

Petroleum Refining Overview



Topics

Energy consumption & petroleum's place

- Size of U.S. industry
- Major refiners

Petroleum products

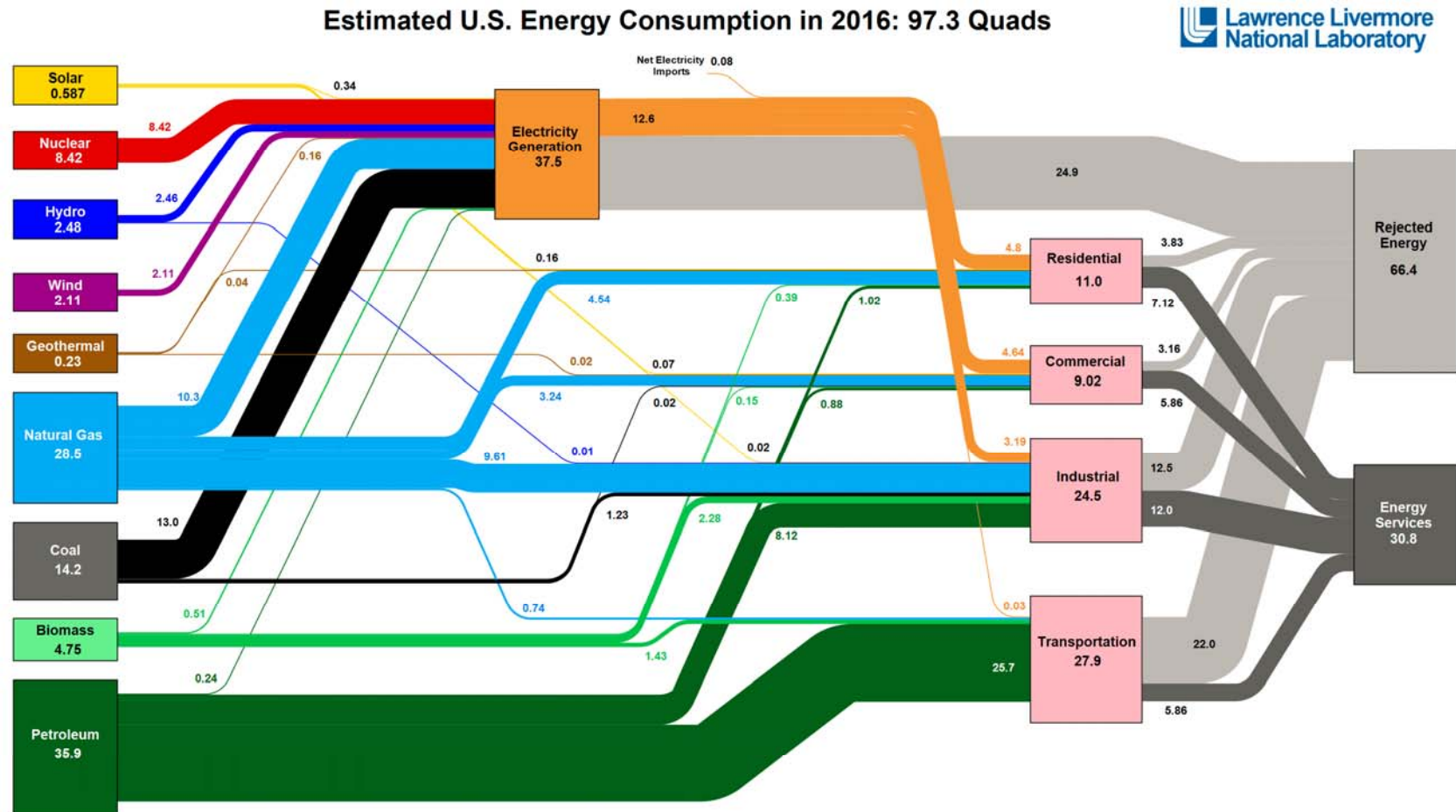
Basic petroleum economics

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

Generalized Petroleum Refinery

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

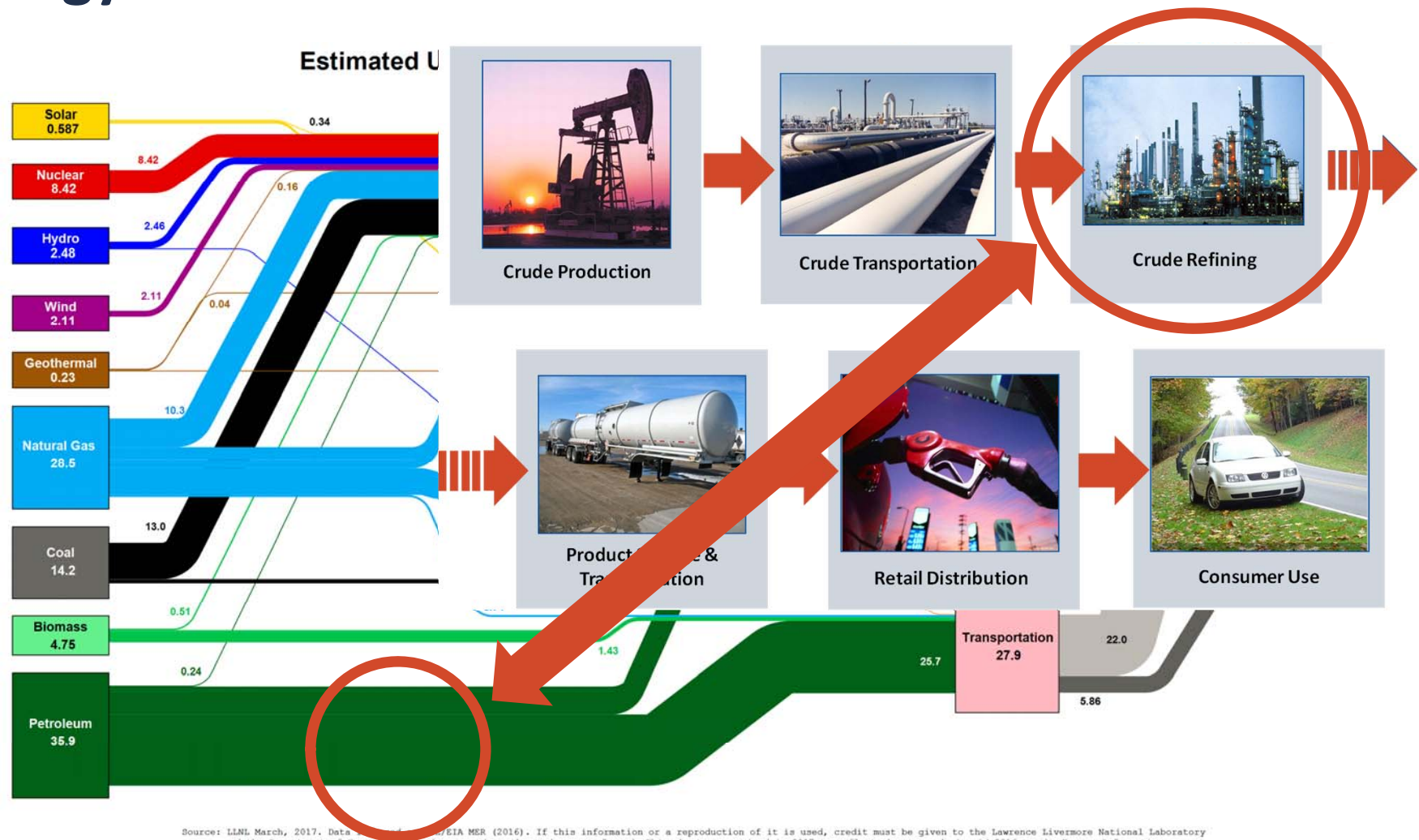
Energy Markets Are Interconnected



Source: LLNL March, 2017. Data is based on DOE/EIA MER (2016). 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. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. 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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<https://flowcharts.llnl.gov/commodities/energy>

World & U.S. Refining Capacity

HOW THE WORLD'S LARGEST REFINERS RANK

Table 1

Rank	Rank	Company	Crude
Jan. 1, 2015	Jan. 1, 2014		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	QAO 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

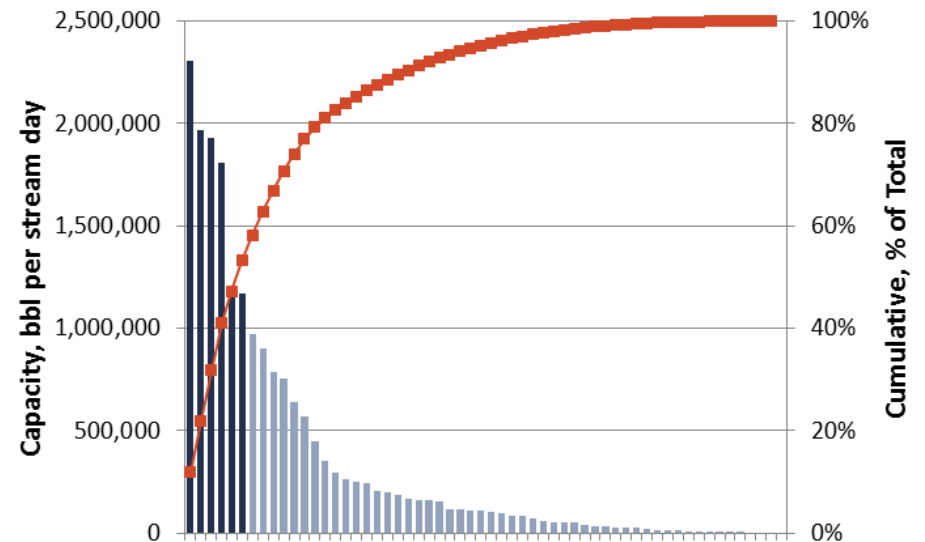
¹Includes partial interests in refineries not wholly owned by the company. ²Includes holdings in Caltex Oil and GS Caltex.

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

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

Corporation	Capacity Barrels per Stream Day	Capacity Barrels per Calendar Day	Availability
VALERO ENERGY CORP	2,307,500	2,180,300	94%
PHILLIPS 66 COMPANY	1,967,944	1,856,200	94%
MARATHON PETROLEUM CORP	1,931,500	1,817,000	94%
EXXON MOBIL CORP	1,807,500	1,725,400	95%
ROYAL DUTCH/SHELL GROUP	1,191,000	1,129,018	95%
ANDEAVOR	1,171,300	1,109,615	95%
Total	19,506,319	18,345,727	94%

Capacities for LLC refineries split among the partner companies



EIA, Jan. 1, 2017 database, published June 2017

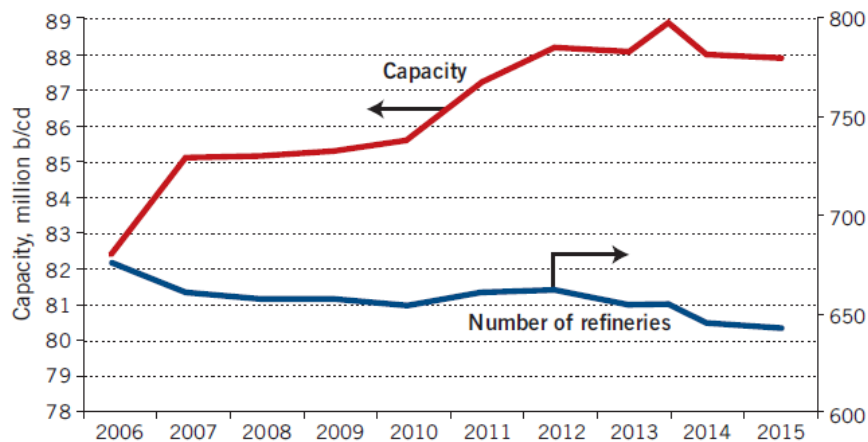
<http://www.eia.gov/petroleum/refinerycapacity/>

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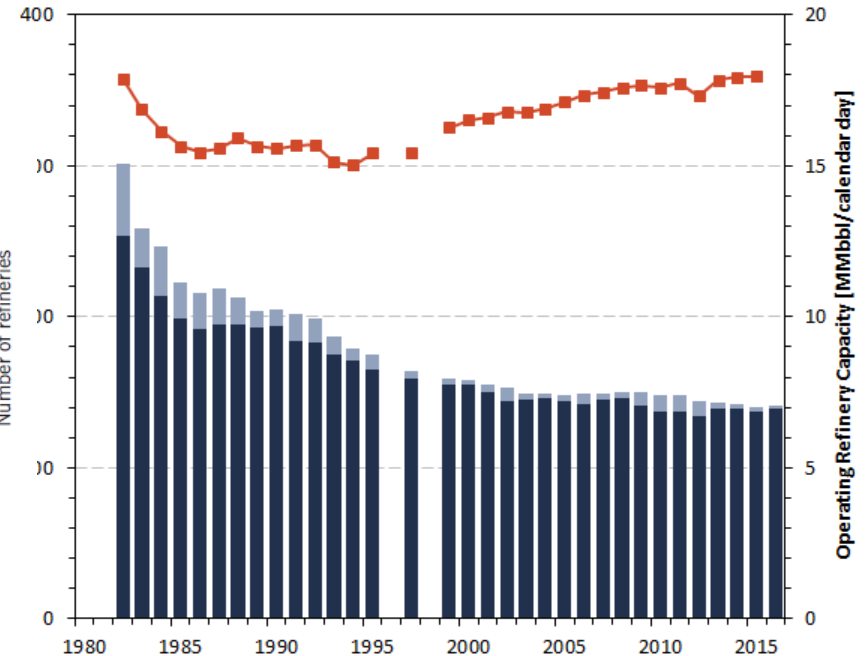
Number & Capacity of World & U.S. Refineries

WORLDWIDE REFINING*



*As of Jan. 1 of each year.

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



Source:

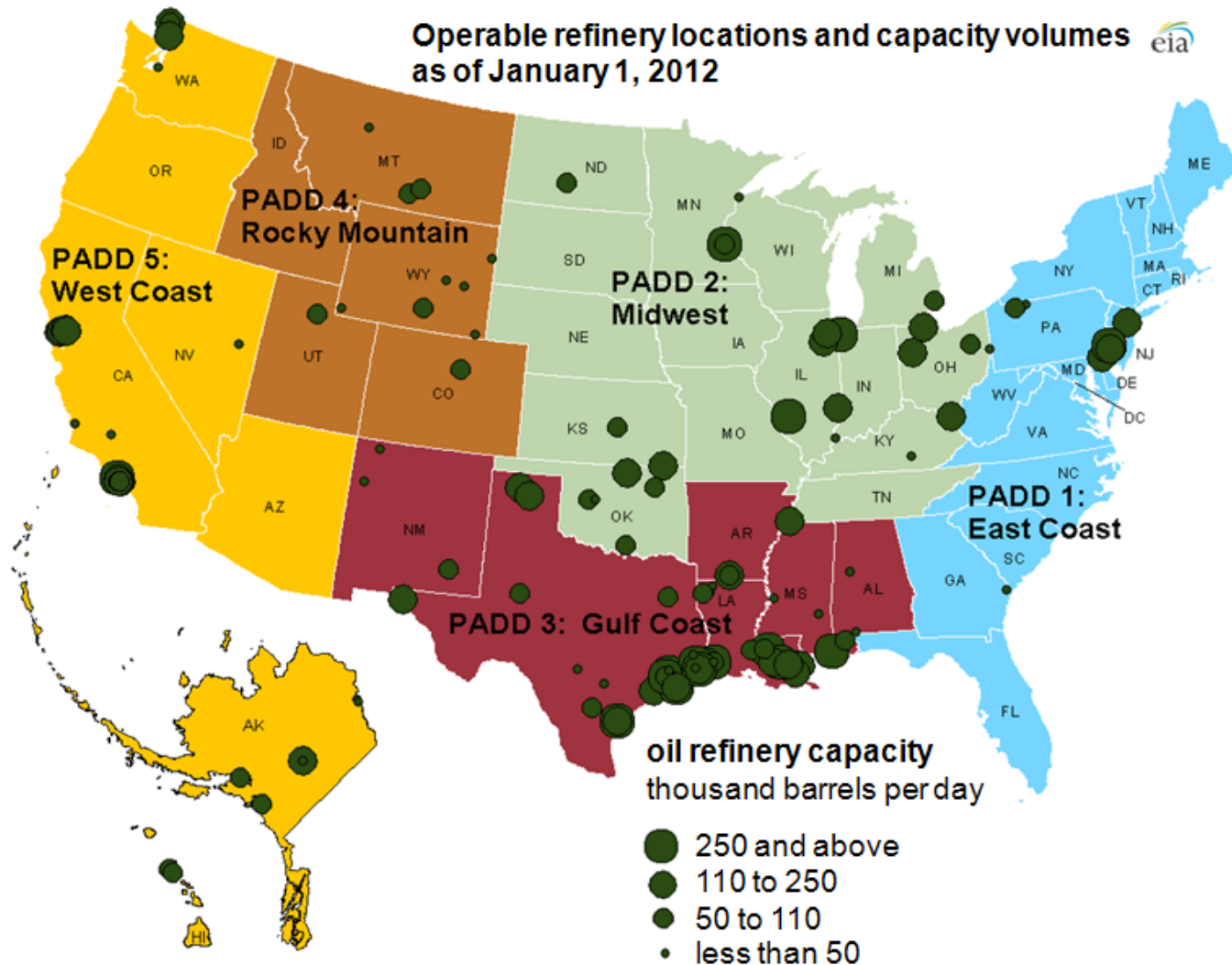
EIA, Jan. 1, 2016 database, published June 2016

http://tonto.eia.doe.gov/dnav/pet/pet_pnp_cap1_dc_u_nus_a.htm

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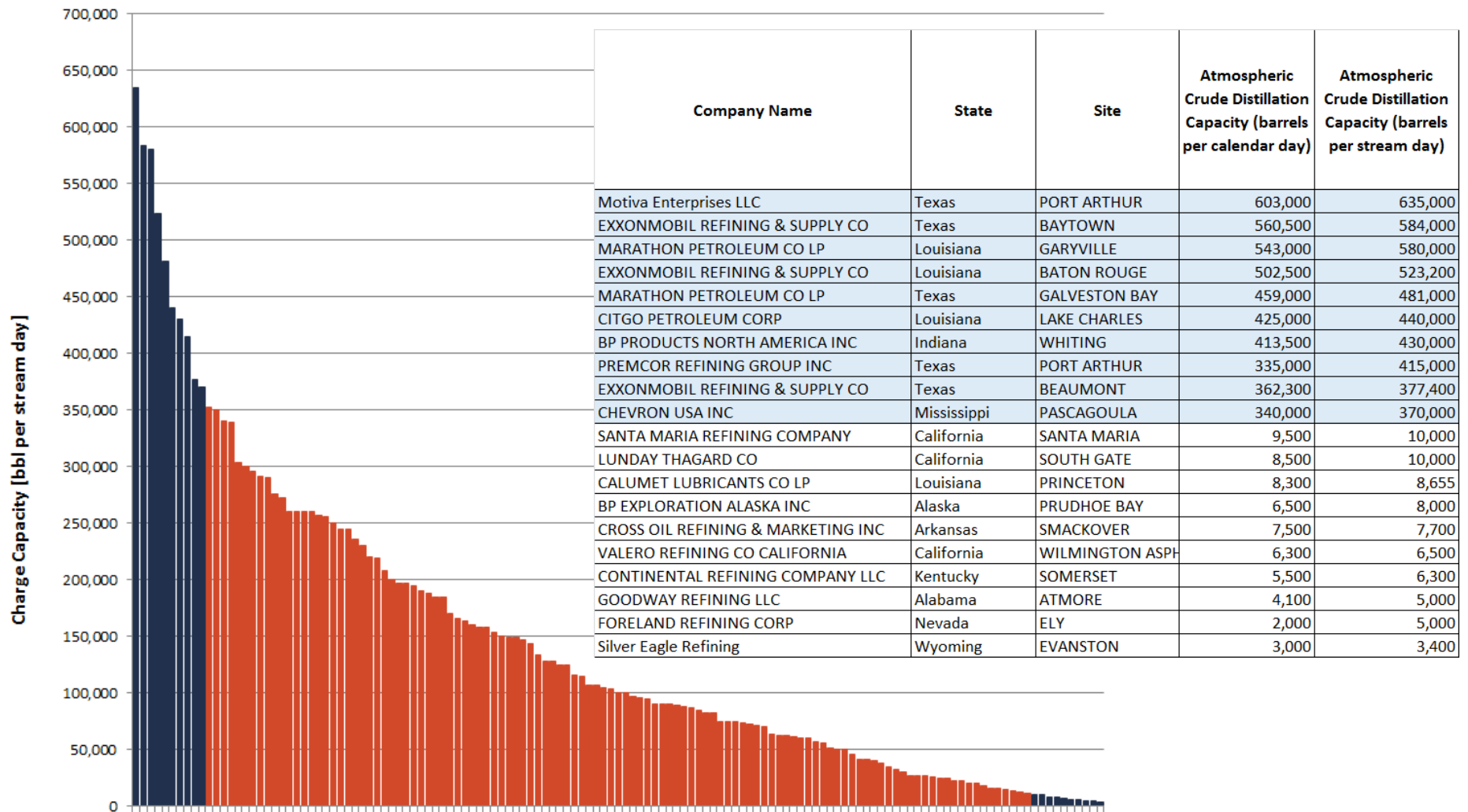
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Locations of U.S. Refineries



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

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



EIA, Jan. 1, 2017 database, published June 2017
<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

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Recent changes to the slate of US refineries

Motiva completed \$10 billion JV expansion in 2013

- Increased to 600,000 bpd capacity, now largest in US
 - Operating problems caused near immediate shut down of new crude distillation train
- Plan to export refined products

Changes in operations

- Tesoro to shut down Carson, CA's FCCU in 2017 & integrate into adjacent Wilmington refinery

Changes in ownership

- PBF Energy purchased two ExxonMobil refineries
 - Chalmette, LA, 189,00 bpd refinery (from ExxonMobil / PdVSA, November 2015)
 - Torrance, CA, 155,00 bpd refinery (June 2016)
- Tesoro buying Dakota Prairie Refining (June 2016)
- Par Pacific Holdings purchased Wyoming Refining Co (July 2016)
- Tesoro bought Western Refining (June 2017) & will be known as Andeavor (August 2017)

New Grass-Roots Refineries in U.S.?

Year Built	First Operated	Location	Original Owner	Original Capacity Bbl/cd	Current Owner	2014 Capacity Bbl/cd	Type
2014	2015	Dickinson, ND	Dakota Prairie	19,000	Dakota Prairie Refining	19,000	Simple
2014	2015	Galena Park, TX	Kinder Morgan	43,000	Kinder Morgan	43,000	Simple
2008	2008	Douglas, WY	Interline Resources	3,000	Antelope Refining	3,800	Simple
1998	1998	Atmore, AL	Goodway	4,100	Goodway	4,100	Simple
1993	1993	Valdez, AK	Petro Star	26,300	Petro Star	55,000	Simple
1991	1992	Ely, NV	Petro Source	7,000	Foreland	2,000	Simple
1986	1987	North Pole, AK	Petro Star	6,700	Petro Star	19,700	Simple
1985	1986	Prudhoe Bay, AK	ARCO	12,000	ConocoPhillips	15,000	Simple
1981	1982	Thomas, OK	OK Refining	10,700	Ventura	12,000	Simple
1979	1980	Wilmington, CA	Huntway	5,400	Valero	6,300	Simple
1978	1979	Vicksburg, MS	Ergon	10,000	Ergon	23,000	Simple
1978	1979	North Slope, AK	ARCO	13,000	BP Exp AK	10,500	Simple
1978	1978	<i>North Pole, AK</i>	<i>Earth Resources</i>	<i>22,600</i>	<i>Flint Hills</i>	<i>126,535</i>	<i>Simple</i>
1977	1978	Lake Charles, LA	Calcasieu	6,500	Calcasieu	78,000	Simple
1976	1977	Garyville, LA	Marathon	200,000	Marathon	522,000	Complex
1976	1977	Krotz Springs, LA	Gold King	5,000	Alon	80,000	Complex
1975	1975	Corpus Christi, TX	Saber	15,000	Valero	200,000	Complex

<http://www.eia.gov/tools/faqs/faq.cfm?id=29&t=6>, updated January 26, 2016

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New Grass-Roots Refineries in U.S.?

Simple refineries near oil production

- Kinder Morgan, Galena Park, TX – 50,000 bpd (condensate splitter)
- Dakota Prairie Refinery – 20,000 bpd Bakken crude topping unit with diesel hydrotreating
- MHA Clean Fuels Refinery, 15,000 bpd refinery on the Fort Berthold Indian Reservation near Makoti, ND
 - Ground broken May 2013. Phase I construction underway as of May 2015.
- Plans near Bakken production
 - Quantum Energy & Native Son Holdings planning 40,000 bpd refinery near Berthold, ND
 - Meridian Energy Group planning 55,000 bpd refinery near Belfield, ND – expected 2018 startup – may operate on midstream tolling concept

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

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 (Mcf/d)	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 Hydrotreating	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

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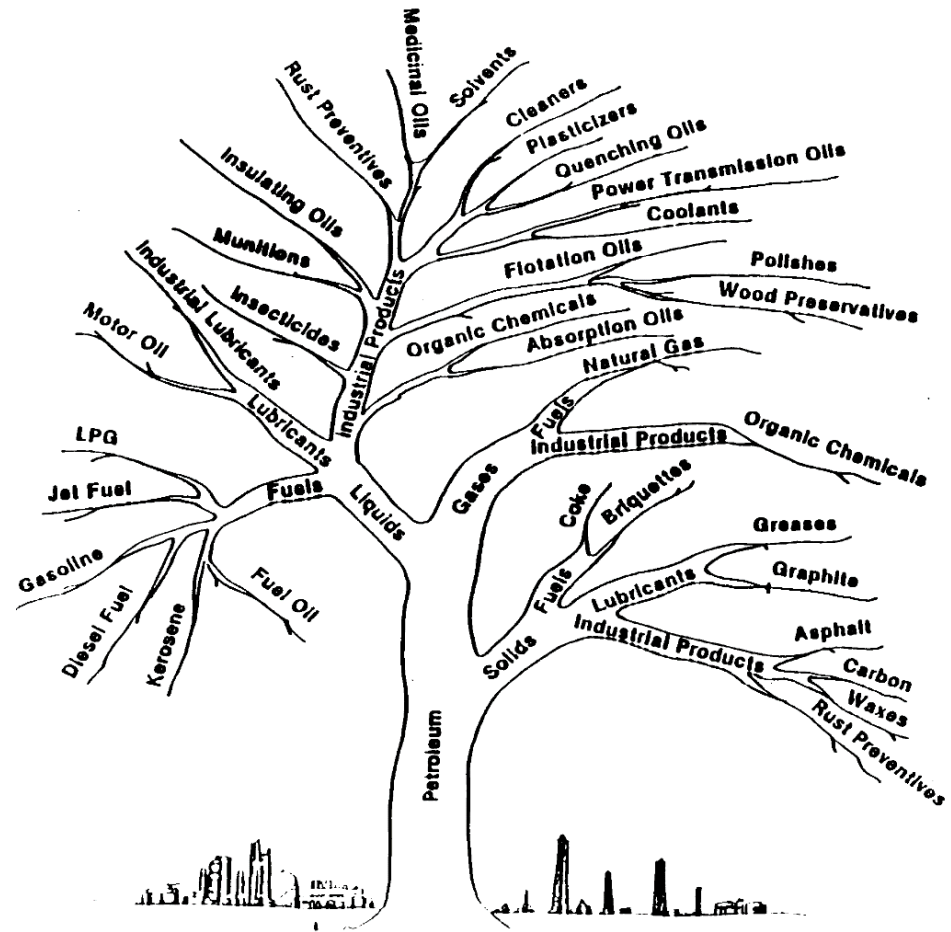
Petroleum products

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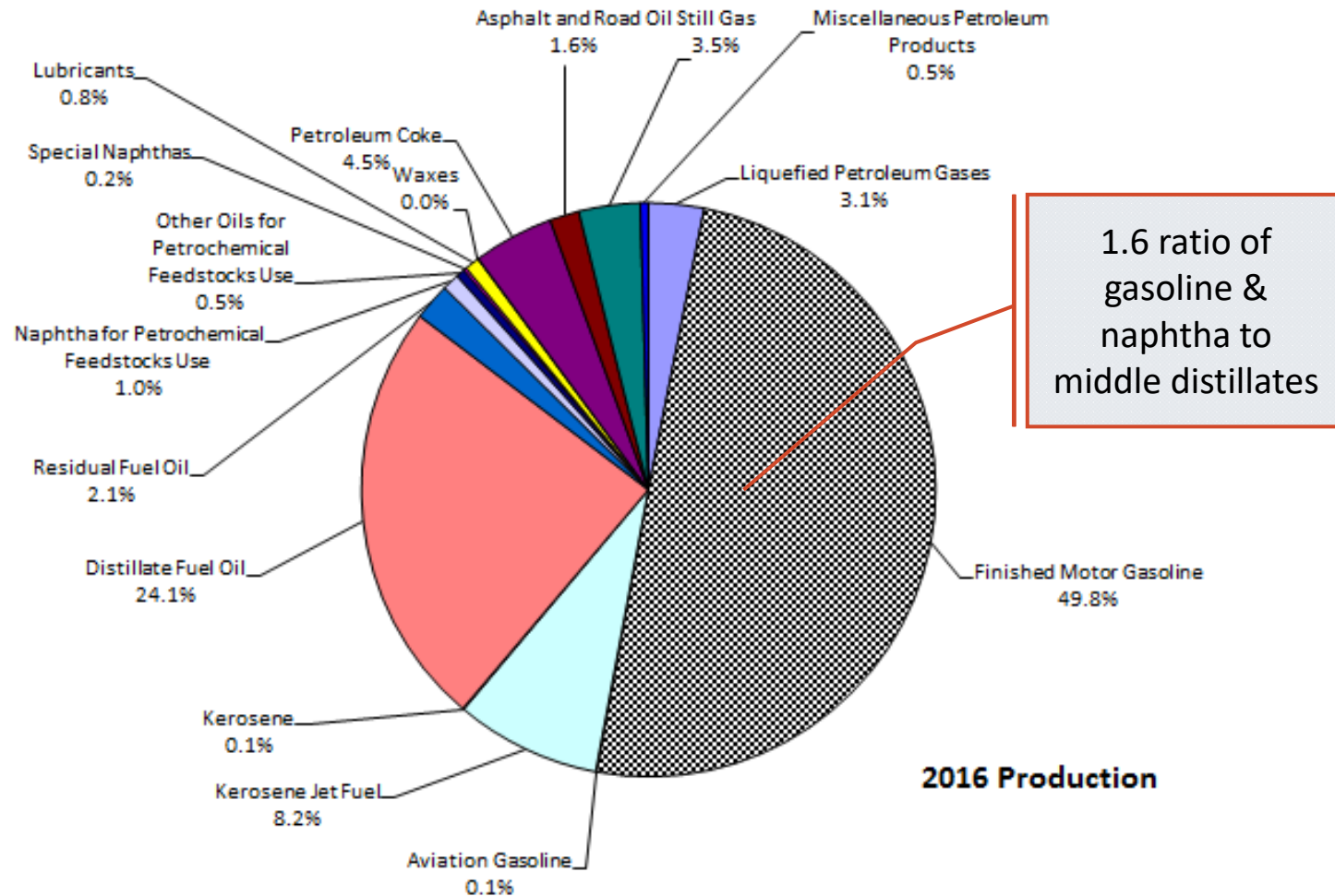
Petroleum Products

- 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)

U.S. Refinery & Blender Net Production



EIA, refinery yield – updated April 7, 2017

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?

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, 7/5/2017

■ Prices

- WTI Cushing Spot \$45.39 per bbl
- Brent \$48.08 per bbl
- RBOB Gasoline \$1.5121 per gal
- Heating Oil \$1.4851 per gal

■ 5-3-2 Spreads

- WTI:

$$\frac{42 \times (3 \times 1.5121 + 2 \times 1.4851)}{5} - 45.39 = \$17.66 \text{ per bbl}$$

- Brent:

$$\frac{42 \times (3 \times 1.5121 + 2 \times 1.4851)}{5} - 48.08 = \$14.97 \text{ per bbl}$$

Crude Oil & Natural Gas

INDEX	UNITS	PRICE
CL1:COM WTI Crude Oil (Nymex)	USD/bbl.	45.39
CO1:COM Brent Crude (ICE)	USD/bbl.	48.08
CP1:COM Crude Oil (Tokyo)	JPY/kl	33,840.00
NG1:COM Natural Gas (Nymex)	USD/MMBtu	2.84

Refined Products

INDEX	UNITS	PRICE
XB1:COM RBOB Gasoline (Nymex)	USd/gal.	151.21
HO1:COM Heating Oil (Nymex)	USd/gal.	148.51
QS1:COM Gasoil (Nymex)	USD/MT	440.75
JX1:COM Kerosene (Tokyo)	JPY/kl	49,060.00

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

Prices Are Crude Specific

US CRUDE PRICES

	3-31-17 \$/bbl*
Alaska-North Slope 27°	46.15
Light Louisiana Sweet	45.97
California-Midway Sunset 13°	44.35
California Buena Vista Hills 26°	52.06
Wyoming Sweet	46.85
East Texas Sweet	44.50
West Texas Sour 34°	42.00
West Texas Intermediate	47.00
Oklahoma Sweet	47.00
Texas Upper Gulf Coast	40.75
Michigan Sour	39.00
Kansas Common	46.00
North Dakota Sweet	39.00

*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.

Ref: Statistics, *Oil & Gas Journal*, April 10, 2017

Updated: July 5, 2017

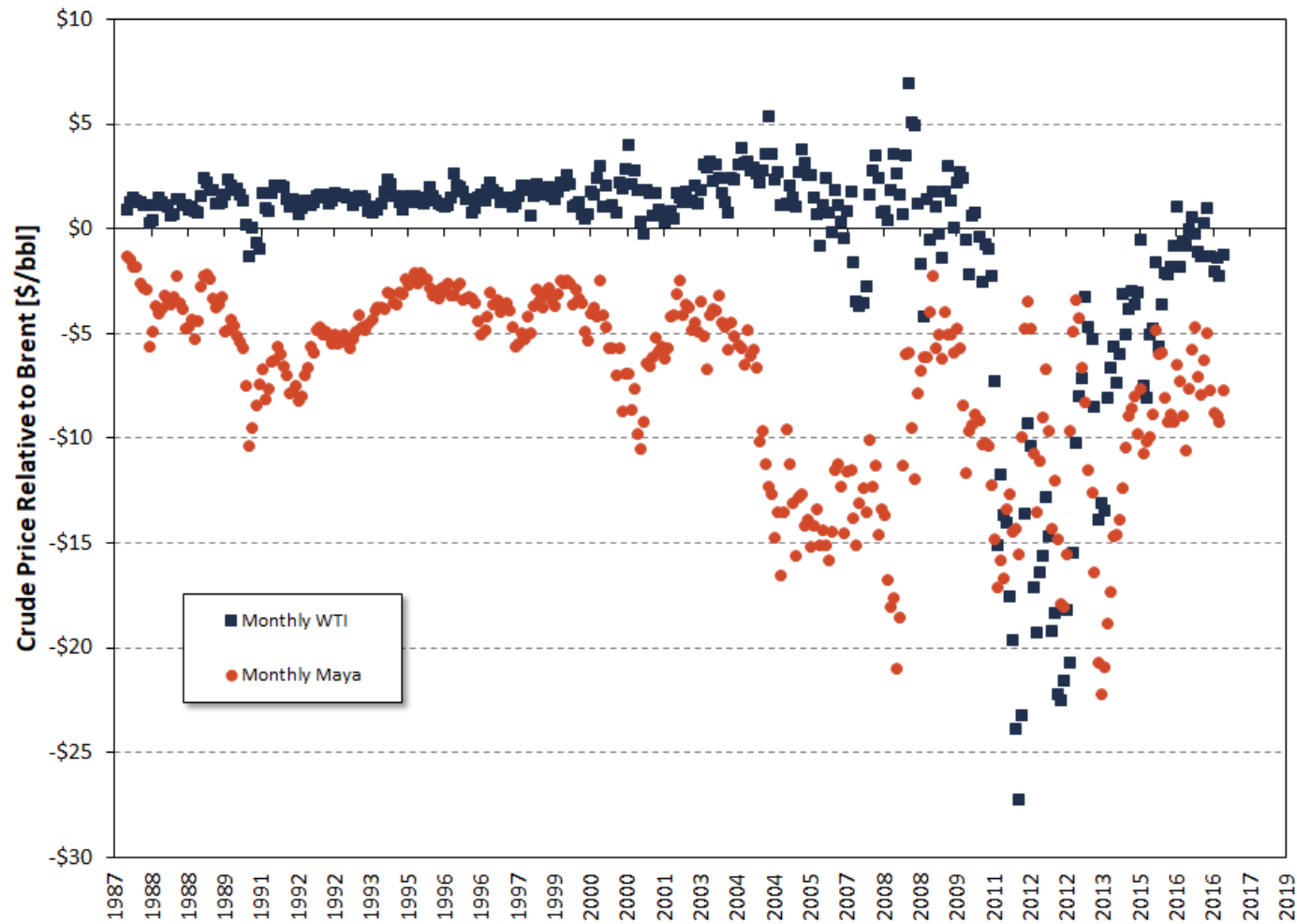
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WORLD CRUDE PRICES

OPEC reference basket	Wkly. avg.	3-31-17 — Mo. avg., \$/bbl — Jan.-17 Feb.-17	\$/bbl 49.45
OPEC reference basket	52.40		53.37
Arab light-Saudi Arabia	52.29		53.63
Basrah light-Iraq	51.66		52.66
Bonny light 37°-Nigeria	54.98		55.24
Es Sider-Libya	53.08		53.46
Girassol-Angola	54.41		55.21
Iran heavy-Iran	51.90		53.16
Kuwait export-Kuwait	51.48		52.85
Marine-Qatar	53.44		54.14
Merey-Venezuela	46.81		47.03
Minas 34°-Indonesia	50.63		51.19
Murban-UAE	55.97		56.31
Oriente-Ecuador	48.64		50.08
Saharan blend 44°-Algeria	54.84		55.06
Other crudes			
Fateh 32°-Dubai	53.71		54.41
Isthmus 33°-Mexico	54.98		56.09
Brent 38°-UK	54.58		55.06
Urals-Russia	53.42		53.67
Differentials			
WTI/Brent	(2.08)		(1.66)
Brent/Dubai	0.87		0.65

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

Prices Are Crude Specific



EIA published monthly production data – updated July 5, 2017

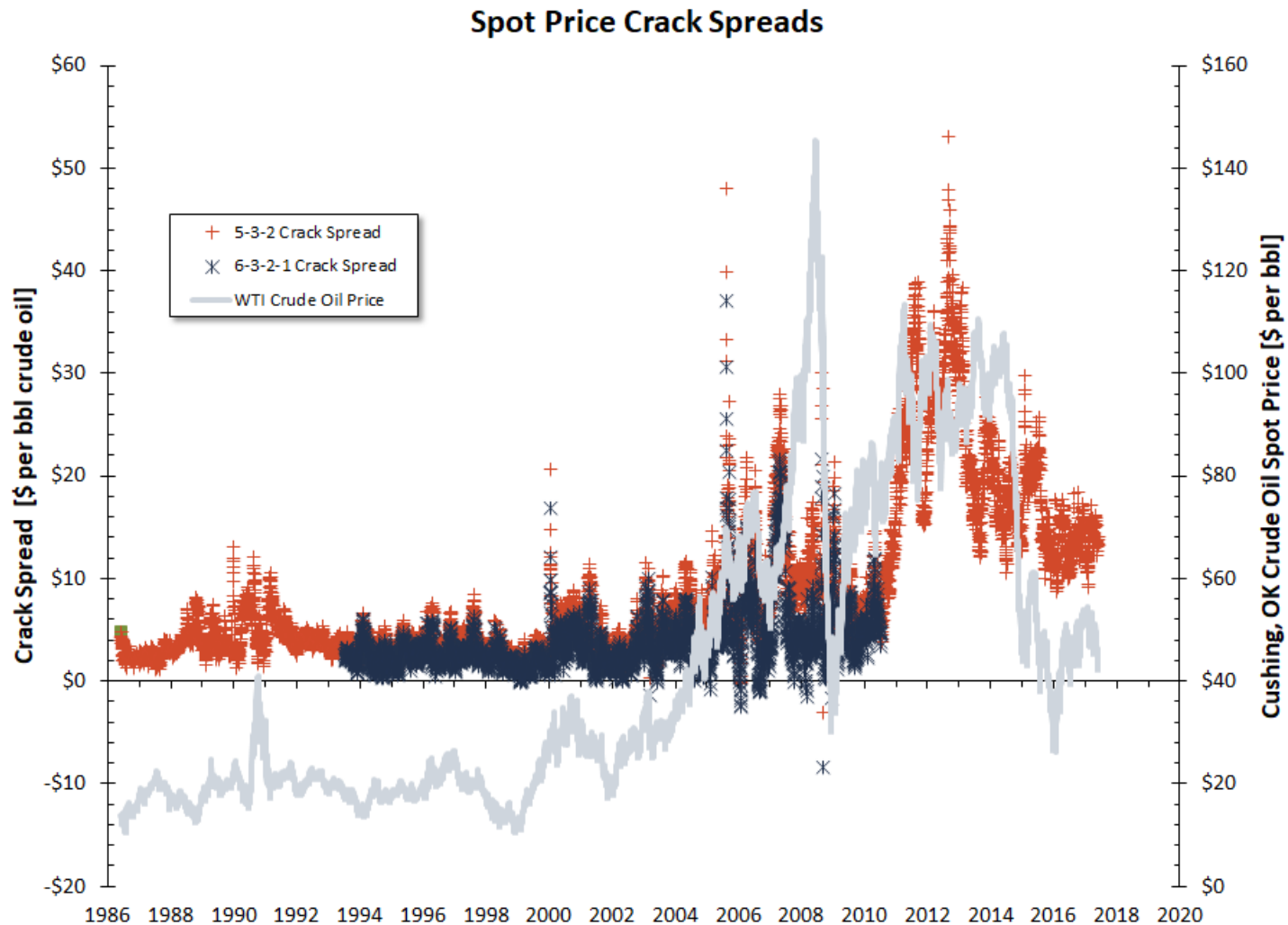
http://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm

<http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=IMX2810004&f=M>

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Historical Crude Prices & Crack Spreads



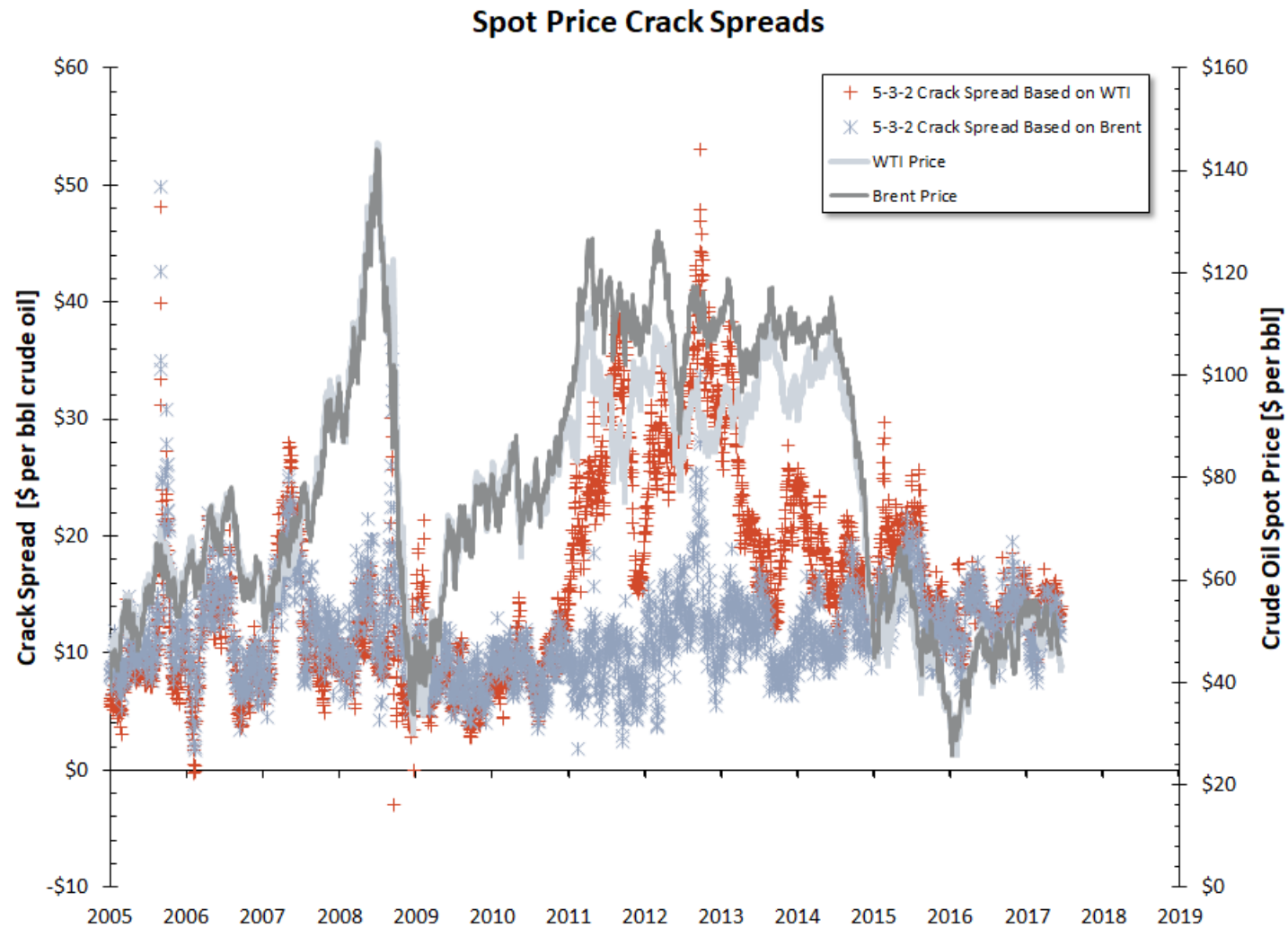
Updated April 7, 2017

Source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm

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Historical Crude Prices & Crack Spreads



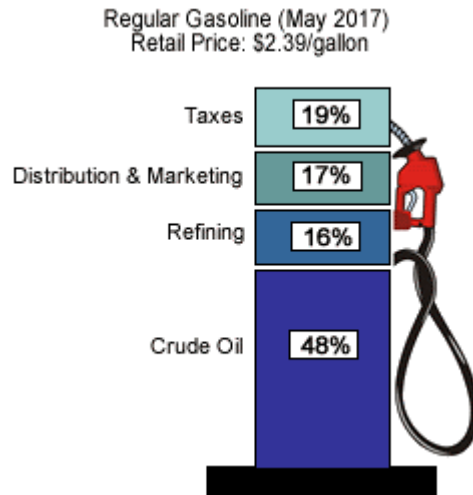
Updated April 7, 2017

Source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm

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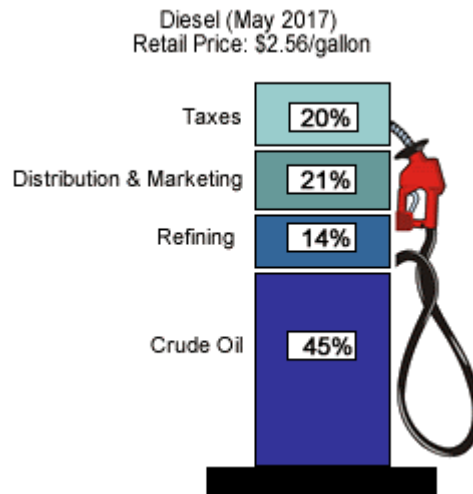
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Gasoline & Diesel Retail vs. Wholesale Prices



Gasoline Retail Cost Contributions

		Per Gallon	Per Barrel
Retail Price		\$2.39	\$100.38
Taxes	19%	\$0.45	\$19.07
Distribution & Marketing	17%	\$0.41	\$17.06
Refining	16%	\$0.38	\$16.06
Crude Oil	48%	\$1.15	\$48.18
Refinery Costs / Wholesale Price		\$1.53	\$64.24



Diesel Retail Cost Contributions

		Per Gallon	Per Barrel
Retail Price		\$2.56	\$107.52
Taxes	20%	\$0.51	\$21.50
Distribution & Marketing	21%	\$0.54	\$22.58
Refining	14%	\$0.36	\$15.05
Crude Oil	45%	\$1.15	\$48.38
Refinery Costs / Wholesale Price		\$1.51	\$63.44

Source: <http://www.eia.gov/petroleum/gasdiesel/>
Updated July 5, 2017

How do energy prices compare?

	Given Price		Heating Value			Price [\$/MWh]	Price [\$/MMBtu]	Relative to Natural Gas
RBOB Gasoline - wholesale	1.7462	\$ per gallon	115,000	Btu/gal	LHV	51.81	15.18	4.7
Heating Oil - wholesale	1.6284	\$ per gallon	130,500	Btu/gal	LHV	42.58	12.48	3.8
WTI Crude Oil	52.24	\$ per bbl	5.8	MMBtu/bbl	HHV	30.73	9.01	2.8
Brent Crude Oil	55.24	\$ per bbl	5.8	MMBtu/bbl	HHV	32.50	9.52	2.9
Ethanol - Chicago	1.594	\$ per gallon	75,700	Btu/gal	LHV	71.85	21.06	6.5
Natural Gas - Henry Hub	3.26	\$ per MMBtu			HHV	11.12	3.26	1.0
Propane - Mt.Belvieu	0.64	\$ per gallon	90,905	Btu/gal	HHV	24.02	7.04	2.2
Powder River Basin Coal (low sulfur)	11.50	\$ per ton	8,800	Btu/lb	HHV	2.23	0.65	0.2
Illinois Basin (high sulfur)	31.65	\$ per ton	11,800	Btu/lb	HHV	4.58	1.34	0.4
Electricity (Residential, winter season)	4.604	¢ per kWh				46.04	13.49	4.1
Electricity (Residential, summer, over 500 kWh)	9.000	¢ per kWh				90.00	26.38	8.1
Electricity (Small Commercial, winter season)	3.920	¢ per kWh				39.20	11.49	3.5
Electricity (Small Commercial, summer season)	6.450	¢ per kWh				64.50	18.90	5.8
Hydrogen dispensed cost	4.03	\$ per kg	324.2	Btu/scf	HHV	102.20	29.95	9.2

References:

Gasoline, Heating Oil, & Crude Oil from Bloomberg (4/9/2017, May delivery)

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

Propane & Ethanol prices from NYMEX (4/9/2017, May delivery)

<http://quotes.ino.com/exchanges/category.html?c=energy>

Coal from US EIA Coal News & Markets (week ending 3/31/17).

http://www.eia.gov/coal/news_markets/

Xcel Energy electric tariff book (as of 8/5/2016)

<http://www.xcelenergy.com/staticfiles/xcel/PDF/Regulatory/CO-Rates-&Regulations-Entire-Electric-Book.pdf>

Hydrogen cost from DOE report, DOE Hydrogen & Fuel Cells Program Record, Sept. 24, 2012

http://www.hydrogen.energy.gov/pdfs/12024_h2_production_cost_natural_gas.pdf

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Generalized Petroleum Refinery

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Early History

Commerical 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.

Standard Oil Trust

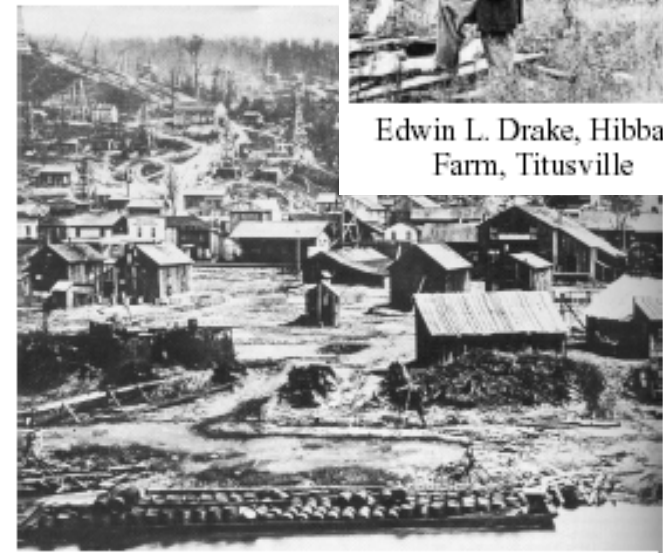
- John D. Rockefeller acquired petroleum interests during the late 1800s. Organized as the Standard Oil Trust in 1882.
- U.S. Supreme Court dissolved in 1911. 34 companies spun off.

Change in product demand

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



Edwin L. Drake, Hibbard Farm, Titusville



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

Implementation of Technologies

<i>Year</i>	<i>Process name</i>	<i>Purpose</i>	<i>By-products, etc.</i>
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	Hydrosulfurization	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

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Description of Petroleum Refinery

Manages hydrocarbon molecules

Organized & coordinated arrangement of manufacturing processes

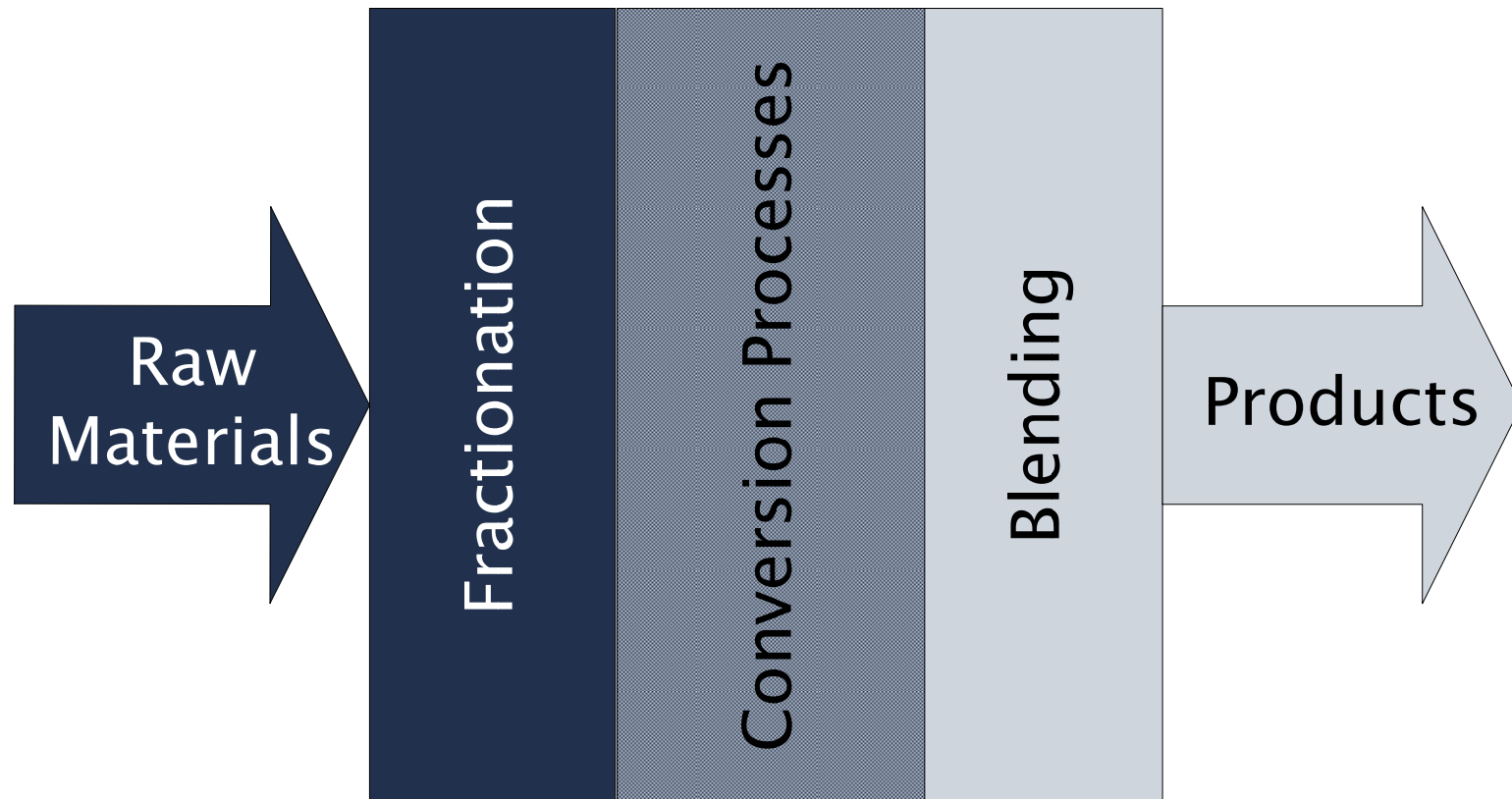
- Provide physical & chemical change of crude oil
- Salable products with specifications & volumes as demanded by the marketplace

Complete refinery will include:

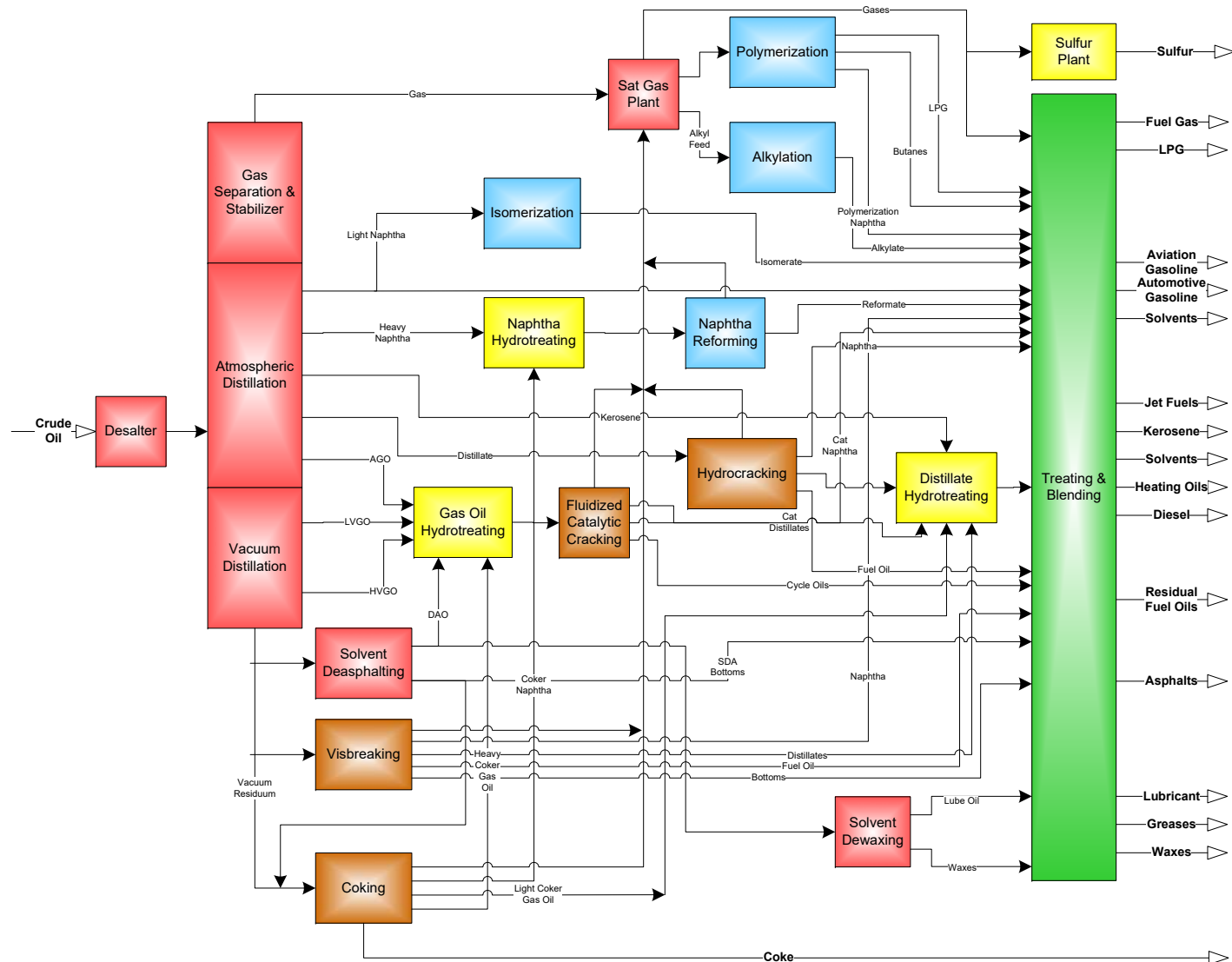
- Conversion units
- Tankage for storage
 - Typically 28 to 32 days of storage
- Dependable source for electric power
- Waste disposal & treatment facilities
- Product blending facilities
- Around the clock operations



Petroleum Refinery Block Flow Diagram



Petroleum Refinery Block Flow Diagram



Summary

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Summary

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

- In the U.S. petroleum accounts for 36% 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

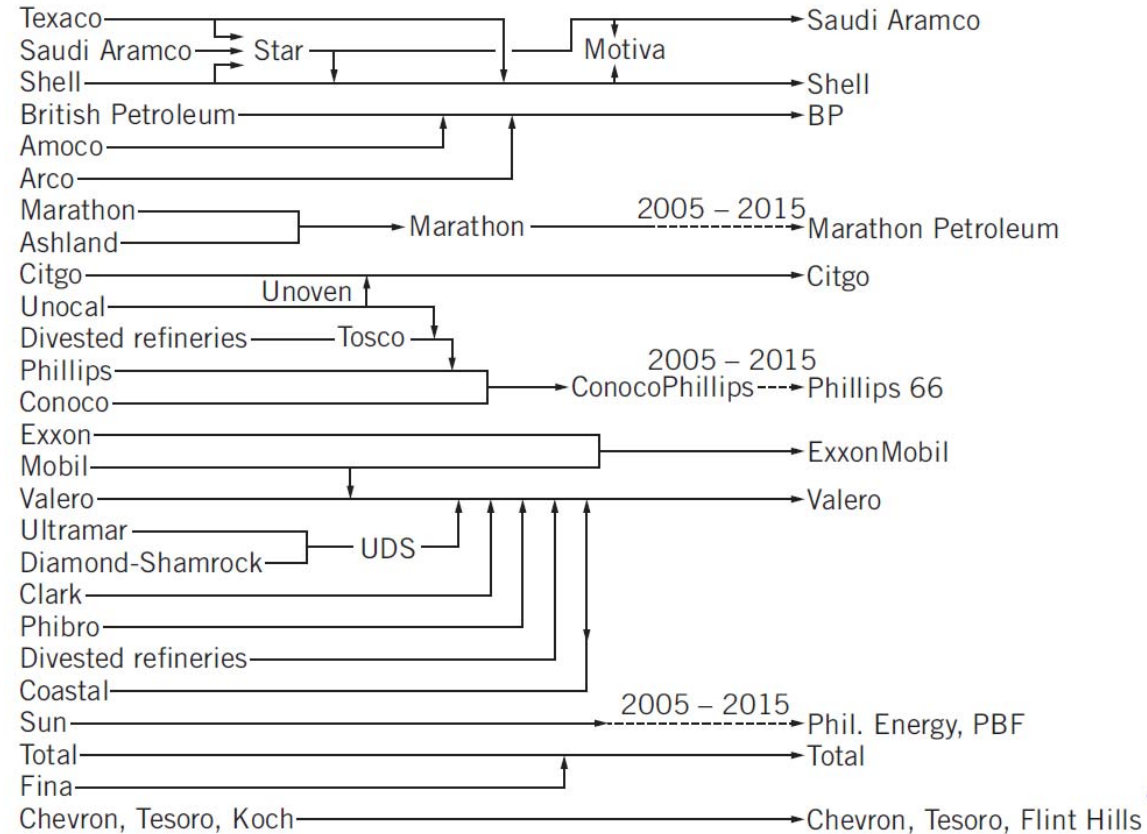
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Refiner's Realignment

REFINERS' REALIGNMENT, 1995 – 2015

FIG. 1



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

Recent Refinery Closures

Location	Owner	CDU Capacity Closed (MBPD)	Year Closed	Location	Owner	CDU Capacity Closed (MBPD)	Year Closed
Perth Amboy, NJ	Chevron	80	2008	Keihin Ohgimachi, Japan	Showa Shell	120	2011
Bakersfield, CA	Big West	65	2008	Clyde, Australia	Shell	75	2011
Westville, NJ	Sunoco	145	2009	Porto Marghera, Italy	ENI	70	2011
Bloomfield, NM	Western	17	2009	Marcus Hook, PA	Sunoco	175	2011
Teesside, UK	Petroplus	117	2009	Harburg, Germany	Shell	107	2012
Gonfreville, France*	Total	100	2009	Berre, France	LyondellBassel	105	2012
Dunkirk, France	Total	140	2009	Coryton, U.K.	Petroplus	220	2012
Japan*	Nippon Oil	205	2009	Petit Couronne, France ¹	Petroplus	160	2012
Toyama, Japan	Nihonkai Oil	57	2009	St. Croix, U.S.V.I	Hovensa	350	2012
Arpechim, Romania *	Petrom	70	2009	Aruba	Valero	235	2012
Cartagena*	REPSOL	100	2009	Rome, Italy	TotalErg	82	2012
Bilboa*	REPSOL	100	2009	Fawley, U.K.*	ExxonMobil	80	2012
Arpechim, Romania	OMV	70	2010	Trecate, Italy*	ExxonMobil	70	2012
Japan*	Cosmo	94	2010	Paramo, Czech Republic	Unipetrol	20	2012
Nadvornaja, Ukraine	Privat Group	50	2010	Lisichansk, Ukraine	TNK-BP	175	2012
Montreal, Canada ¹	Shell	130	2010	Bakersfield/Paramount, CA	Alon	90	2012
Yorktown, Virginia	Western	65	2010	Ewa Beach, Hawaii	Tesoro	94	2013
Reichstett, France	Petroplus	85	2010	Port Reading, NJ	Hess	N/A	2013
Wilhelmshaven, Germany	Phillips 66	260	2010	Venice, Italy	ENI	80	2013
Ingolstadt, Germany	Bayernoil	90	2010	Sakaide, Japan	Cosmo Oil	140	2013
Cremona, Italy	Tamoil	94	2011	Japan	Indemitsu Kosan	100	2014
St. Croix, U.S.V.I.*	Hovensa	150	2011	Japan	Nippon	200	2014
Funshun, China	PetroChina	70	2011	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

¹The Petit Couronne refinery has shut completely when processing deal with Shell ended in December 2012

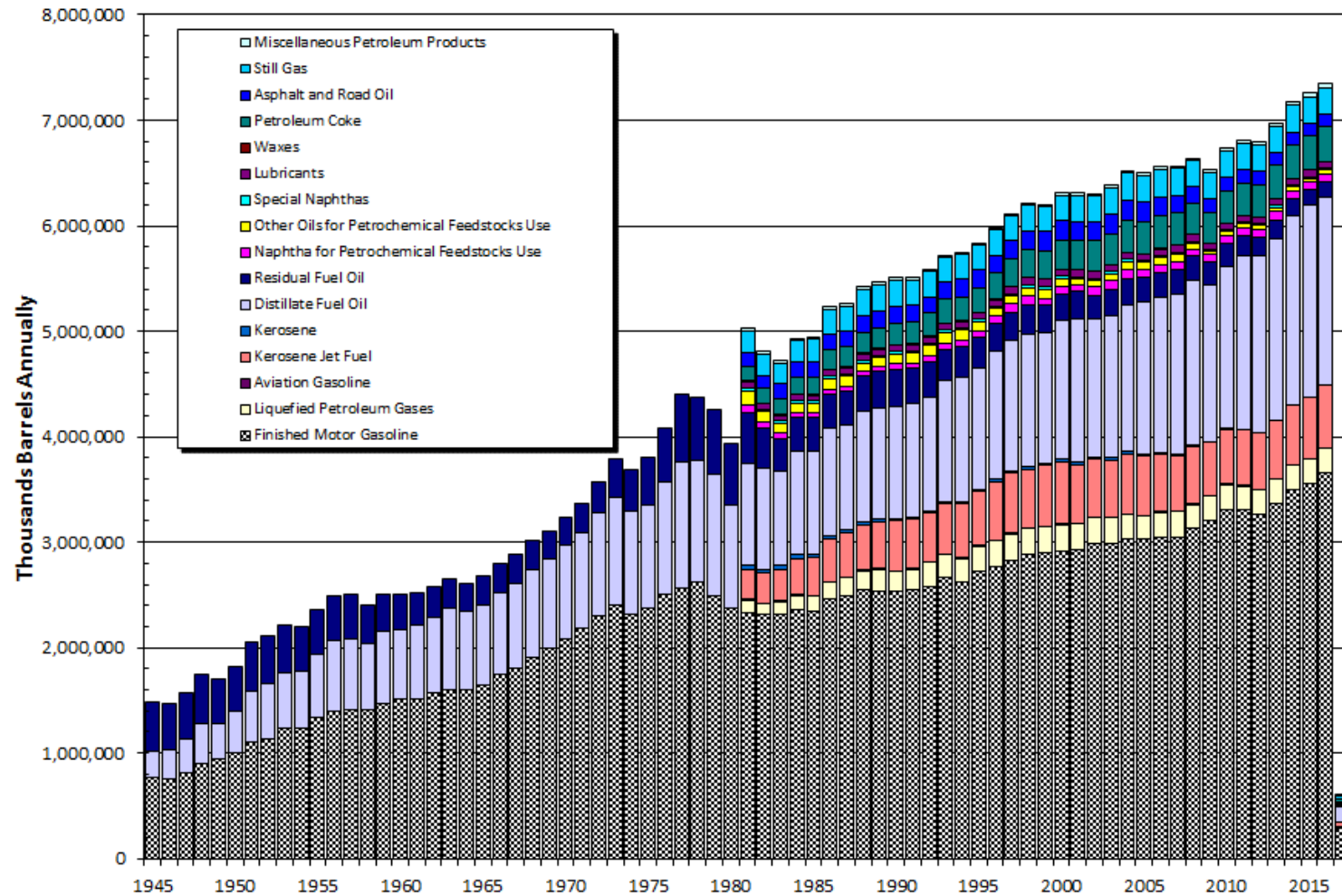
²Alon announced the closure of these refineries for economic reasons, may restart

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

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U.S. Refinery & Blender Net Production



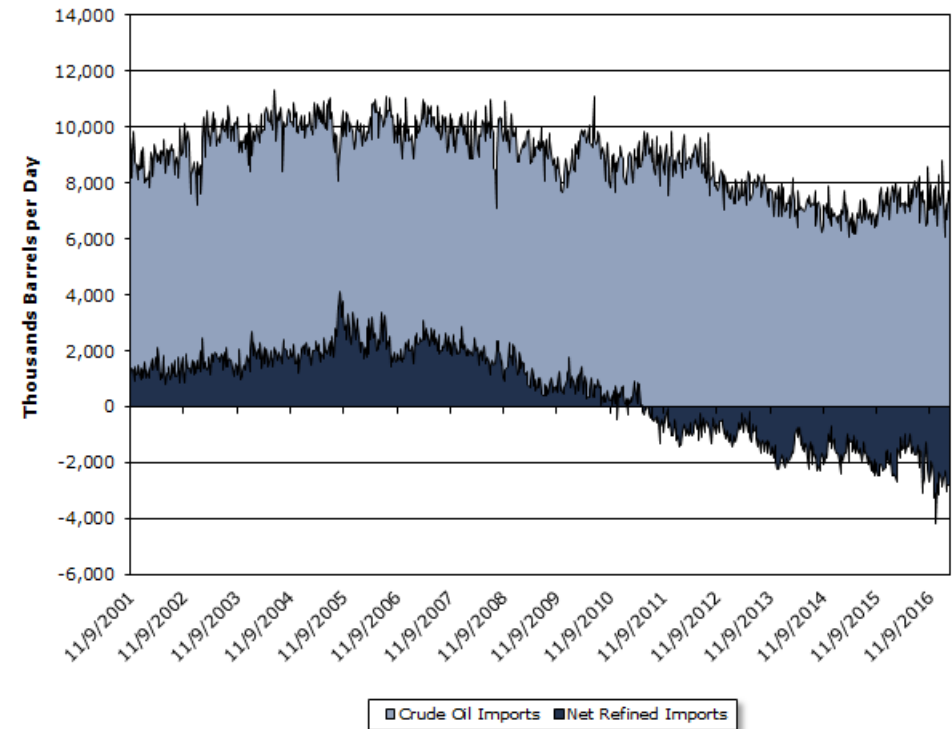
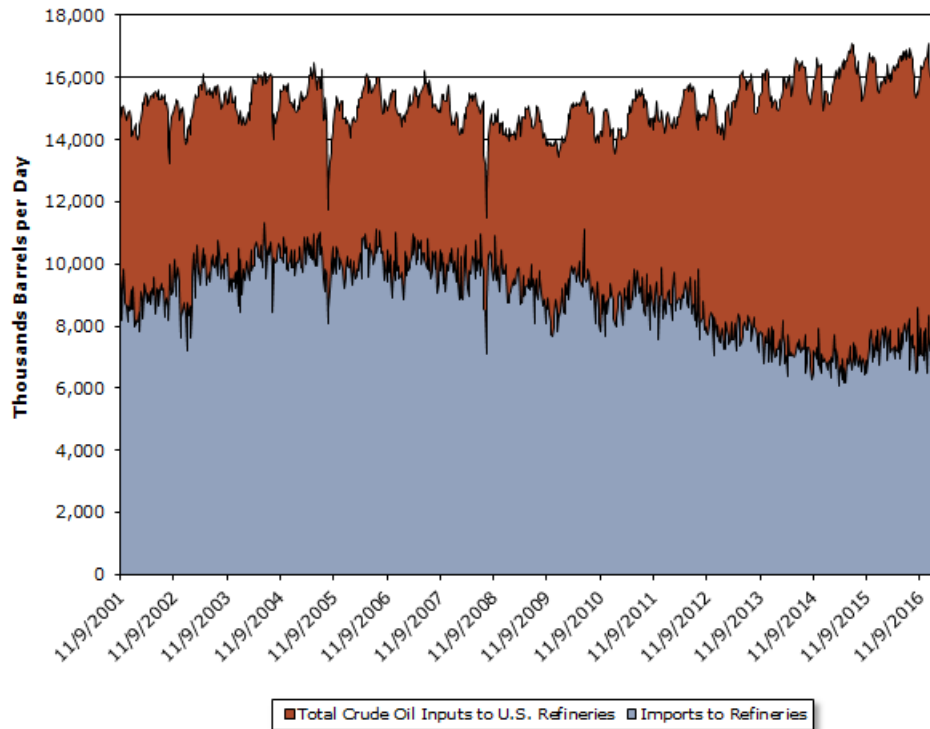
Includes production to January 2017 – updated April 7, 2017

Source: http://tonto.eia.doe.gov/dnav/pet/pet_pnp_refp_dc_nus_mbbi_m.htm

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U.S. Oil from Imports



EIA published data used for charts – updated April 7, 2017

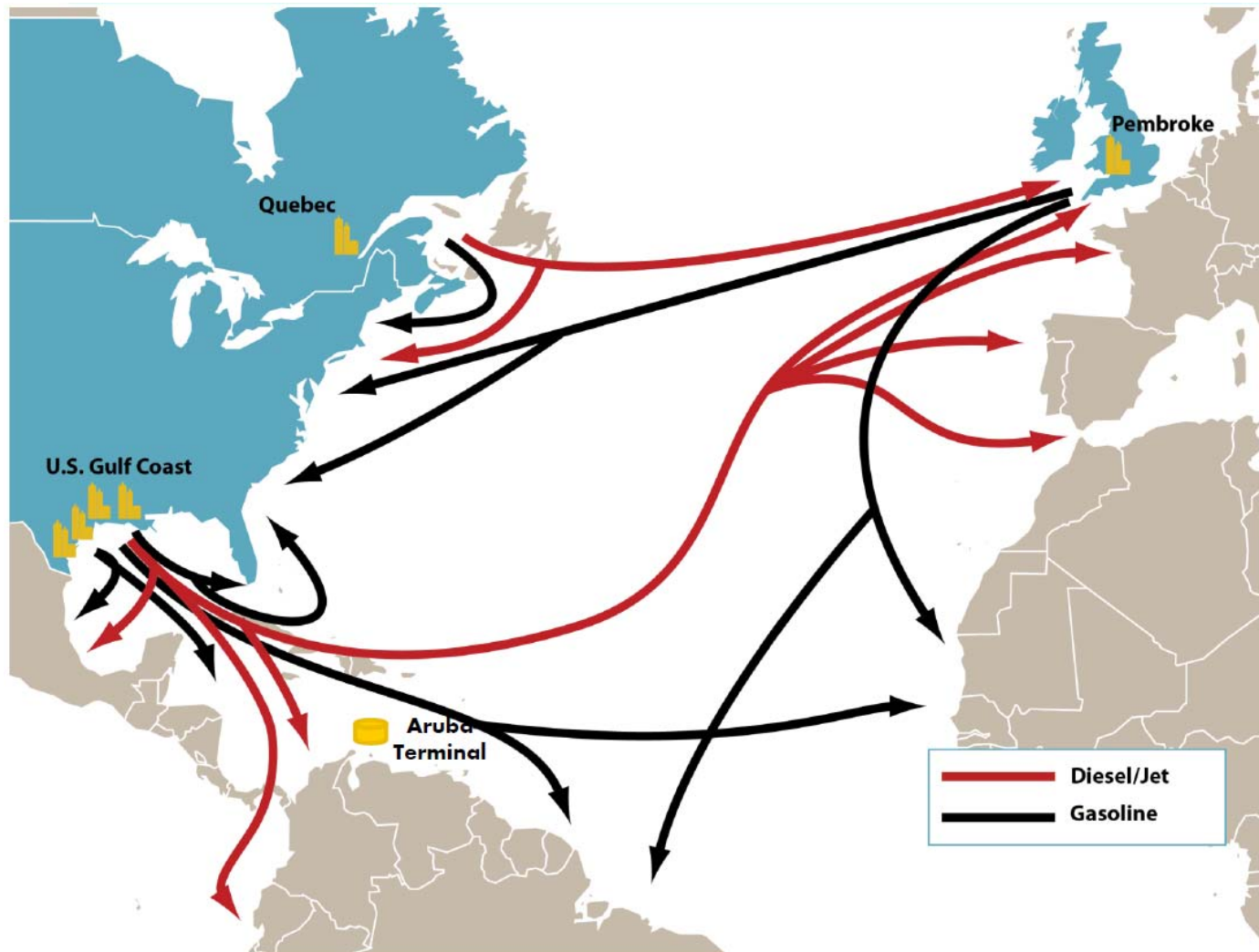
http://www.eia.gov/dnav/pet/pet_move_wkly_dc_nus-z00_mbbldp_w.htm

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

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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.

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

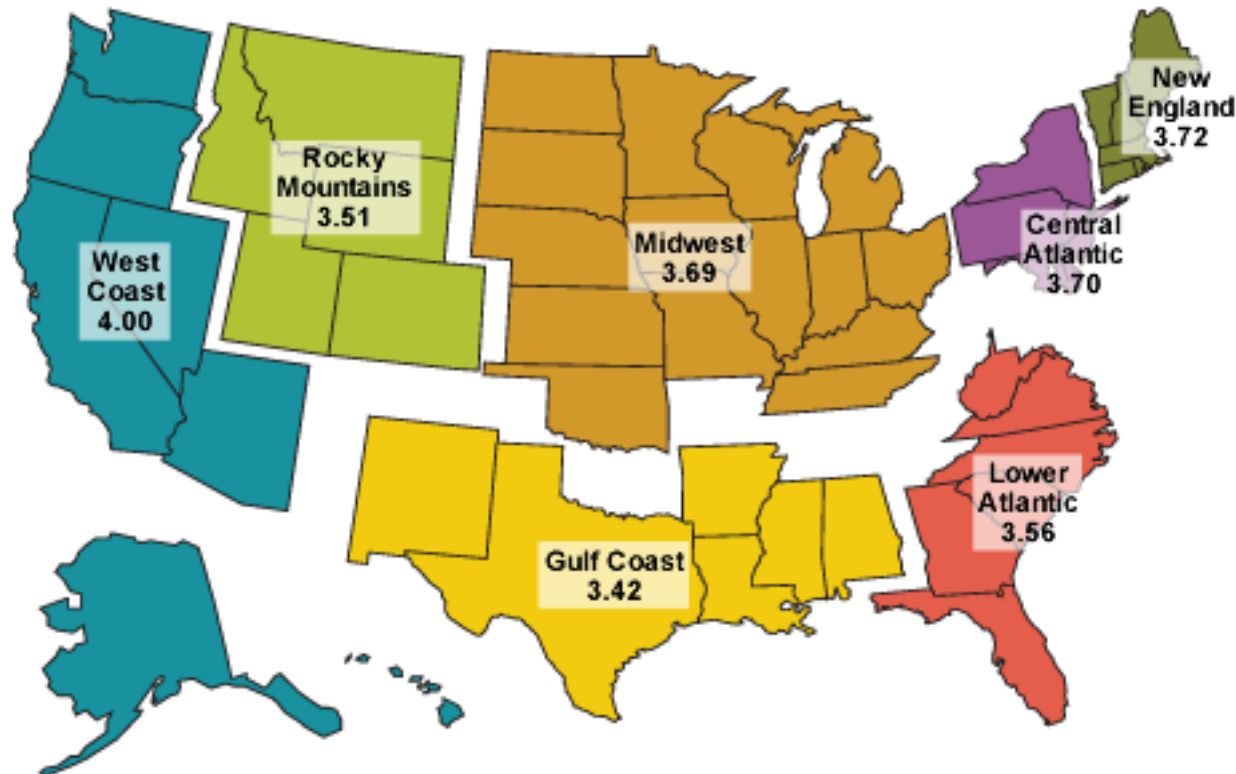
WORLD CRUDE PRICES

OPEC reference basket	Wkly. avg.	1-17-14 — Mo. avg., Oct.-13	\$/bbl 104.17 \$ /bbl — Nov.-13
OPEC reference basket	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.

Pump prices are not the same across U.S.

Regular grade gasoline prices at retail outlets by region
for June 9, 2014 (dollars per gallon, including taxes)

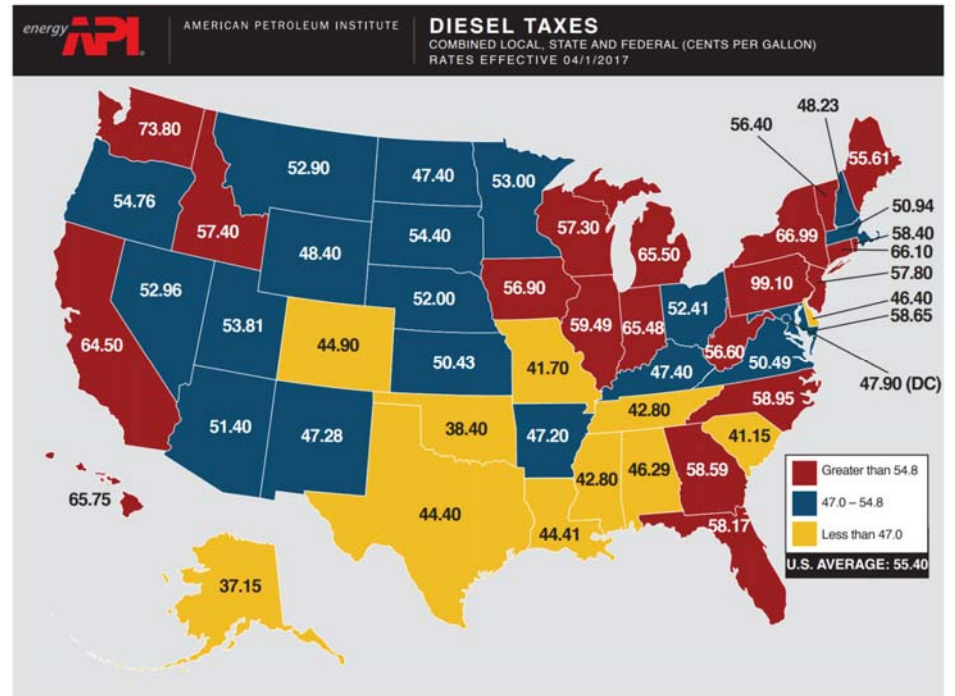
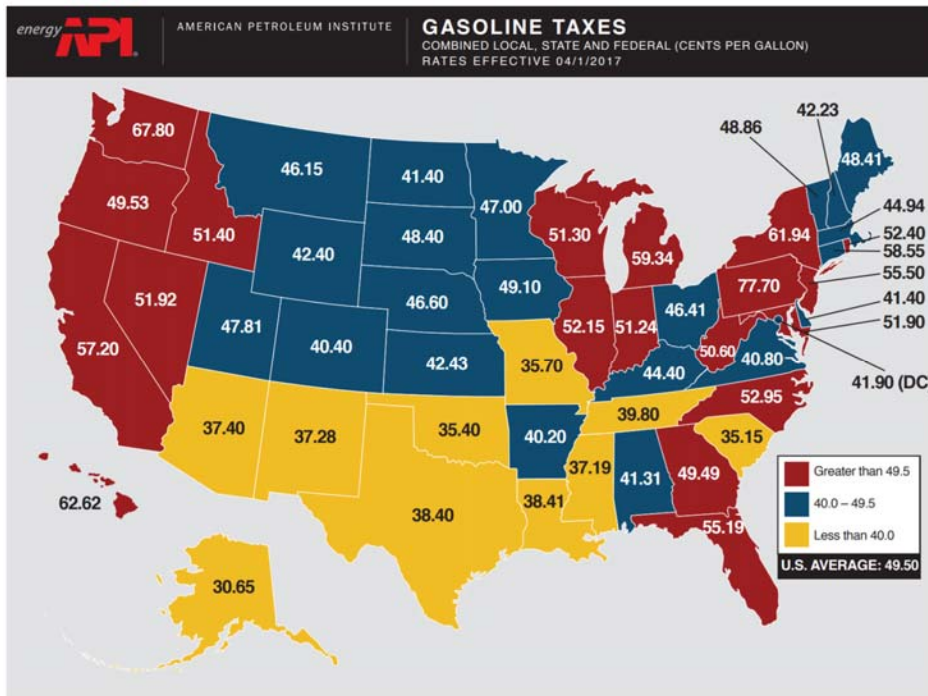


Source: U.S. Energy Information Administration, EIA-878, Motor Gasoline Price Survey.

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

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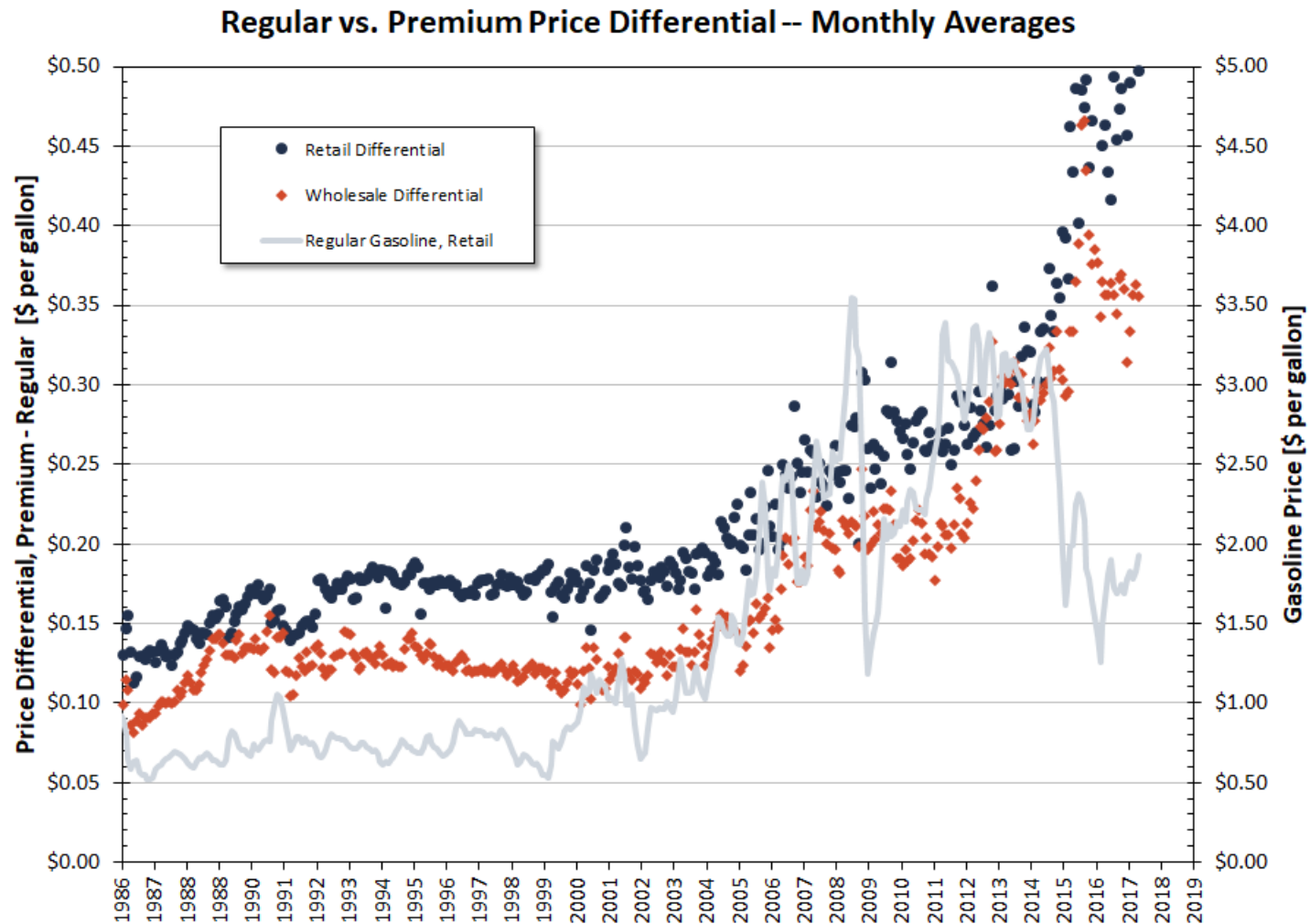
Gasoline & Diesel Taxes not the same across U.S.



Source: <http://www.api.org/oil-and-natural-gas-overview/industry-economics/fuel-taxes>
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Differential Between Regular & Premium Gasolines



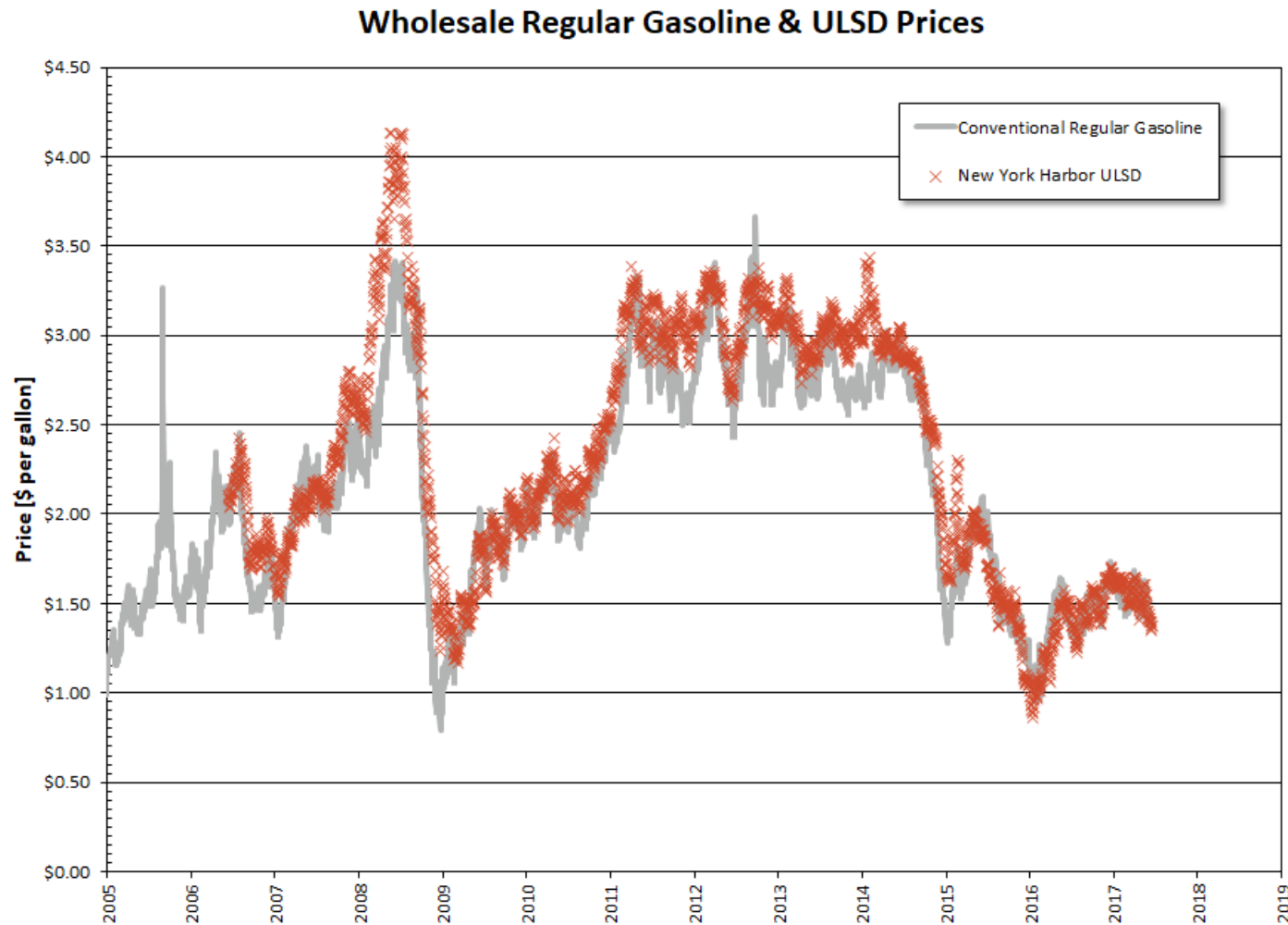
Updated Jul 5, 2017

Source: http://www.eia.gov/dnav/pet/pet_pri_refmg_dcu_nus_m.htm

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Comparison Wholesale Regular Gasoline & ULSD



Updated August 4, 2016

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 $\pm 25\%$

Not included:

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

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

Updated: July 5, 2017

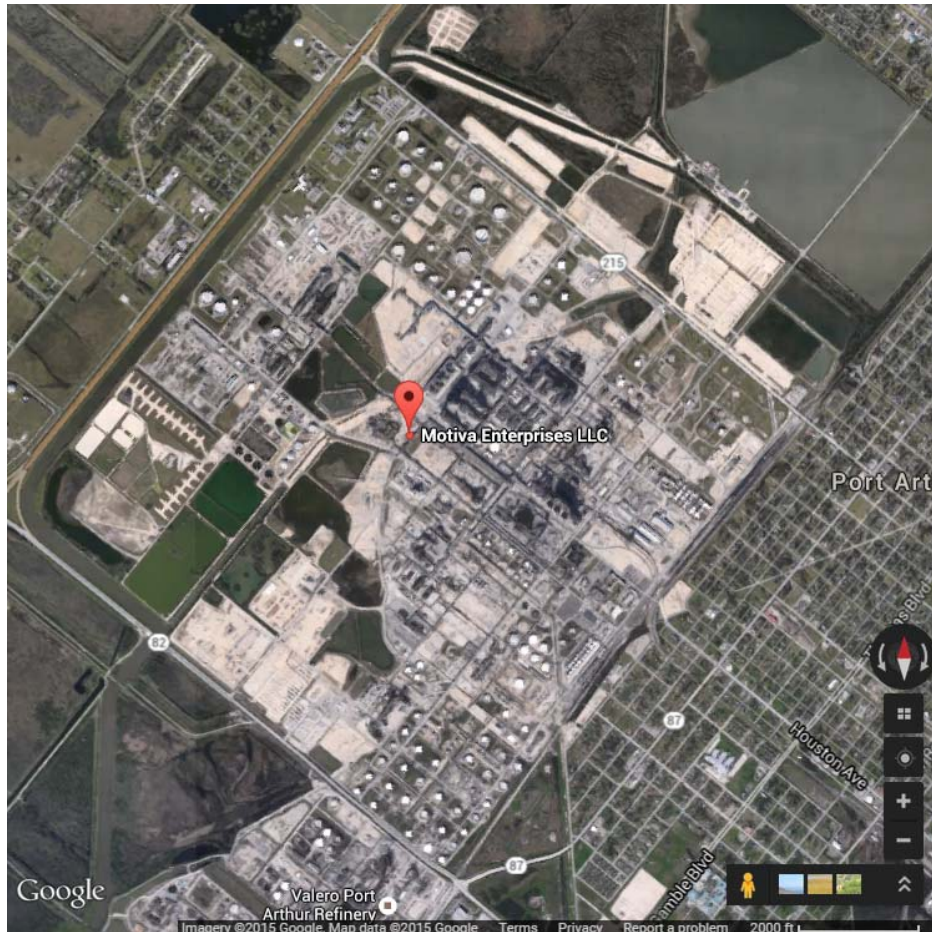
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Table 8

PROCESS COST FUNCTIONS			
Process Unit	Cost, \$ million = $\alpha \cdot \text{capacity}^\beta$		Units of Capacity
	α	β	
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 Year Basis
Delayed Coking curves modified to match Gary, et. al., textbook

Satellite View of Selected U.S. Refineries

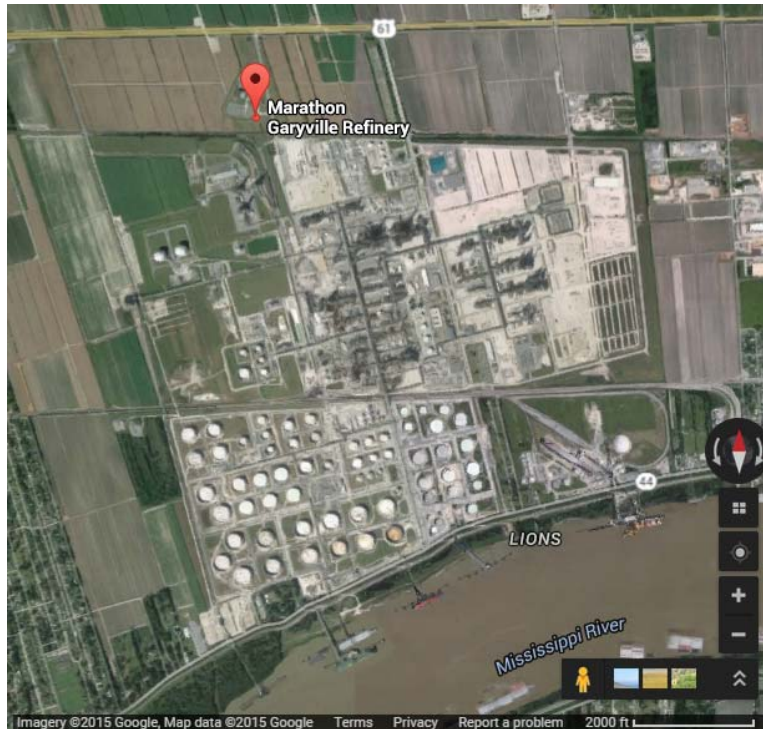


Motiva Enterprises LLC, Port Arthur, TX
603,000 bbl per calendar day

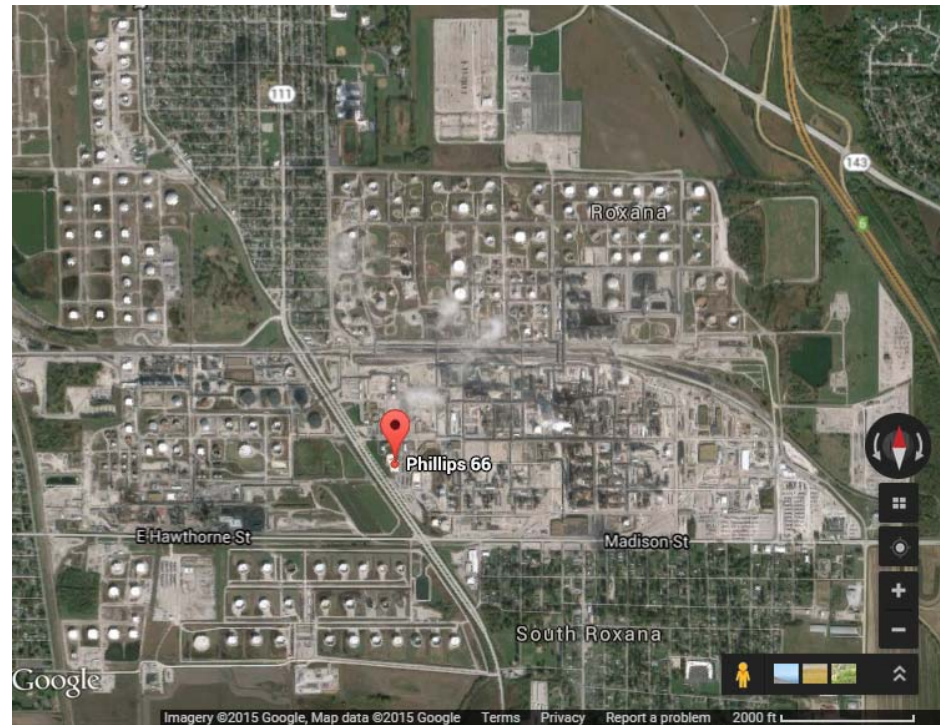


Dakota Prairie Refinery, Dickinson, ND
19,000 bbl per calendar day

Satellite View of Selected U.S. Refineries

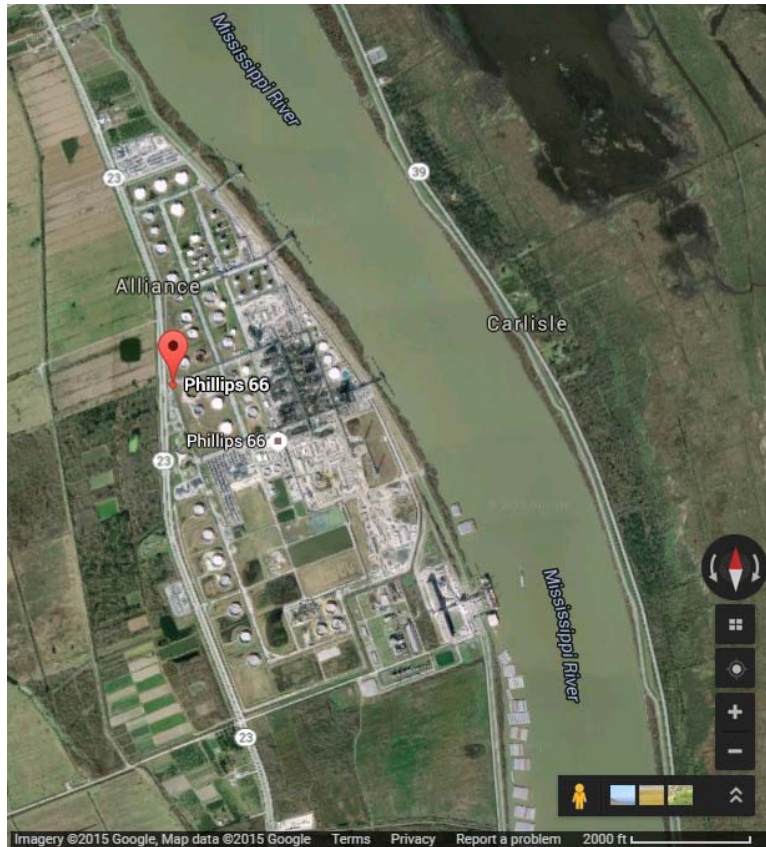


Marathon Garyville Refinery, Garyville, LA
451,000 bbl per calendar day



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

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