

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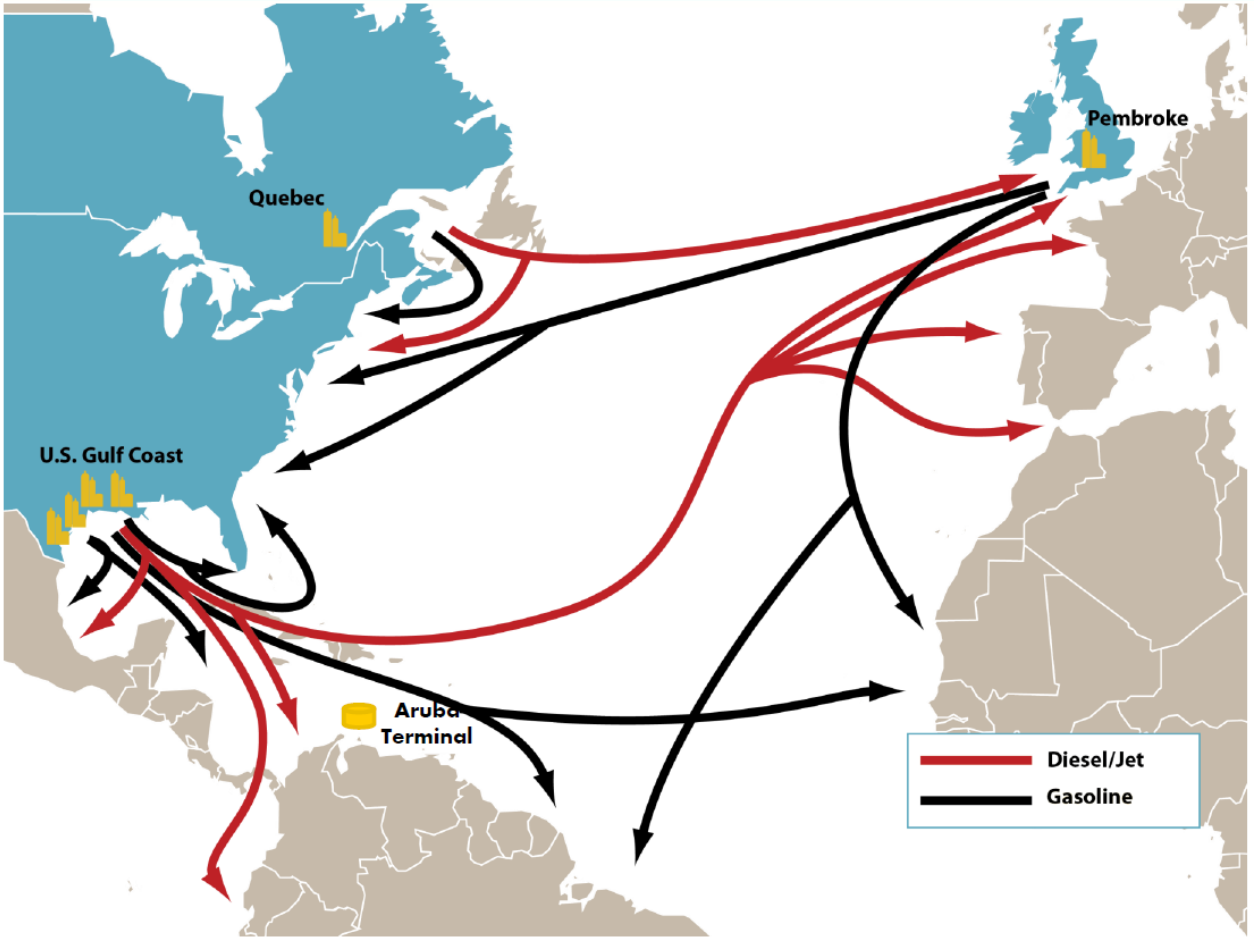
Import/Export Refined Products – Valero Example



Ref: Valero, *UBS Global Oil and Gas Conference*, May 21-22, 2013

Prices Are Crude Specific – Historical Example

US CRUDE PRICES

	1-17-14 $/bbl*
Alaska-North Slope 27°	93.40
Light Louisiana Sweet	89.74
California-Midway Sunset 13°	93.85
California Buena Vista Hills 26°	101.63
Wyoming Sweet	85.87
East Texas Sweet	88.00
West Texas Sour 34°	85.75
West Texas Intermediate	90.75
Oklahoma Sweet	90.75
Texas Upper Gulf Coast	84.50
Michigan Sour	82.75
Kansas Common	89.75
North Dakota Sweet	74.94

*Current major refiner's posted prices except N. Slope lags 2 months. 40° gravity crude unless differing gravity is shown.
Source: Oil & Gas Journal. Data available at PennEnergy Research Center.

WORLD CRUDE PRICES

OPEC reference basket	Wkly. avg. 1-17-14 $/bbl	— Mo. avg., $/bbl — Oct.-13	Nov.-13
OPEC reference basket	104.17	106.69	104.97
Arab light-Saudi Arabia		107.14	104.84
Basrah light-Iraq		103.69	101.63
Bonny light 37°-Nigeria		112.44	111.47
Es Sider-Libya		108.74	107.57
Girassol-Angola		110.20	108.83
Iran heavy-Iran		107.69	106.87
Kuwait export-Kuwait		106.13	104.73
Marine-Qatar		106.61	105.83
Merey-Venezuela		96.80	94.83
Murban-UAE		110.13	109.36
Oriente-Ecuador		95.16	89.72
Saharan blend 44°-Algeria		111.04	109.27
Other crudes			
Minas 34°-Indonesia		106.98	104.28
Fateh 32°-Dubai		106.70	105.95
Isthmus 33°-Mexico		99.84	93.83
Tia Juana light 31°-Venezuela		NA	NA
Brent 38°-UK		109.04	107.97
Urals-Russia		108.28	107.73
Differentials			
WTI/Brent		(8.63)	(14.21)
Brent/Dubai		2.34	2.02

Source: OPEC Monthly Oil Market Report.
Data available at PennEnergy Research Center.

Ref: Statistics, *Oil & Gas Journal*, January 27, 2014

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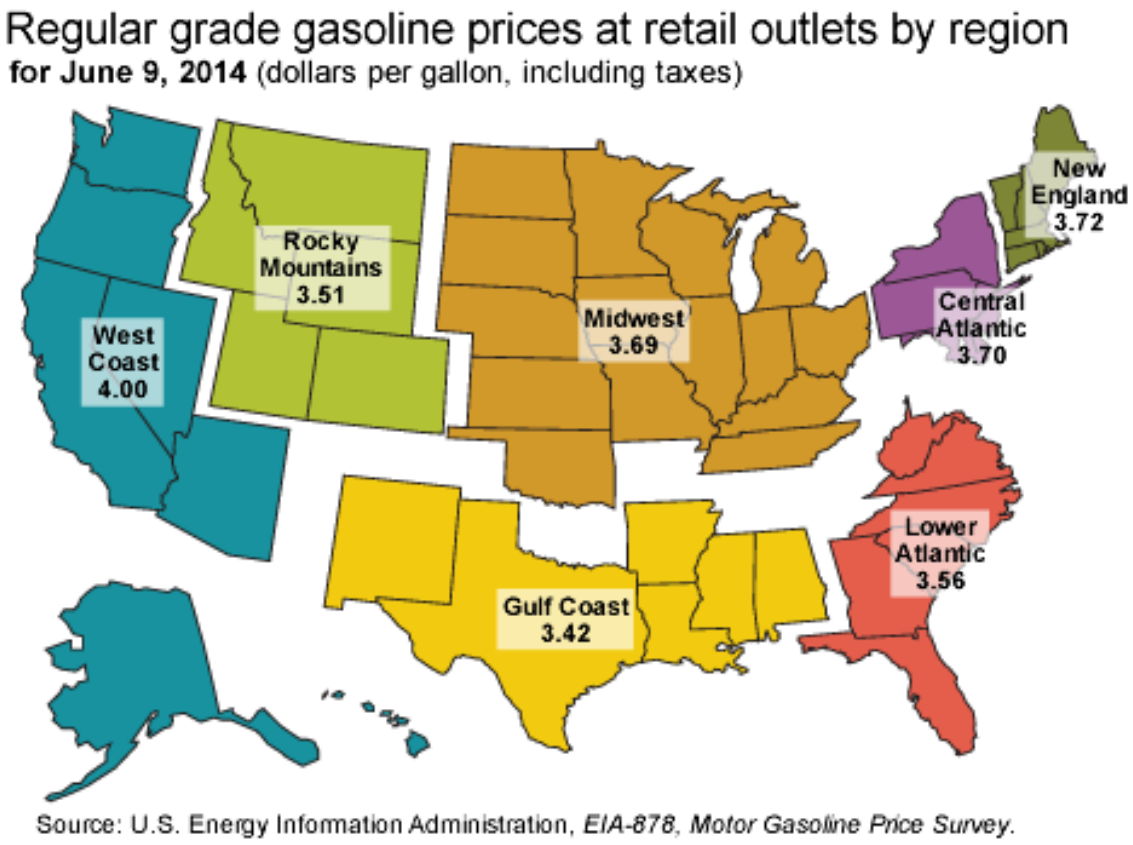
Pump prices are not the same across U.S.



Source: http://www.eia.gov/petroleum/images/gasoline_prices_map_375.png
Downloaded August 4, 2016

Updated: August 5, 2019

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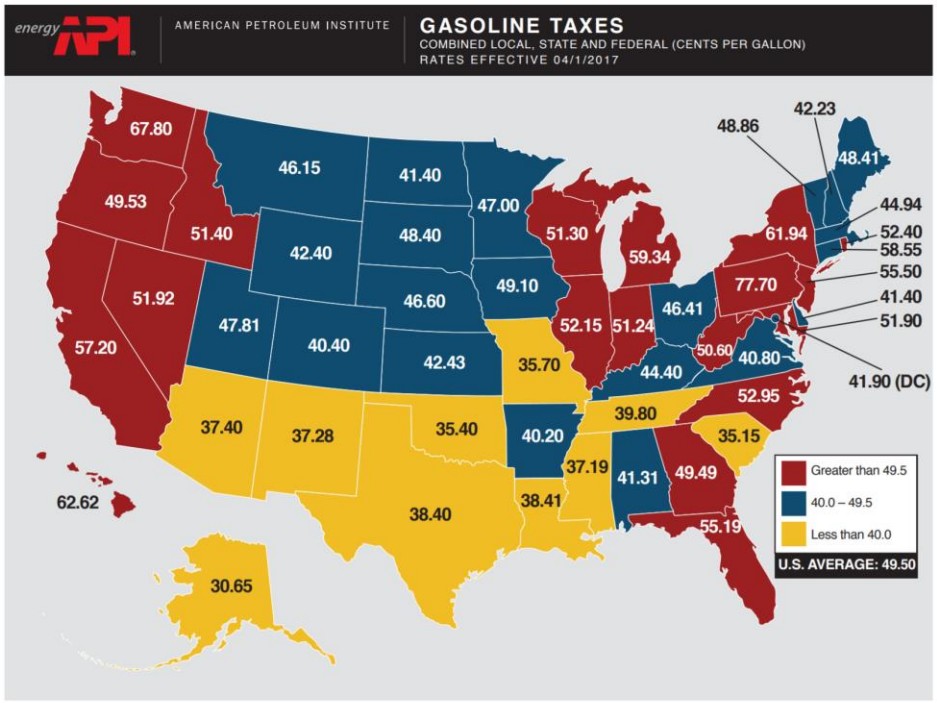
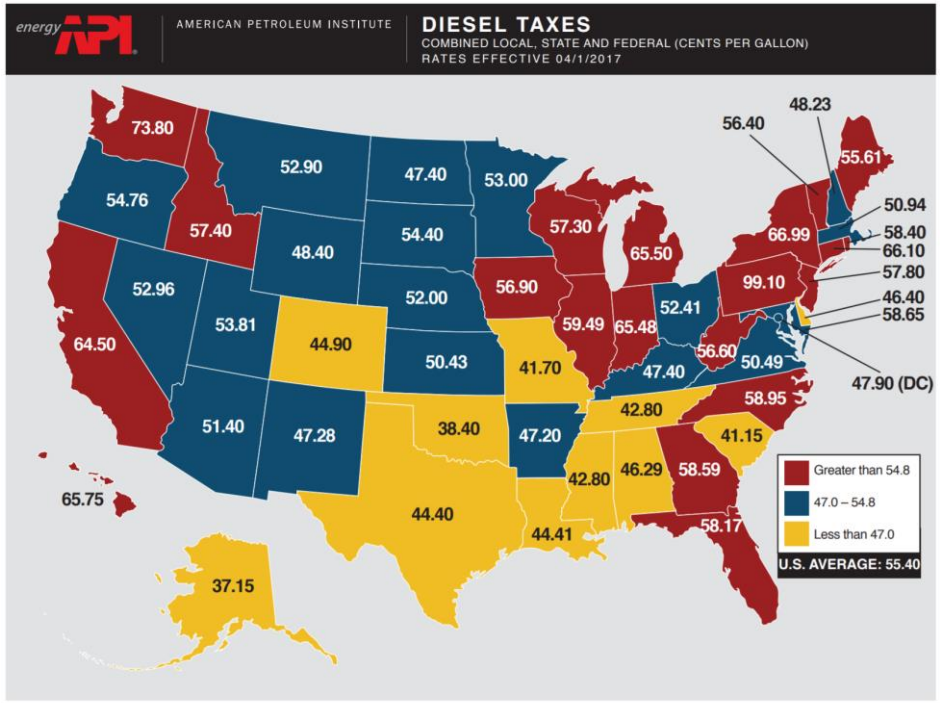
Gasoline & Diesel Taxes not the same across U.S.





Source: http://www.api.org/oil-and-natural-gas-overview/industry-economics/fuel-taxes
Downloaded July 5, 2017

Updated: August 5, 2019

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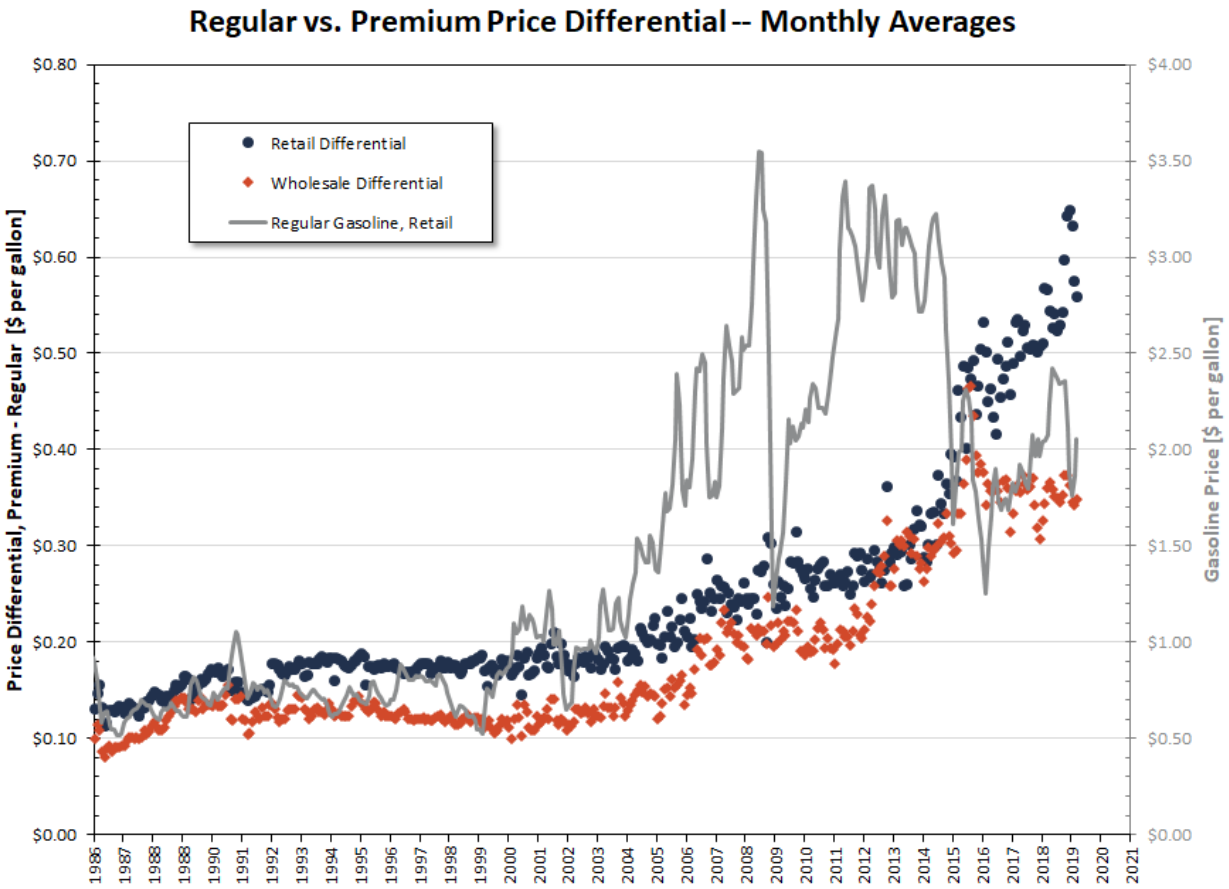
Differential Between Regular & Premium Gasolines



Updated June 25, 2019
Source: http://www.eia.gov/dnav/pet/pet_pri_refmg_dcu_nus_m.htm

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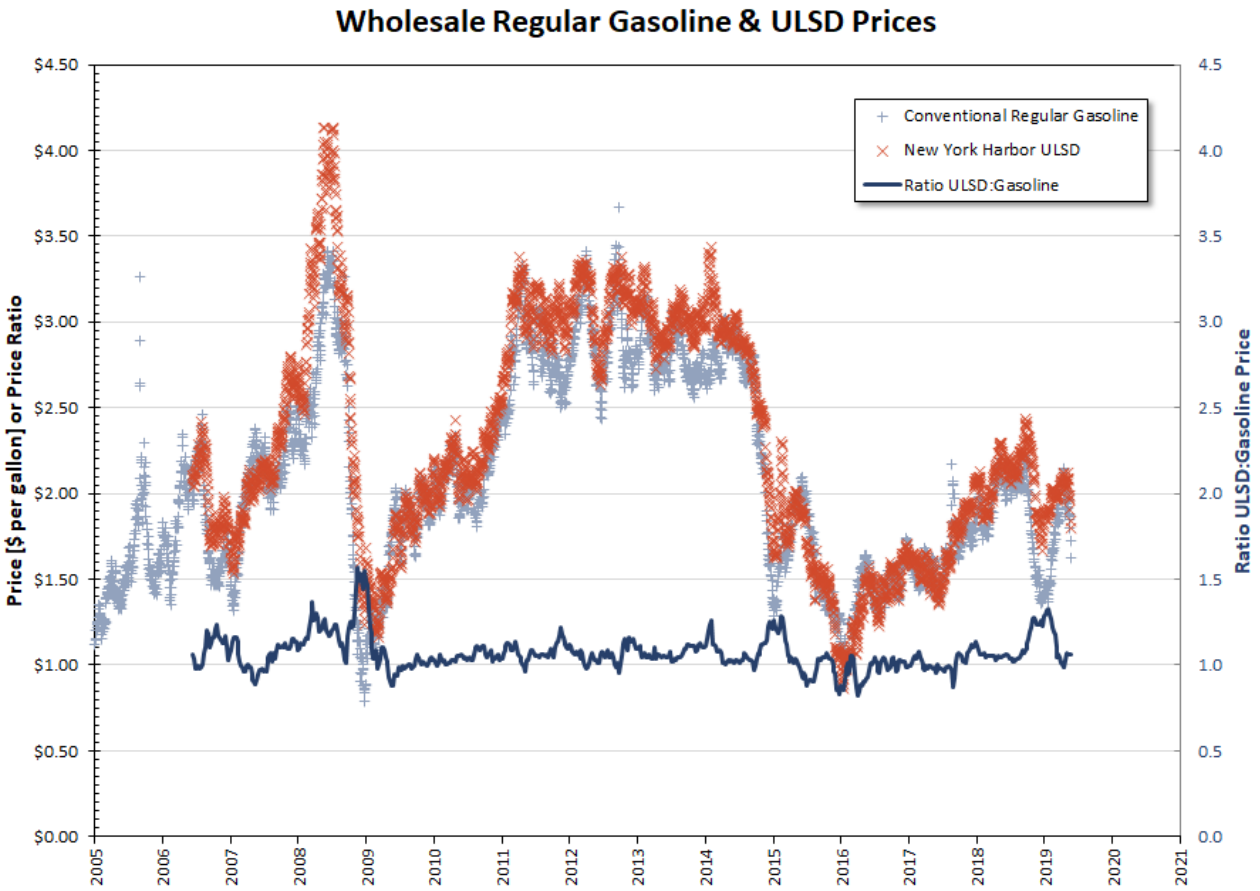
Comparison Wholesale Regular Gasoline & ULSD



Updated June 25, 2019
Source: http://www.eia.gov/dnav/pet/pet_pri_refmg_dcu_nus_m.htm

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Process Cost Estimates

Accounts for size impact on installed cost

Developed from reported final costs & supplemented with engineering estimates

Meant to represent "typical" values – no better than ±25%

Not included:

- Working capital
- Inventories
- Start-up expenses
- Cost of land
- Site preparation
- Taxes
- Licenses
- Permits
- Duties

PROCESS COST FUNCTIONS Table 8

Process Unit	Cost, $ million = α * capacity$^{\beta}$ α	β	Units of Capacity
Desalter	0.44	0.555	1,000 b/sd
Atmospheric distillation	8.20	0.510	1,000 b/sd
Vacuum distillation	8.34	0.493	1,000 b/sd
Delayed coking			
30 bbl feed/ton coke	*17.56*	*0.657*	1,000 b/sd
10 bbl feed/ton coke	*24.42*	*0.644*	1,000 b/sd
Visbreaking	5.80	0.741	1,000 b/sd
Fluid catalytic cracking			
Distillate feed	24.67	0.461	1,000 b/sd
Resid feed	32.98	0.510	1,000 b/sd
Catalytic hydrocracking			
1,000 scf/bbl H_2	15.65	0.719	1,000 b/sd
3,000 scf/bbl H_2	26.18	0.714	1,000 b/sd
Catalytic hydrotreating			
Naphtha desulfurization	4.96	0.524	1,000 b/sd
Distillate desulfurization	8.62	0.576	1,000 b/sd
Resid desulfurization	8.61	0.834	1,000 b/sd
Catalytic reforming			
Semiregenerative	7.96	0.572	1,000 b/sd
Continuous	12.19	0.547	1,000 b/sd
Isomerization			
Butane	9.57	0.514	1,000 b/sd
Pentane/hexane; once through	3.11	0.565	1,000 b/sd
Pentane/hexane; recycle	6.17	0.599	1,000 b/sd
Alkylation	12.19	0.606	1,000 b/sd
Hydrogen production			
Steam methane reforming	3.35	0.599	MMscfd
Partial oxidation	5.44	0.601	MMscfd
Gas processing			
1 gal/Mscf	1.91	0.627	MMscfd
10 gal/Mscf	4.38	0.593	MMscfd
20 gal/Mscf	5.83	0.610	MMscfd
Amine gas treating	0.064	0.746	gpm
Sulfur recovery	2.64	0.412	long ton/day
Sulfur removal			
S-zorb, gasoline	4.77	0.602	1,000 b/sd
S-zorb, diesel	4.62	0.553	1,000 b/sd
Dewaxing	5.82	0.598	1,000 b/sd
Ether production	8.96	0.472	1,000 b/sd

2005 U.S. Gulf Coast Cost Yeat Basis
Delayed Coking curves modified to match Gary, et. al., textbook

Kaiser & Gary, "Study updates refinery investment cost curves", *Oil & Gas Journal*, Apr. 23, 2007, pp 84-94.
(Delayed coking curves may have been switched)

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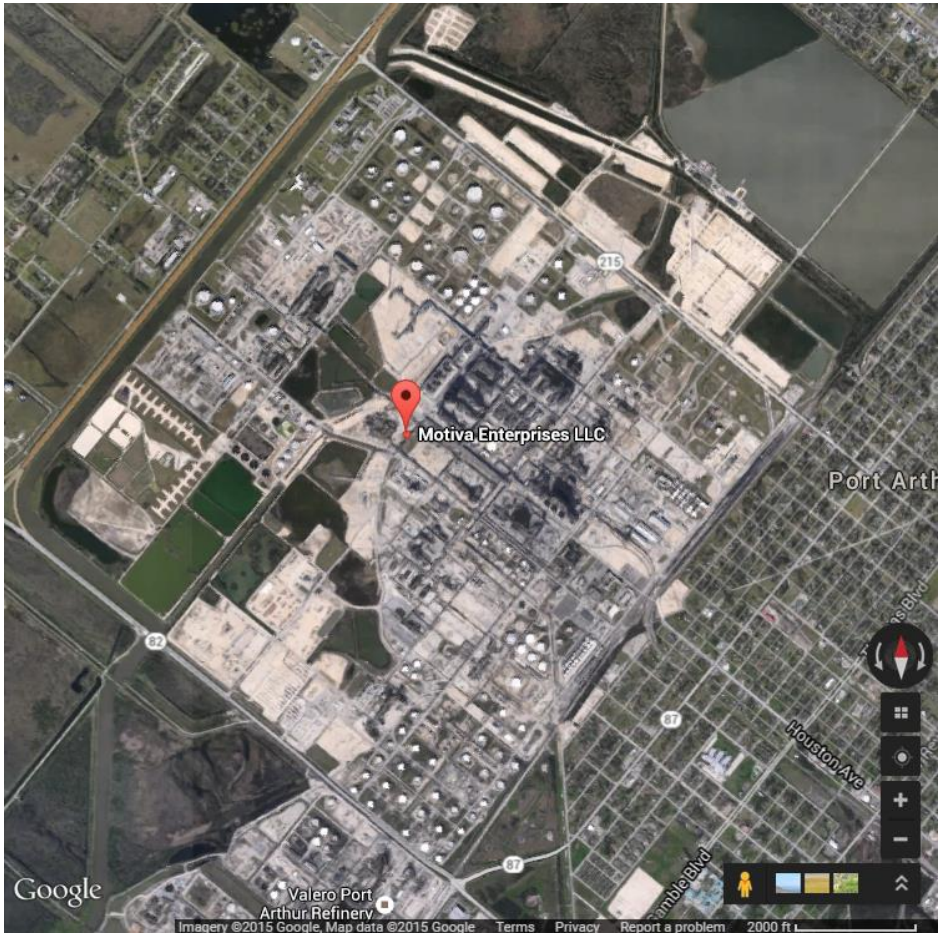
Satellite View of Selected U.S. Refineries



Motiva Enterprises LLC, Port Arthur, TX
603,000 bbl per calendar day

Dakota Prairie Refinery, Dickinson, ND
19,000 bbl per calendar day

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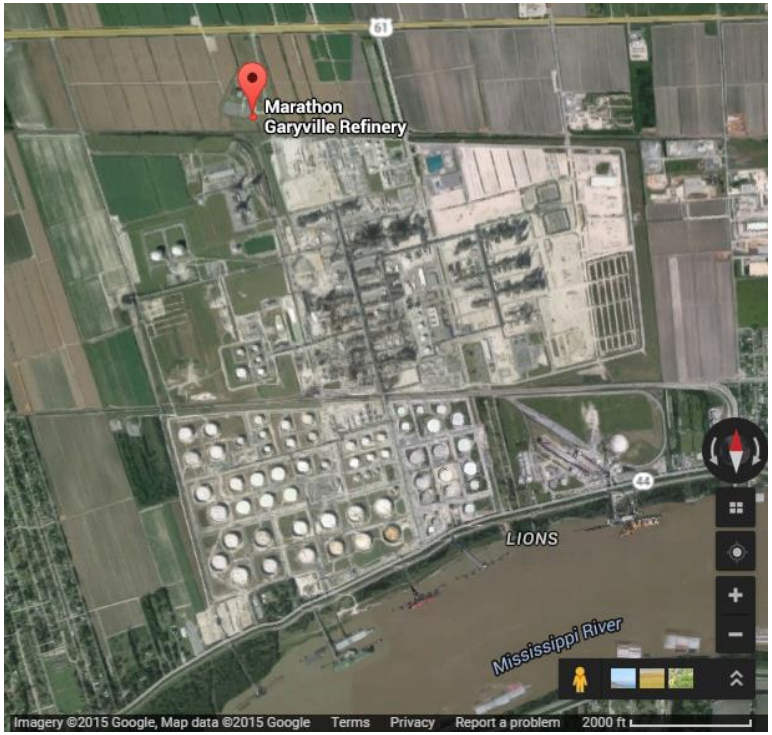
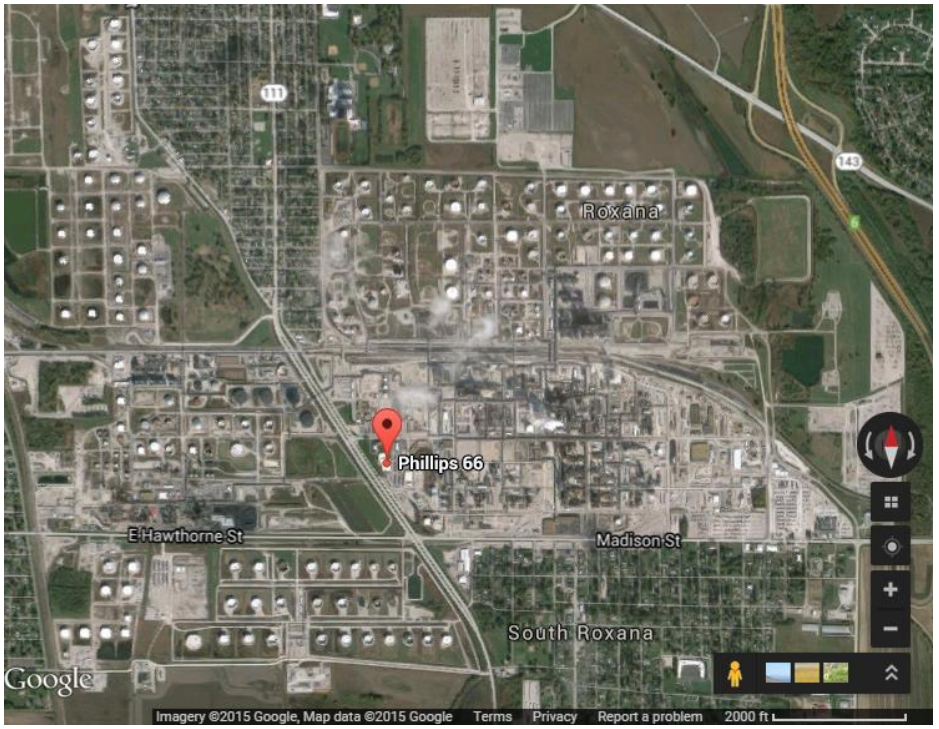
Satellite View of Selected U.S. Refineries



Marathon Garyville Refinery, Garyville, LA
451,000 bbl per calendar day



Wood River Refinery, Roxanna, IL
336,000 bbl per calendar day

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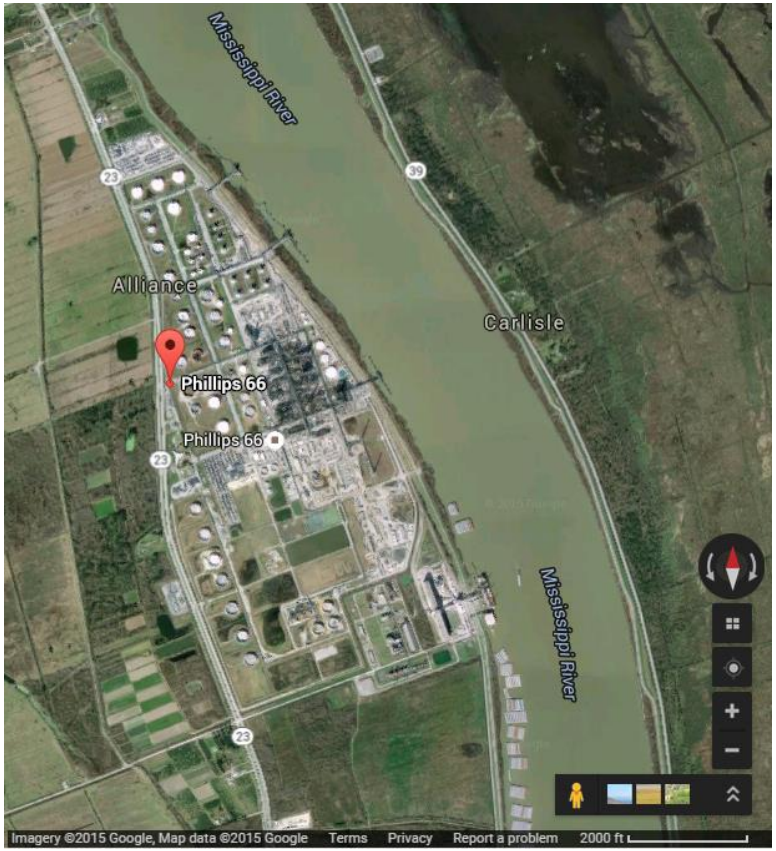
Satellite View of Selected U.S. Refineries



Phillips 66 Alliance Refinery, Belle Chasse, LA
247,000 bbl per calendar day

Suncor Refinery, Commerce City, CO
103,000 bbl per calendar day

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