Petroleum Production, Transportation, & Refining

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Topics

- Energy consumption & petroleum’s place
- Oil reserves
- Oil sources & production
- Pipelines
- Petroleum Refining
Energy Markets Are Interconnected

Estimated U.S. Energy Use in 2013: ~97.4 Quads

Source: LLNL 2014. Data is based on DOE/EIA-0015(2014-01), March, 2014. 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 85% for the residential and commercial sectors, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-Mi-410527

Petroleum Pathway

- Crude Production
- Crude Transportation
- Crude Refining
- Crude Storage & Transportation
- Retail Distribution
- Consumer Use
Worldwide trade of refined products

- In general, United States prefers gasoline to diesel whereas the rest of the world prefers diesel to gasoline
  - FCC-based refineries will still produce a great deal of gasoline even when trying to maximize diesel production. Foreign incentive to ship excess gasoline to US, especially to the East Coast from Europe.
    - 2008 gasoline imports suppressed the cost of gasoline relative to crude oil
  - US refineries increasing the installation of Hydrocracking to produce diesel for export, especially along the Gulf of Mexico

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

- Canadian provinces producing oil
- Other oil producing states
- OPEC member states
- US states producing oil
- North sea oil states
Proven Oil Reserves
Hubert’s Peak

\[ Q(t) = \frac{Q_{\text{max}}}{1 + ae^{-bt}} \]
Hubert’s Peak

OGJ, 9 Feb 2004 (Jan-Nov 2003)
Origins of Oil & Gas

- Organic life buried in sedimentary rock
- Transformation to hydrocarbons
- Migration from source rocks
- Accumulation of oil & gas
- Flow of oil & gas through porous media
Types of Oil Traps

1. Anticlinal trap

2. Fault trap

3. Stratigraphic trap

http://www.maverickenergy.com/oilgas.htm
Characteristics of Reservoir Rock

Porosity

Permeability

http://www.maverickenergy.com/oilgas.htm
Oil Production

http://www.maverickenergy.com/oilgas.htm
Well Completions

Perforating  Acidizing  Fracturing

http://www.maverickenergy.com/oilgas.htm
Rotary Drilling Rig

Beam Pumping Unit

Directional & Horizontal Wells

- Directional drilling can get you to pay zones that you normally couldn’t reach
- Horizontal wells can expose a much greater drainage area – especially valuable in a tight reservoir
- Cost per well is 2X – 3X that of vertical well but productivity can be 15X – 20X.

http://www.horizontaldrilling.org/
Unconventional Resources

• Petroleum & natural gas formed from decomposing organic matter in “source rock”

• Conventional – gas & liquids migrate through permeable rock toward the surface until it is stopped by some trapping mechanism

• Unconventional – gas & liquids are trapped at the source rock because of extremely low permeabilities

What is hydraulic fracturing?

Hydraulic fracturing, or “fracking,” involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer, in this case the Marcellus Shale, to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.

What is hydraulic fracturing?

Hydraulic fracturing, or fracking, is a method of forcing natural gas or oil from rock layers deep below the Earth's surface.

**How fracking works ...**

1. A pressurized mixture of sand, water and chemicals is injected into a horizontally drilled well.
2. The mix cracks the shale and fills the cracks with sandy grit, allowing natural gas to flow up the well.
3. The recovered water is stored in lined pits or taken to a treatment plant.

**... and why it's controversial**

Much of the water used in fracking is collected from the well and processed, but some communities have raised concerns that potentially carcinogenic chemicals can escape into drinking water.

- Nearby water wells face a slight risk of contamination. (There's about a 1% chance of a hydraulic fracture extending beyond 1,150 feet of a fracture zone.)
- Scientists worry that concrete well casings can crack and leak chemicals.
- Environmentalists fear that cracks created by fracking can spread to existing cracks in the rock layer and become pathways to ground water.

1 – Based on research published this year in Marine and Petroleum Geology

Sources: Duke University; U.S. Energy Information Administration; National Research Council; Marine and Petroleum Geology
By Dan Vergano and Karl Gelles, USA TODAY

http://c1wsolutions.wordpress.com/2014/07/30/a-solution-to-frackings-water-problems/
Major tight-oil production in U.S.

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

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


http://www.bp.com/sectiongenericarticle.do?categoryld=9036694&contentId=7067647
Oil Platforms
Deep Sea Production

Ormen Lange - Scenario 15A

Total No. of Wells: 10
Plateau length: 13 km
Production ACOG: 5.5 KMcm³A
Design Rates:
- Gas: 955 Mscf/d
- Injection
- Condensate: 20,270 bbl/d
- Water: 2,520 bbl/d

Ormen Lange - Scenario 15C

Total No. of Wells: 15
Plateau length: 8.3 km
Production ACOG: 15 BMcm³A
Design Rates:
- Gas: 455 Mscf/d
- Injection
- Condensate: 750 bbl/d
- Water: 2,950 bbl/d
Major U.S. Pipelines

Major US Pipelines

Source: REXTAG Strategies Corp and the Alaska Department of Natural Resources, as interpreted by API (2/26/09)
Proposed Keystone Pipeline Expansion

- Keystone XL Pipeline important to bring oils sands & northern tight oil to Gulf Coast
- Section south from Cushing important to improve flow of all mid-continent oil.
  - Started flow early 2014, up to 700,000 bpd capacity

How Pipelines Work

Association of Oil Pipelines, http://www.aopl.org/aboutPipelines/?fa=howPipelinesWork
Batching in Product Pipelines

- Goal is to minimize product downgrade during shipping
- Preferred sequence to ship these products out of refinery:

- Considerations
  - Interface between the two gasolines can be "downgraded" to the 87 octane (because of octane effects)
  - Interface between the ULSD & Heating Oil can be downgraded to the Heating Oil (because of sulfur effects)
  - Interface between 87 octane gasoline & ULSD have similar sulfur contents but different boiling point properties – typically returned to refinery for additional processing – “transmix”

RefinerLink, http://www.refinerlink.com/blog/Pipelines_Ship_Refinery_Products_to_Pump/
Louisiana Offshore Oil Port (LOOP)

http://blog.nola.com/tpmoney/2009/05/louisiana_offshore_oil_port_is.html

http://www.economicpopulist.org/content/gustav-eying-gulf-oil-and-loop
Transportation Infrastructure is Key

- Keystone XL Pipeline important to bring oils sands & northern tight oil to Gulf Coast
  - Section south from Cushing important to improve flow of all mid-continent oil. Started flow early 2014, up to 700,000 bpd capacity

- Rail has become preferred method to bring incremental barrels out of Bakken & Eagle Ford
  - Safety concerns – train derailments July 2013 Quebec (40 dead) & December 2013 ND
  - Concerns about increased emissions, especially in California
  - ANSI & API released new recommended practices for shipping crude by rail (ANSI/API Recommended Practice 3000) in September 2014
    - Available for free at this web page


Transportation by Rail in U.S.

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

http://peoriastation.blogpeoria.com/2012/03/24/bnsf-galesburg-yards-new-tracks-are-in-service/

What Does Tight Oil Mean for U.S. Refiners?

- Until Marketlink pipeline (southern leg of Keystone XL) operational expect prices for Mid Continent crude oils to be below market
  - January 2014 expected to start shipments
- 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)
- Recent investments to allow refiners to process heavy sour crudes might limit the ability to utilize tight oil
  - Exporting tight oil while importing heavy oil is very possible if permitted by U.S. government
- Environmental 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

World & U.S. Refining Capacity

**HOW THE WORLD’S LARGEST REFINERS RANK**

<table>
<thead>
<tr>
<th>Rank</th>
<th>1-Jan-14</th>
<th>Company</th>
<th>Capacity b/cd¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>ExxonMobil Corp.</td>
<td>5,583,000</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Royal Dutch Shell PLC</td>
<td>4,109,239</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Sinopec</td>
<td>3,971,000</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>BP PLC</td>
<td>2,858,364</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>Saudi Aramco</td>
<td>2,851,500</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>Valero Energy Corp.</td>
<td>2,775,500</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>Petroleos de Venezuela SA</td>
<td>2,678,000</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>China National Petroleum Corp.</td>
<td>2,675,000</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>Chevron Corp.²</td>
<td>2,539,600</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>Phillips 66</td>
<td>2,514,200</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>Total SA</td>
<td>2,304,326</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>Petroleo Brasiliero SA</td>
<td>1,997,000</td>
</tr>
<tr>
<td>13</td>
<td>17</td>
<td>Marathon Petroleum Co. LP</td>
<td>1,714,000</td>
</tr>
<tr>
<td>14</td>
<td>13</td>
<td>Petroleos Mexicanos</td>
<td>1,703,000</td>
</tr>
<tr>
<td>15</td>
<td>14</td>
<td>National Iranian Oil Co.</td>
<td>1,451,000</td>
</tr>
<tr>
<td>16</td>
<td>15</td>
<td>JX Nippon Oil &amp; Energy Corp.</td>
<td>1,423,200</td>
</tr>
<tr>
<td>17</td>
<td>16</td>
<td>Rosneft</td>
<td>1,293,000</td>
</tr>
<tr>
<td>18</td>
<td>18</td>
<td>OAO Lukoil</td>
<td>1,217,000</td>
</tr>
<tr>
<td>19</td>
<td>19</td>
<td>SK Innovation</td>
<td>1,115,000</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>Repsol YPF SA</td>
<td>1,105,500</td>
</tr>
<tr>
<td>21</td>
<td>21</td>
<td>Kuwait National Petroleum Co.</td>
<td>1,085,000</td>
</tr>
<tr>
<td>22</td>
<td>22</td>
<td>Pertamina</td>
<td>993,000</td>
</tr>
<tr>
<td>23</td>
<td>23</td>
<td>Agip Petroli SPA</td>
<td>904,000</td>
</tr>
<tr>
<td>24</td>
<td>24</td>
<td>Flint Hills Resources</td>
<td>714,400</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>Sunoco Inc.</td>
<td>505,000</td>
</tr>
</tbody>
</table>

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

“Western Europe leads global refining contraction”, *Oil & Gas Journal*, pp 34-48, Dec. 2, 2013

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

<table>
<thead>
<tr>
<th>Company</th>
<th>Capacity Barrels per Calendar Day</th>
<th>Capacity Barrels per Stream Day</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALERO ENERGY CORP</td>
<td>1,904,300</td>
<td>2,046,500</td>
<td>93%</td>
</tr>
<tr>
<td>EXXON MOBIL CORP</td>
<td>1,951,950</td>
<td>2,045,900</td>
<td>95%</td>
</tr>
<tr>
<td>PHILLIPS 66 COMPANY</td>
<td>1,831,600</td>
<td>1,938,755</td>
<td>94%</td>
</tr>
<tr>
<td>MARATHON PETROLEUM CORP</td>
<td>1,714,000</td>
<td>1,817,500</td>
<td>94%</td>
</tr>
<tr>
<td>ROYAL DUTCH/ SHELL GROUP</td>
<td>1,126,525</td>
<td>1,170,500</td>
<td>96%</td>
</tr>
<tr>
<td>CHEVRON CORP</td>
<td>943,271</td>
<td>1,013,700</td>
<td>93%</td>
</tr>
</tbody>
</table>

**Total**

19,064,210

**Capacities for LLC refineries split among the partner companies**

EIA, Jan. 1, 2014 database, published June 2014
[http://www.eia.gov/petroleum/refinerycapacity/](http://www.eia.gov/petroleum/refinerycapacity/)
“Western Europe leads global refining contraction”, *Oil & Gas Journal*, pp. 34-48, Dec. 2, 2013

Source:
EIA, Jan. 1, 2014 database, published June 2014
http://tonto.eia.doe.gov/dnav/pet/pet_pnp_cap1_dcu_nus_a.htm
Crude Oil as Refinery Feedstock

- Crude Oil
  - Complex mixture of hydrocarbons & heterocompounds
  - Dissolved gases to non-volatiles (1000°F+ boiling material)
  - C\textsubscript{1} to C\textsubscript{90*}
- Composition surprisingly uniform

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>84 - 87</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>11 - 14</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0 - 0.2</td>
</tr>
<tr>
<td>Other elements</td>
<td>0 - 0.1</td>
</tr>
</tbody>
</table>
Primary Hydrocarbon Molecular Types

- **Paraffins**
  - Carbon atoms connected by single bond
  - Other bonds saturated with hydrogen

- **Naphthenes**
  - Ringed paraffins (cycloparaffins)
  - All bonds saturated with hydrogen

- **Aromatics**
  - Six carbon ring (multiple bonding)
  - All bonds are unsaturated

- **Olefins**
  - Usually not in crude oil
  - Formed during processing
  - At least two carbon atoms connected by double bond
Example Heterocompounds

Dibenzothiophenes

Trinaphthenobenzothiophenes

Carbazoles

Dinaphthenoquinolines

Carboxylic Acids

Amides

Azathioephenes

Disulfides

Composition & Analysis of Heavy Petroleum Fractions
K.H. Altgelt & M.M. Boduszynski
Marcel Dekker, Inc., 1994, pg. 16

Petroleum Refining Technology & Economics – 5th Ed.
by James Gary, Glenn Handwerk, & Mark Kaiser, CRC Press, 2007
Characteristics of Petroleum Products

Refining Overview – Petroleum Processes & Products,
by Freeman Self, Ed Ekholm, & Keith Bowers, AIChE CD-ROM, 2000
Crude Oils Are Not Created Equal
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
  - Depends upon the local economics & contractual limitations

Ref: Unknown origin. Possibly Socony-Vacuum Oil Company, Inc. (1943)
Raw Crude vs. Refined Product
Petroleum Products

- Refinery Fuel Gas (Still Gas)
- Liquefied Petroleum Gas (LPG)
  - Ethane & Ethane-Rich Streams
  - Propanes
  - Butanes
- Gasoline
  - Naphtha
- Middle Distillates
  - Kerosene
  - Jet Fuel
  - Diesel, Home Heating, & Fuel Oil
- Gas Oil & Town Gas
- Lubricants
- Wax
- Asphalt & Road Oil
- Petroleum Coke
- Petrochemicals
- Sulfur

EIA, refinery yield – updated April 20, 2014
http://tonto.eia.doe.gov/dnav/pet/pet_pnp_pct_dc_nus_pct_m.htm
Motor Gasoline Volatility Classes (ASTM D 4814-13)

### TABLE 1 Vapor Pressure and Distillation Class Requirements

<table>
<thead>
<tr>
<th>Vapor Pressure/Distillation Class</th>
<th>Vapor Pressure, max, kPa (psi)</th>
<th>10 vol%</th>
<th>50 vol%</th>
<th>90 vol%</th>
<th>90 vol% End Point</th>
<th>Distillation Residue, vol%</th>
<th>Driveability Index, °C(°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>54(7.8)</td>
<td>70(158)</td>
<td>77(170)</td>
<td>121(250)</td>
<td>190(374)</td>
<td>225(437)</td>
<td>2</td>
</tr>
<tr>
<td>A</td>
<td>62(9.0)</td>
<td>70(158)</td>
<td>77(170)</td>
<td>121(250)</td>
<td>190(374)</td>
<td>225(437)</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>69(10.0)</td>
<td>65(149)</td>
<td>77(170)</td>
<td>118(245)</td>
<td>190(374)</td>
<td>225(437)</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>79(11.5)</td>
<td>60(140)</td>
<td>77(170)</td>
<td>116(240)</td>
<td>185(365)</td>
<td>225(437)</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>93(13.5)</td>
<td>55(131)</td>
<td>77(170)</td>
<td>113(235)</td>
<td>185(365)</td>
<td>225(437)</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>103(15.0)</td>
<td>50(122)</td>
<td>77(170)</td>
<td>110(230)</td>
<td>185(365)</td>
<td>225(437)</td>
<td>2</td>
</tr>
</tbody>
</table>

\[ Di[^\circ C] = (Di[^\circ F] - 176)/1.8 \]

### TABLE 4 Schedule of Seasonal and Geographical Volatility Classes

<table>
<thead>
<tr>
<th>State</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep 1-15</th>
<th>Sep 16-30</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>D-4</td>
<td>D-4</td>
<td>D-4/C-3</td>
<td>C-3/A-3</td>
<td>A-3 (C-3)</td>
<td>A-3(^C)</td>
<td>A-3(^D)</td>
<td>A-2</td>
<td>A-2/C-3</td>
<td>C-3</td>
<td>C-3/D-4</td>
<td>D-4</td>
<td></td>
</tr>
<tr>
<td>Alaska</td>
<td>E-6</td>
<td>E-6</td>
<td>E-6</td>
<td>E-6/D-4</td>
<td>D-4</td>
<td>D-4</td>
<td>D-4</td>
<td>D-4</td>
<td>D-4/E-6</td>
<td>E-6</td>
<td>E-6</td>
<td>E-6</td>
<td></td>
</tr>
<tr>
<td>Arizona: (^\circ) N 34(^\circ) Latitude and E111¼ Longitude</td>
<td>D-4</td>
<td>D-4</td>
<td>D-4/C-3</td>
<td>C-3/A-2</td>
<td>A-2 (B-2)</td>
<td>A-1</td>
<td>A-1</td>
<td>A-1</td>
<td>A-2/B-2</td>
<td>C-3/D-4</td>
<td>D-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Coast</td>
<td>D-4</td>
<td>D-4/C-3</td>
<td>C-3/A-3</td>
<td>A-3 (C-3)</td>
<td>A-2(^D), H</td>
<td>A-2(^D), H</td>
<td>A-2(^D), H</td>
<td>A-2/B-2</td>
<td>B-2/C-3</td>
<td>C-3/D-4</td>
<td>D-4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

52
What are Octane Numbers?

- References:
  - iso-octane $\Rightarrow 100$ (2,2,4-trimethylpentane)
  - n-heptane $\Rightarrow 0$
- Tendency for auto-ignition upon compression
  - Gasoline — bad
  - Tendency of gasoline to cause “pinging” in engine
  - Higher octane needed for higher compression ratios
- Different types (typically RON > MON)
  - RON — Research Octane Number
    - Part throttle knock problems
  - MON — Motor Octane Number
    - More severe — high speed & high load conditions
  - $(R+M)/2$ — Road Octane Number
    - Average of MON & RON
    - Reported at the pump
Middle Distillates

• General classifications
  ▪ Kerosene
  ▪ Jet fuel
  ▪ Distillate fuel oil
    • Diesel
    • Heating oil

• Properties
  ▪ Flash point
  ▪ Cloud point / Pour point
  ▪ Aniline point
  ▪ Cetane number
  ▪ Viscosity
  ▪ Water & sediment
What are Cloud & Pour Points?

- Indicate the tendency to form solids at low temperatures – the higher the temperature the higher the content of solid forming compounds (usually waxes)

  - Cloud Point
    - Temperature at which solids start to precipitate & give a cloudy appearance
    - Tendency to plug filters at cold operating temperatures

  - Pour Point
    - Temperature at which the oil becomes a gel & cannot flow

Solidification of diesel fuel in a fuel-filtering device after sudden temperature drop

“Consider catalytic dewaxing as a tool to improve diesel cold-flow properties”, Rakoczy & Morse, Hydrocarbon Processing, July 2013
Comparison of Boiling Ranges
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, 1/4/2015

  - **Prices**
    - WTI Cushing Spot  $52.69 per bbl
    - Brent  $56.42 per bbl
    - RBOB Gasoline  $1.4334 per gal
    - Heating Oil  $1.7957 per gal

  - **5-3-2 Spreads**
    - WTI:
      \[
      \frac{42 \times (3 \times 1.4334 + 2 \times 1.7957) - 5 \times 52.69}{5} = 13.60 \text{ per bbl}
      \]
    - Brent:
      \[
      \frac{42 \times (3 \times 1.4334 + 2 \times 1.7957) - 5 \times 56.42}{5} = 10.09 \text{ per bbl}
      \]
Prices Are Crude Specific

### US Crude Prices

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

*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

<table>
<thead>
<tr>
<th>OPEC reference basket</th>
<th>Wkly. avg. 1-17-14 $/bbl</th>
<th>Oct-13 Mo. avg., $/bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPEC reference basket</td>
<td>106.69</td>
<td>104.17</td>
</tr>
<tr>
<td>Arab light-Saudi Arabia</td>
<td>107.14</td>
<td>104.84</td>
</tr>
<tr>
<td>Basrah light-Iraq</td>
<td>103.69</td>
<td>101.63</td>
</tr>
<tr>
<td>Bonny light 37°-Nigeria</td>
<td>112.44</td>
<td>111.47</td>
</tr>
<tr>
<td>Es Sider-Libya</td>
<td>108.74</td>
<td>107.57</td>
</tr>
<tr>
<td>Girassol-Angola</td>
<td>110.20</td>
<td>108.83</td>
</tr>
<tr>
<td>Iran heavy-Iran</td>
<td>107.69</td>
<td>106.87</td>
</tr>
<tr>
<td>Kuwait export-Kuwait</td>
<td>106.13</td>
<td>104.73</td>
</tr>
<tr>
<td>Marine-Qatar</td>
<td>106.61</td>
<td>105.83</td>
</tr>
<tr>
<td>Merey-Venezuela</td>
<td>96.80</td>
<td>94.83</td>
</tr>
<tr>
<td>Murban-UAE</td>
<td>110.13</td>
<td>109.36</td>
</tr>
<tr>
<td>Oriente-Ecuador</td>
<td>95.16</td>
<td>89.72</td>
</tr>
<tr>
<td>Saharan blend 44°-Algeria</td>
<td>111.04</td>
<td>109.27</td>
</tr>
</tbody>
</table>

**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 |


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*COLORADO SCHOOL OF MINES*

EARTH ENERGY ENVIRONMENT

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Historical Crude Prices & Margins

Updated Jan. 2, 2015
Source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm
Prices Are Crude Specific

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
Historical Crude Prices & Crack Spreads

Spot Price Crack Spreads

- 5-3-2 Crack Spread
- 6-3-2-1 Crack Spread
- WTI Crude Oil Price

Updated Jan. 2, 2015
Source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm
Historical Crude Prices & Crack Spreads

Updated Jan. 2, 2015
Source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm
Description of Petroleum Refinery

- Manages hydrocarbon molecules
- Organized 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:
  - Tankage for storage
  - Dependable source for electric power
  - Waste disposal & treatment facilities
  - Product blending facilities
  - Around the clock operations
  - Conversion units
Petroleum Refinery Schematic

Raw Materials -> Refinery Processes -> Products
Petroleum Refinery Schematic

Raw Materials → Fractionation → Conversion Processes → Blending → Products
Catalytic Cracking

- Catalytically crack carbon-carbon bonds in gas oils
  - Fine catalyst in fluidized bed reactor allows for immediate regeneration
  - Lowers average molecular weight & produces high yields of fuel products
  - Produces olefins
- Attractive feed characteristics
  - Small concentrations of contaminants
    - Poison the catalyst
  - Small concentrations of heavy aromatics
    - Side chains break off leaving cores to deposit as coke on catalyst
    - Must be intentionally designed for heavy resid feeds
- Products may be further processed
  - Further hydrocracked
  - Alkylated to improve gasoline anti-knock properties
Naphtha Reforming

- Purpose to enhance aromatic content of naphtha
  - Improve the octane rating for gasoline
  - Hydrogen as by-product
    - Used in hydrotreating to remove sulfur & nitrogen
- Primary reactions
  - Dehydrogenation
    Naphthenes $\rightarrow$ Aromatics
  - Isomerization
    Normal Paraffins $\rightarrow$ Branched Isoparaffins
- Reformate desirable for gasoline but ...  
  - High octane number, low vapor pressure, very low sulfur levels, & low olefins concentration
  - US regulations on levels of benzene, aromatics, & olefins – air quality concerns

Dehydrogenation

\[ \text{C}_7\text{H}_{14} + 3\text{H}_2 \rightarrow \text{C}_7\text{H}_{10} + \text{H}_2 \]

Isomerization

\[ \text{CH}_3\text{CH}_2\text{CH}_3 \leftrightarrow \text{CH}_3\text{CH} = \text{CH}_2 \]

Dehydrocyclization

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 + \text{H}_2 \rightarrow \text{C}_7\text{H}_{16} + \text{H}_2 \]

\[ \text{CH}_3\text{CHCH}_3 \rightarrow \text{C}_7\text{H}_{16} + \text{H}_2 \]
Delayed Coking

- Process heavy residuum to produce distillates (naphtha & gas oils) that may be catalytically upgraded
  - Hydrotreating, catalytic cracking, and/or hydrocracking
- Attractive for heavy residuum not suitable for catalytic processes
  - Large concentrations of resins, asphaltenes, & heteroatom compounds (sulfur, nitrogen, oxygen, metals)
- Metals, sulfur, & other catalyst poisons generally end up in coke
  - Sold for fuel & other purposes
- Carbon rejection process