

Petroleum Refining Future?



COLORADO SCHOOL OF MINES

Topics

Fossil Fuels or Electricity?

- Petroleum's place in energy production & consumption

Gasoline or Diesel? Residual Fuel Oils (Marine Fuel)?

- Shift of gasoline to diesel
- New international specifications on residual fuels

Oil: Light Sweet or Heavy Sour?

- Impact of changing supply

Role of Biofuels in the U.S.?

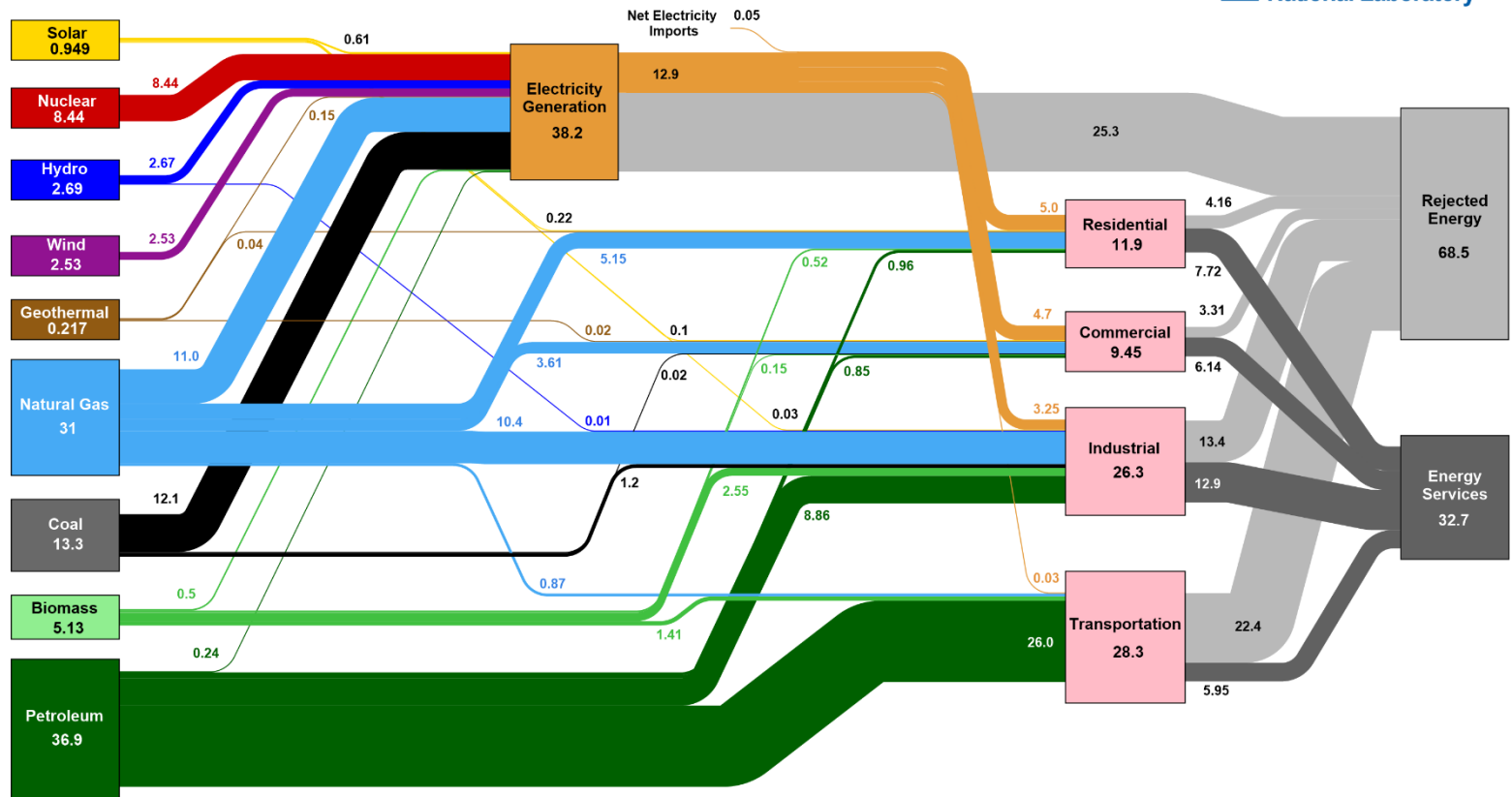
- Clean Air Act & Amendments
- American Energy Independence & Security Act 2007
 - Renewable Fuel Standards – 1st generation & advanced biofuels

Fossil Fuels or Electricity?



Energy Markets Are Interconnected

Estimated U.S. Energy Consumption in 2018: 101.2 Quads



Source: LLNL March, 2019. Data is based on 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 BTO-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>

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/xcel/PDF/Regulatory/CO-Rates-&-Regulations-Entire-Electric-Book.pdf>

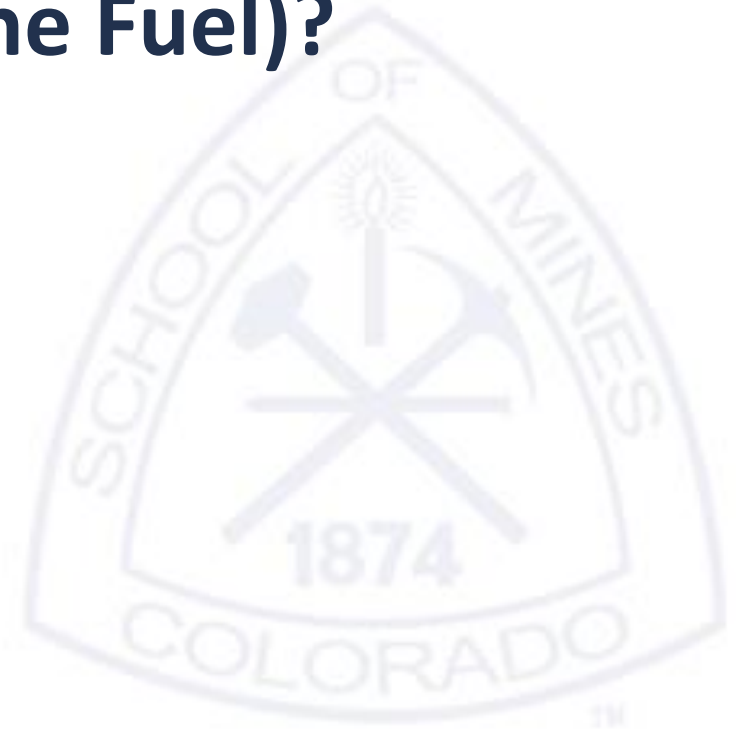
Ave. hydrogen cost, CA, from "Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California," Dec. 2015 (page 7)

<http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf>

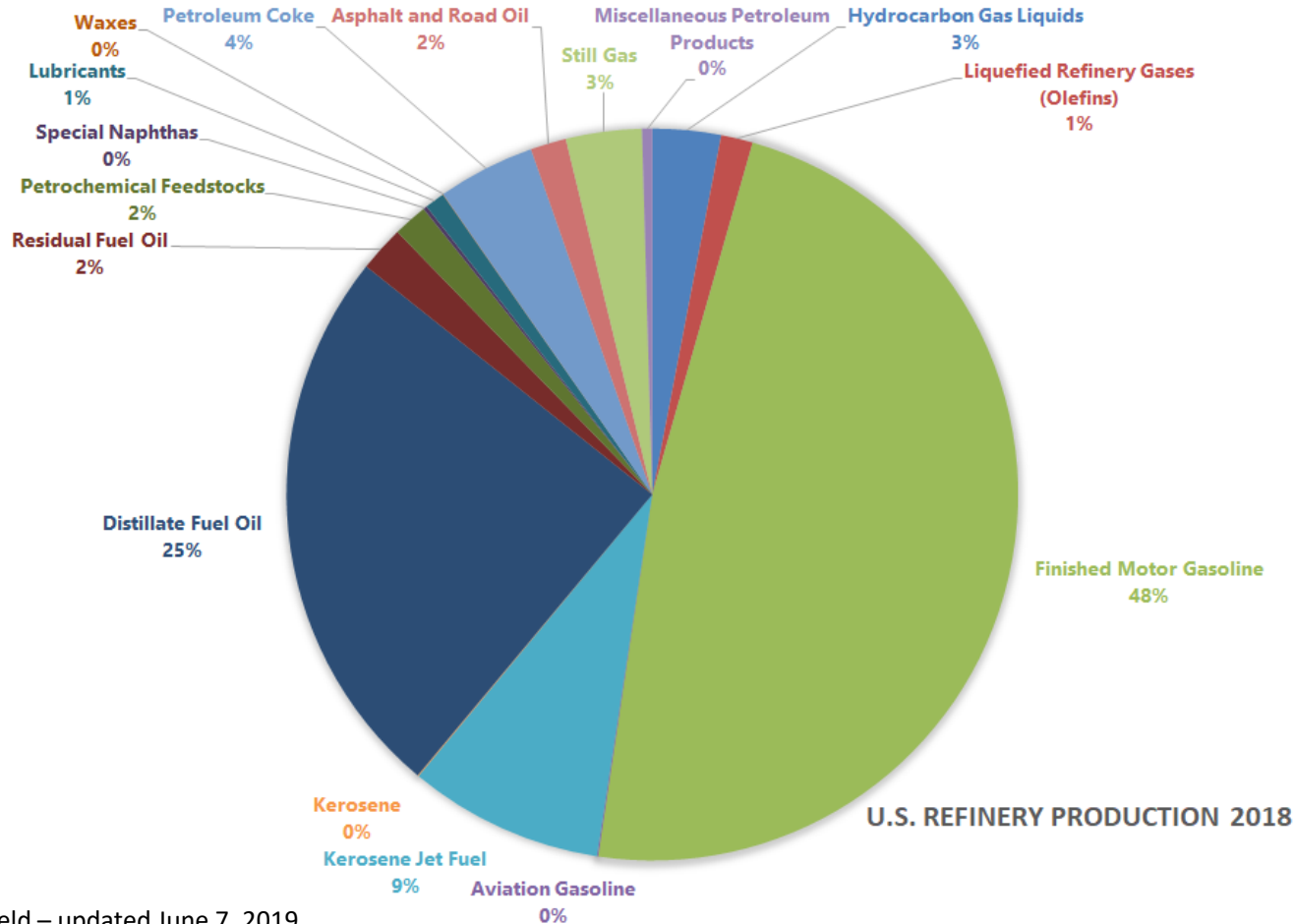
Updated: August 5, 2019

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Gasoline or Diesel? Residual Fuel Oils (Marine Fuel)?

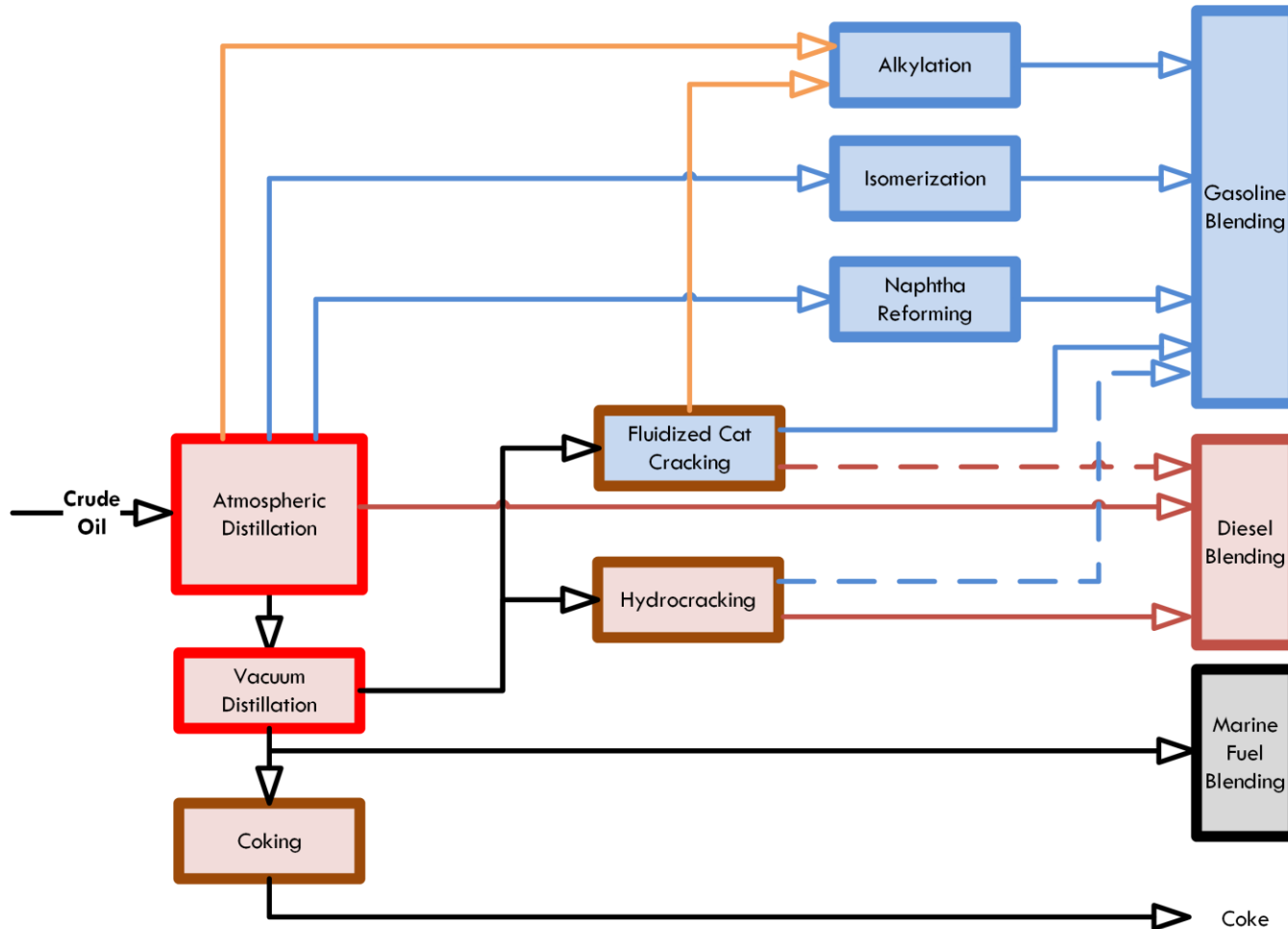


U.S. Refinery & Blender Net Production



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

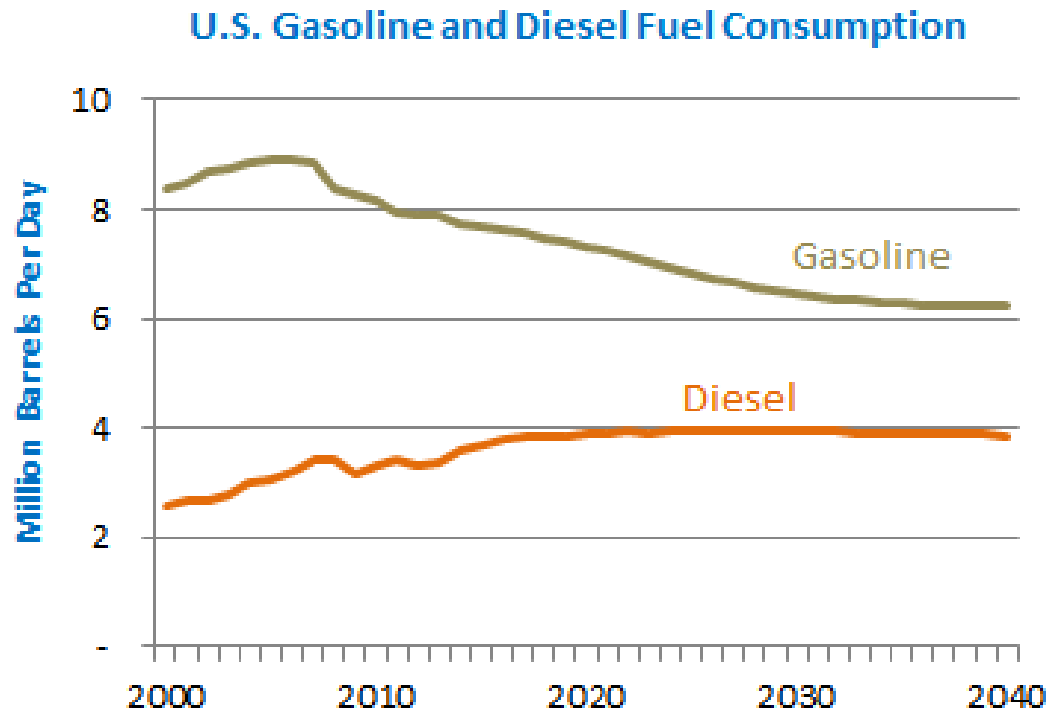
Simplified Refinery BFD



Gasoline/Diesel Demand Trends

Since 2007 U.S. oil refining focus has been to maximize distillate production at the expense of gasoline production

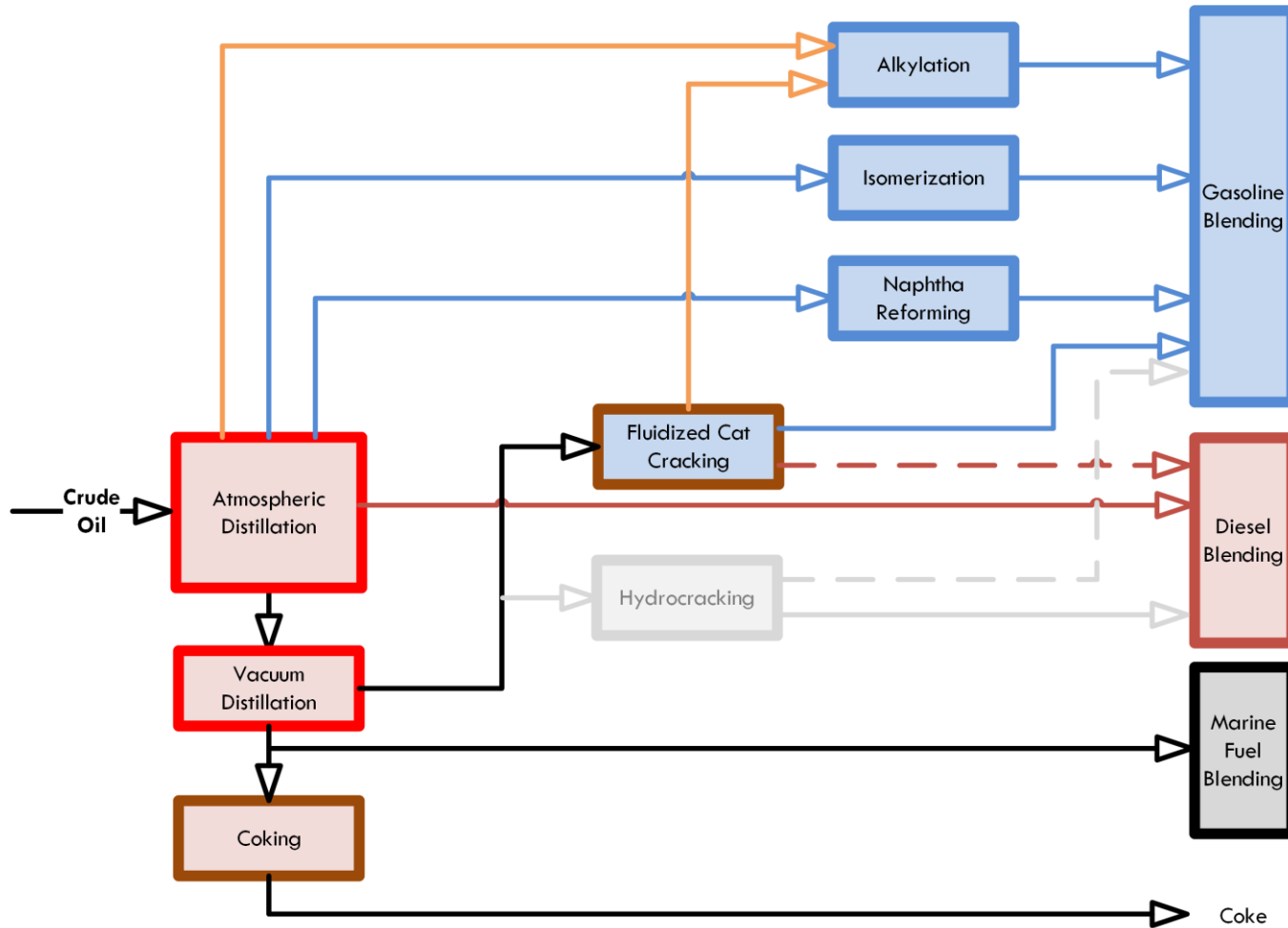
- U.S. gasoline consumption has been decreasing
- U.S. & worldwide diesel consumption continuing to rise



Data from EIA.gov

Ref: http://www.refinerlink.com/blog/Value_Hydrocrackers_US_Refining/

Little Flexibility Without Hydrocracker



Residual Fuel Oils

No. 6 Fuel Oil / Residual Fuel Oil / Marine Fuel

- Market has been declining in last 20 years – primarily used by ships
 - Many ships moving to use diesel for marine diesels or gas turbines
- More power plants use coal or natural gas
- Environmental reductions in sulfur levels
- “Emission-control areas” (ECAs) will shift to low-sulfur diesel oil (MDO) starting January 1, 2015 – U.S., Canada, Caribbean, & northern Europe
- Other option on-board emissions-scrubbing systems

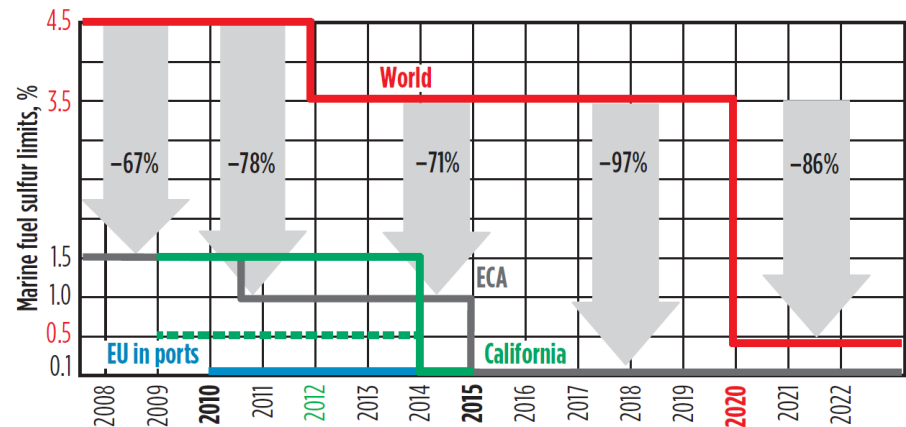


FIG. 1. New sulfur limits for marine fuels, 2008-2020.

“Methanol takes on LNG for future marine fuels”, *Hydrocarbon Processing*, May 2015

Oil: Light Sweet or Heavy Sour?

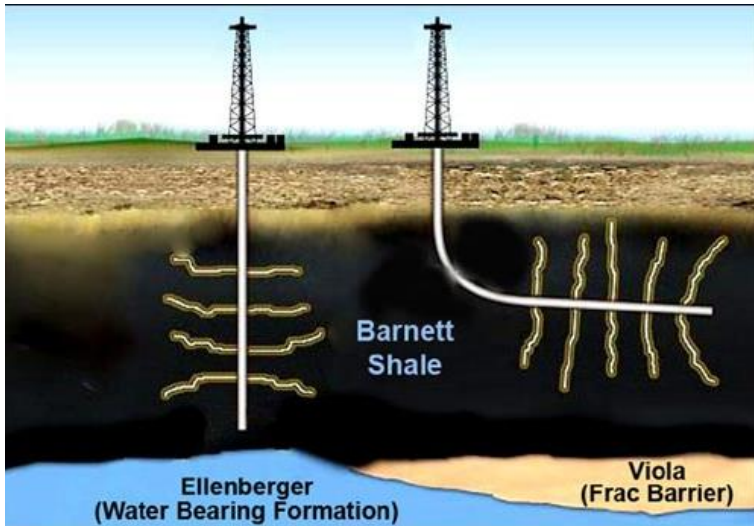


Tight Oil from Shale Formations

Tight oil production made possible by improved technology: directional drilling & hydraulic fracturing

Tight oil from the Bakken has made North Dakota the 3rd largest producing state in the US

Overall U.S. is now the largest oil producing country (as of February 2018)



Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI. Updated: May 9, 2011

http://www.eia.gov/oil_gas/rpd/northamer_gas.jpg

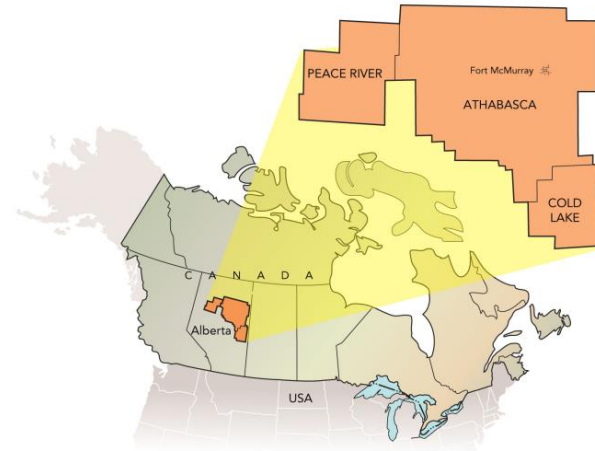
<http://www.horizontaldrilling.org/>

Canadian Oil Sands

Heavy oils produced by various technologies

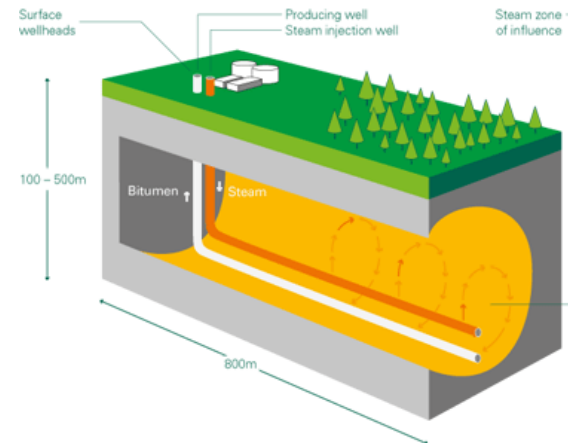
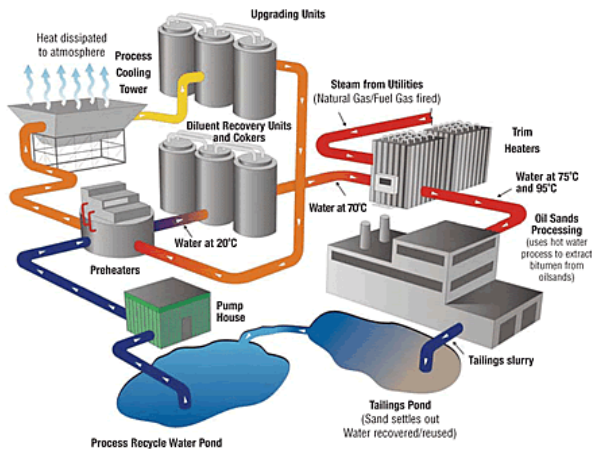
- Surface mining & hot water extraction
- *In situ* heating
 - CSS (Cyclic Steam Stimulation)
 - SAGD (Steam Assisted Gravity Drainage)
- Upgrading
 - Exported product much lighter than feedstock

Canada oil sands areas



Source: Government of Alberta Energy

<http://www.ogi.com/unconventional-resources/oil-sands.html>



<http://www.bp.com/sectiongenericarticle.do?categoryId=9036694&contentId=7067647>

<http://newenergyandfuel.com/http://newenergyandfuel.com/2009/08/12/making-syncrude/>

Tight Oil & Oil Sands Considerations

Tight oil tends to be light & sweet – replacement to WTI

Products from oil sands depend upon production technology

- Mining & *in situ* SAGD production gives heavy & sour product – compete with other imported heavy oils
 - Must be mixed with light diluent to allow transport (“dilbit”)
 - Excess naphtha & LPG in the northern region viewed as source of diluent
- Product from upgraders would be light – compete with tight oils
- Oil Sands projects tend to be very expensive & require high crude oil market price for cost recovery
 - Largest undeveloped projects are Canadian oil sands projects requiring estimated \$128 to \$159 per bbl¹

Expectation is that each type will separately displace imported oil from the US refiner’s crude slate

¹ http://www.carbontracker.org/site/wp-content/uploads/2014/08/CTI_Oil_Gas_Majors_Company_Factsheets_August_2014_FULL.pdf

Transportation Infrastructure is Key

\$7 billion Keystone XL Pipeline had been proposed to bring oils sands to Gulf Coast

U.S. government approval status

- Had been rejected November 2015 after 6 years of evaluation
- Reinstated January 2017

In many respects the section south from Cushing was the most important part to improve flow of all mid-continent oil.

- Started flow early 2014, up to 700,000 bpd capacity
- WTI & Brent differential closed up



<http://www.washingtonpost.com/wp-srv/special/nation/keystone-xl-map/>

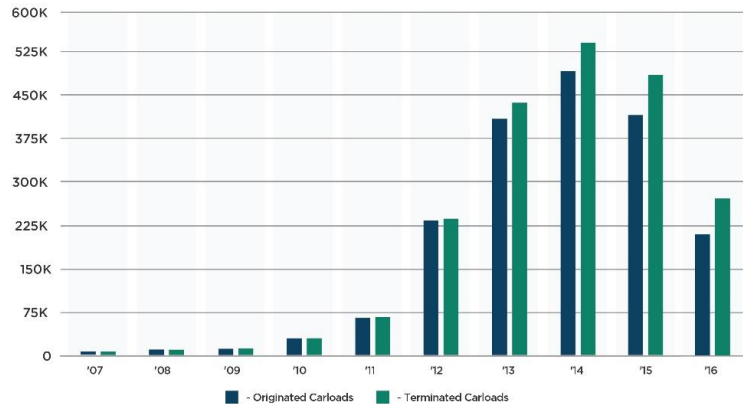
Transportation Infrastructure is Key

Rail became preferred method to bring incremental barrels out of Bakken & Eagle Ford



CRUDE OIL BY RAIL

Originations vs. Terminations, 2007-2016



<http://www.cpr.ca/en/ship-with-cp/where-you-can-ship/bakken-shale/Documents/bakken.pdf>

America's freight railroads support the nation's energy renaissance by moving domestic energy resources such as crude oil. Since 2009, when domestic crude oil production started to surge, U.S. railroads have originated more than two million carloads of crude oil. To help ensure the safety of crude oil movements, freight railroads have implemented new operating protocols and advocated for stronger tank car design standards, while federal regulators have issued more stringent safety regulations related to crude oil transport.

Notes: Data are for U.S. Class I railroads.
Source: Association of American Railroads



<https://www.aar.org/Pages/Crude-Oil-Rail-Traffic.aspx>

Transportation Infrastructure is Key

Rail as preferred method to bring incremental barrels out of Bakken & Eagle Ford

- Concerns from communities
 - Increased emissions, especially in California
 - Advertising timing of oil shipments could be a matter of home security
- Safety concerns – train derailments July 2013 Quebec (40 dead), December 2013 ND, & others
- ANSI & API released new recommended practices for shipping crude by rail (ANSI/API Recommended Practice 3000) in September 2014



"U.S. sets new final rule on oil, ethanol trains", Aug. 4, 2015
<http://www.agprofessional.com/news/us-sets-new-final-rule-oil-ethanol-trains>

Rail Safety

New rules from US DOT & Canadian transportation officials went into effect Oct. 1, 2015

- New tank cars must have an outer shell, a thermal lining, improved top and bottom fittings and thicker 9/16ths-inch steel walls
- By Jan. 1, 2021, trains of at least 70 cars must have electronically controlled brakes to automatically stop all the cars in a train at the same time



Each rail car holds about 30,000 gal (714 bbls)

Implications

- Will require replacing all DOT-111 & non-jacketed CPC-1232 cars for Packing Group I within 5 years

New rules:

<http://www.pennenergy.com/articles/pennenergy/2015/05/oil-and-gas-transportation-us-canada-unveil-rules-to-boost-oil-train-safety.html?cmpid=EnlDailyPetroMay42015>

http://www.downstreambusiness.com/global-refining-petrochemicals-fuels-processing/US-DOT-Issues-Final-Crude-Ethanol-Tank-Car-Rule_141353

Picture: http://www.nytimes.com/2015/05/02/business/energy-environment/us-sets-new-rules-for-oil-shipments-by-rail.html?_r=0

Other Pipeline Projects

450 Mbpd Dakota Access line was to open Q4 2016

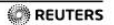
- Allow flow of Bakken oil to gulf coast
- Energy Transfer Partners primary owner
 - Other partners include Phillips 66, Enbridge & Marathon Petroleum
- Reinstated January 2017; started operations June 2017

Dakota pipeline to speed crude to U.S. Gulf

The Dakota Access Pipeline, scheduled to open in the fourth quarter, will make it easier for producers to move barrels of oil to the refining-heavy U.S. Gulf Coast.



Sources: EIA; Kinder Morgan; Energy Transfer Crude Oil Company; Tallgrass Energy
C. Chan, 11/08/2016



<http://www.hydrocarbonprocessing.com/news/2016/08/big-dakota-pipeline-to-give-gulf-coast-refiners-another-option-for-crude-supply>

What Does This Mean for U.S. Refiners?

Tight oil production should ensure domestic supply to refineries needing sweet crude in the next 10 – 15 years

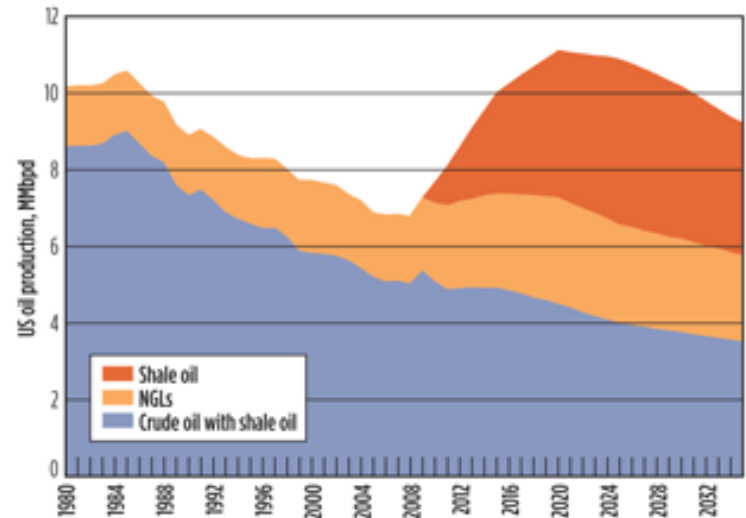
- Expected to peak @ 4.8 million bpd in 2021 (EIA, Dec. 2013)

Investments to allow refiners to process heavy sour crudes might limit the ability to utilize tight oil

- Exporting tight oil recently permitted by U.S. Government
- Expect to still import heavy oil

Public concerns could put the brakes on this production

- High energy requirements for producing Canadian oil sands
- High water quantities needed for tight oil & oil sands production
- Public concerns about hydraulic fracturing
- Public concerns about oil transport by rail
- Public concerns about oil transport by pipeline



<http://www.hydrocarbonprocessing.com/Article/3223989/Channel/194955/Innovative-solutions-for-processing-shale-oils.html>

Role of Biofuels in the U.S.?



Clean Air Act & Amendments

Series of Clean Air Acts

- Air Pollution Control Act of 1955
- Clean Air Act of 1963
- Air Quality Act of 1967
- Clean Air Act Extension of 1970
- Clean Air Act Amendments in 1977 & 1990

1977 Clean Air Act amendments set requirements for "substantially similar gasoline"

- Oxygenates added to make motor fuels burn more cleanly & reduce tailpipe pollution (particularly CO)
- Required that oxygenates be approved by the U.S. EPA
- MTBE & ethanol primary choices

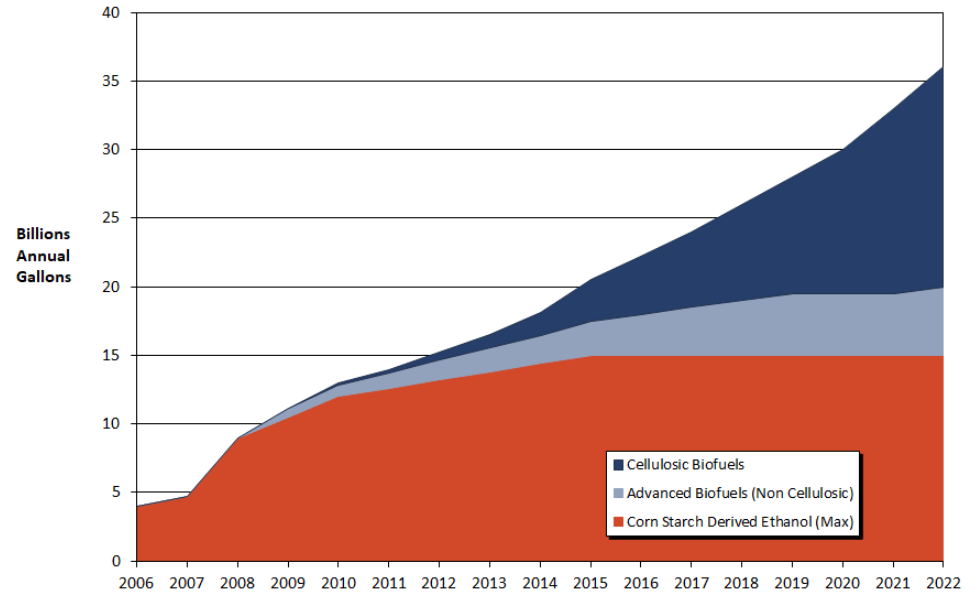
California Phase 3 gasoline regulation approved by California Air Resources Board in December 1999 prohibited gasoline with MTBE after December 31, 2002

- Water quality issues

2007 Renewable Fuel Standard (RFS2)

Energy Independence & Security Act of 2007

| Year | Renewable Fuel Bgal/yr | Advanced Biofuels Bgal/yr | Cellulosic Biofuel Bgal/yr | RFS - AB Bgal/yr |
|------|---------------------------|------------------------------|-------------------------------|---------------------|
| 2006 | 4.000 | | | 4.000 |
| 2007 | 4.700 | | | 4.700 |
| 2008 | 9.000 | | | 9.000 |
| 2009 | 11.100 | 0.600 | | 10.500 |
| 2010 | 12.950 | 0.950 | 0.100 | 12.000 |
| 2011 | 13.950 | 1.350 | 0.250 | 12.600 |
| 2012 | 15.200 | 2.000 | 0.500 | 13.200 |
| 2013 | 16.550 | 2.750 | 1.000 | 13.800 |
| 2014 | 18.150 | 3.750 | 1.750 | 14.400 |
| 2015 | 20.500 | 5.500 | 3.000 | 15.000 |
| 2016 | 22.250 | 7.250 | 4.250 | 15.000 |
| 2017 | 24.000 | 9.000 | 5.500 | 15.000 |
| 2018 | 26.000 | 11.000 | 7.000 | 15.000 |
| 2019 | 28.000 | 13.000 | 8.500 | 15.000 |
| 2020 | 30.000 | 15.000 | 10.500 | 15.000 |
| 2021 | 33.000 | 18.000 | 13.500 | 15.000 |
| 2022 | 36.000 | 21.000 | 16.000 | 15.000 |



Replaced the RFS of the Energy Policy Act of 2005
 Administered by the Environmental Protection Agency
<http://epa.gov/otag/renewablefuels/index.htm>

EPA Clarifications & Adjustments

RFS-2 Advanced Biofuels amounts have had to be adjusted since 2010

- **Significantly** less development of cellulosic biofuels than had been anticipated in 2007

Adjustments required annually

- Have needed to drastically reduce Cellulosic Biofuel
- Increases in allowed biodiesel
- Have started to expand the types of allowable advanced biofuel
- Finalized amounts after 2015 are lower than Standard – took into account “blend wall” & actual fuel sales.
- 2020 targets announced July 2019

| Year | Energy Independence & Security Act of 2007 | | | EPA Clarifications & Adjustments | | | |
|------|--|---------------------------|----------------------------|----------------------------------|--------------------------|----------------------------|------------------------------|
| | Renewable Fuel Bgal/yr | Advanced Biofuels Bgal/yr | Cellulosic Biofuel Bgal/yr | Renewable Fuel Bgal/yr | Advanced Biofuel Bgal/yr | Cellulosic Biofuel Bgal/yr | Biomass Based Diesel Bgal/yr |
| 2006 | 4.000 | | | | | | |
| 2007 | 4.700 | | | | | | |
| 2008 | 9.000 | | | | | | |
| 2009 | 11.100 | 0.600 | | | | | |
| 2010 | 12.950 | 0.950 | 0.100 | 12.950 | 0.950 | 0.0065 | 1.150 |
| 2011 | 13.950 | 1.350 | 0.250 | 13.950 | 1.350 | 0.0066 | 0.800 |
| 2012 | 15.200 | 2.000 | 0.500 | 15.200 | 2.000 | 0.01045 | 1.500 |
| 2013 | 16.550 | 2.750 | 1.000 | 16.550 | 2.750 | 0.0060 | 1.280 |
| 2014 | 18.150 | 3.750 | 1.750 | 16.28 | 2.67 | 0.033 | 1.63 |
| 2015 | 20.500 | 5.500 | 3.000 | 16.93 | 2.88 | 0.123 | 1.73 |
| 2016 | 22.250 | 7.250 | 4.250 | 18.11 | 3.61 | 0.230 | 1.90 |
| 2017 | 24.000 | 9.000 | 5.500 | 19.28 | 4.28 | 0.311 | 2.00 |
| 2018 | 26.000 | 11.000 | 7.000 | 19.29 | 4.29 | 0.288 | 2.1 |
| 2019 | 28.000 | 13.000 | 8.500 | 19.92 | 4.92 | 0.42 | 2.1 |
| 2020 | 30.000 | 15.000 | 10.500 | 20.04 | 5.04 | 0.54 | 2.43 |
| 2021 | 33.000 | 18.000 | 13.500 | | | | 2.43 |
| 2022 | 36.000 | 21.000 | 16.000 | | | | |

Biodiesel volumes actual. All other volumes ethanol-equivalent.

Advanced Biofuel:

Renewable fuel (other than corn starch derived ethanol) with 50% less than baseline lifecycle greenhouse gas emissions.

Cellulosic Biofuel:

Renewable fuel from lignocellulosic biomass with 60% less than baseline lifecycle greenhouse gas emissions.

Refs:

<http://epa.gov/otaq/fuels/renewablefuels/regulations.htm>

<https://www.epa.gov/sites/production/files/2019-07/documents/rfs-2020-standards-nprm-2019-07-05.pdf>

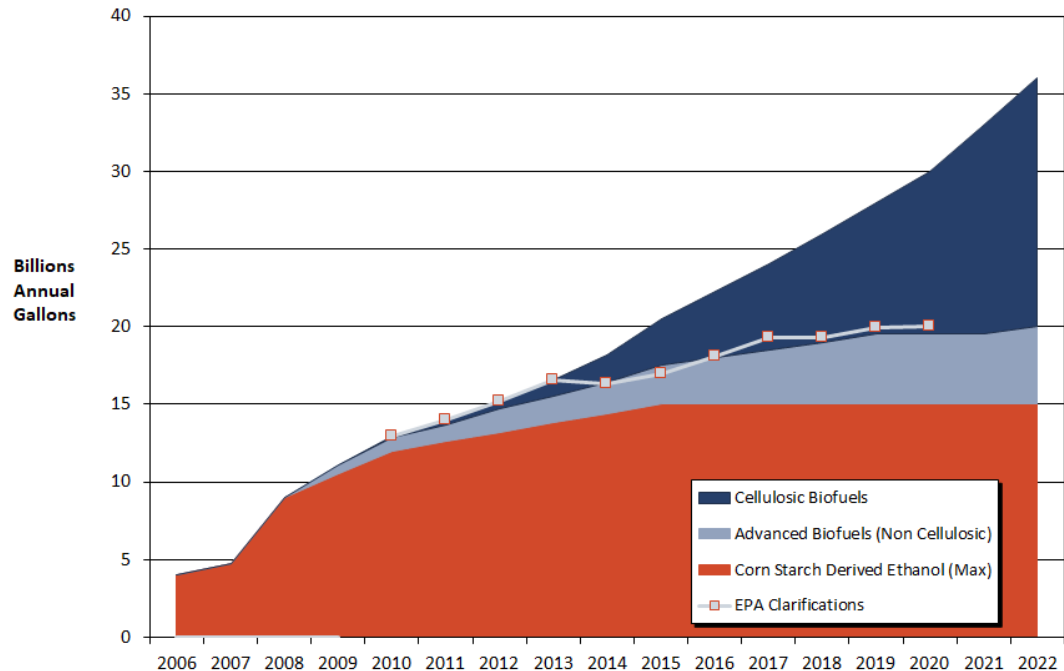
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<https://www.epa.gov/sites/production/files/2019-07/documents/rfs-2020-standards-nprm-2019-07-05.pdf>

“Unforeseen” Issues with RFS-2

Production of advanced biofuels not increasing at rate expected & mandated by the law

- Both technology & commercial issues

The “blend wall” – Enough gasoline to incorporate all this ethanol?

- 136 B gal motor gasoline sold in US in 2012 – E10 can only incorporate 13.6 B gal
 - 2012 requires 15.2 B gal ethanol – 12% greater amount

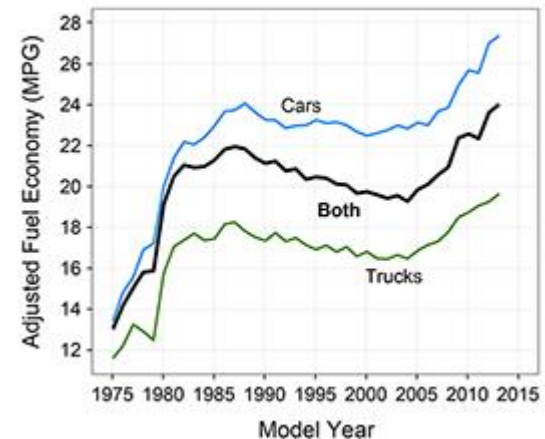
Full amount of renewable fuel will suppress amount of gasoline in the market

- 36 B gal ethanol + 112 B gal gasoline will give energy equivalent of 2012’s 136 B gal gasoline – 82% of the 2012 gasoline amount

Increased CAFE standards give further downward pressure on gasoline demand

- 2007 Energy & Security Act raises to 35 mpg by 2020
 - Increased to 35.5 mpg by 2016 by executive order
- 2025 target for passenger vehicles & light trucks 54.5 mpg
- Electric & plug-in hybrids will increase electricity demand at expense of petroleum

Adjusted Fuel Economy for MY 1975-2013¹



Ref: <http://epa.gov/otaq/fetrends.htm>



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Oil: Light Sweet or Heavy Sour?

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