Oil and Natural Gas

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Global oil consumption fills the University of Michigan stadium every 40 minutes.

107,000 people
• Oil and natural gas are made of a mixture of different hydrocarbons.

• As the name suggests these are large molecules made up of hydrogen atoms attached to a backbone of carbon.
Distillation (‘cracking’)

Small Molecules
- Low boiling point
- Light in colour
- Easy to light
- Runny

Refinery Gas 20°C
Bottled Gas

Petrol 70°C
Petrol for Vehicles

Naphtha 120°C
Chemicals

Kerosine 170°C
Jet fuel, Paraffin for lighting and heating

Diesel 270°C
Diesel fuels

Crude Oil
Lubricating Oil
Lubricating Oils, Waxes, Polishes

Heater
Fuel Oil
Fuel for Ships, Factories and Central Heating

Bitumen 340°C
Roaes and Roofing

Fractioning Column
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~75% used for planes, trains, cars, ships

<table>
<thead>
<tr>
<th>Product</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finished Motor Gasoline</td>
<td>51.4%</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
<td>15.3%</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>12.3%</td>
</tr>
<tr>
<td>Still Gas</td>
<td>5.4%</td>
</tr>
<tr>
<td>Marketable Coke</td>
<td>5.0%</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
<td>3.3%</td>
</tr>
<tr>
<td>Liquefied Refinery Gas</td>
<td>2.8%</td>
</tr>
<tr>
<td>Asphalt and Road Oil</td>
<td>1.7%</td>
</tr>
<tr>
<td>Other Refined Products</td>
<td>1.5%</td>
</tr>
<tr>
<td>Lubricants</td>
<td>0.9%</td>
</tr>
</tbody>
</table>
Gasoline is a mixture of various hydrocarbons (e.g., octane) and additives.

\[
C_8H_{18} + 12.5 \text{O}_8 \Rightarrow 8 \text{CO}_2 + 9 \text{H}_2\text{O} + \text{ENERGY}
\]

- What the engine needs
- Isooctane
- Oxygen
- Products of combustion
- Carbon dioxide
- Water

\[
C_8H_{18} + 12.5 \text{O}_8 \Rightarrow 8 \text{CO}_2 + 9 \text{H}_2\text{O} + \text{ENERGY}
\]
Used to synthesize ammonia, the primary fertilizer that delivers nitrogen to crops.
simple hydrocarbons (natural gas, gasoline) burn easily, can be stored and transported efficiently, and generate energy

**Energy density**

<table>
<thead>
<tr>
<th>Material</th>
<th>Energy Density (MJ/kg)</th>
<th>Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>wood</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>coal</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td>heating oil</td>
<td>38</td>
<td>10</td>
</tr>
<tr>
<td>gasoline</td>
<td>45</td>
<td>12</td>
</tr>
<tr>
<td>methane</td>
<td>55</td>
<td>15</td>
</tr>
</tbody>
</table>
Global Sedimentary Basins

onshore basins; offshore basins

think ‘rivers’, shallow seas/oceans
Ancient Earth

- During mid-Mesozoic times around 150 million years ago, conditions were just right to build up huge thicknesses of Black Shale.

The world’s main oil deposits all formed in warm shallow seas where plankton bloomed but bottom waters were deoxygenated.
Oil and natural gas start life as microscopic plants and animals that live in the ocean.
Today, most plankton can be found where deep ocean currents rise to the surface.

This upwelling water is rich in nutrients and causes the plankton to bloom.

Blooms of certain plankton called dinoflagellates may give the water a red tinge.

Dinoflagellate bloom
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas
Contents of a Stream Bed

- **Dissolved load**
- **Rolling**
- **Sliding**
- **Silt and clay suspended by turbulence**
- **Sand moving by saltation**

**Flow**

**Suspended load**
- Silt and clay
- Sand

**Bed load**
- Gravel

**Rock**
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas.
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas
The **Kimmeridge Clay** is a Black Shale with up to 50% organic matter. It is the main source rock for the North Sea Oil & Gas Province.
As Black Shale is buried, it is heated.

Organic matter is first changed by the increase in temperature into kerogen, which is a solid form of hydrocarbon.

Around 90°C, it is changed into a liquid state, which we call oil.

Around 150°C, it is changed into a gas.

A rock that has produced oil and gas in this way is known as a Source Rock.
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen $\rightarrow$ oil, gas
• Hot oil and gas are less dense than the source rock in which they occur.

• Oil and gas migrate upwards up through the rock in much the same way that the air bubbles of an underwater diver rise to the surface.
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas

Source Rock = BURIED ORGANIC SHALE
~10% Total Organic Carbon (TOC)
Formation of an oil and natural gas “trap”
A magnified image of a sandstone. The rock sample was injected with blue-colored epoxy that is seen here filling pores which are interconnected (permeable). The sample is exceedingly porous and permeable. The grains are loosely packed and there is very little cement filling the space between the grains. The arrow indicates possible pathways for fluid movement.

http://www.kgs.ku.edu/Publications/Oil/primer03.html
Formation of an oil and natural gas “trap”
CONVENTIONAL RESERVOIRS
Jelly Donut

Conventional Drilling

Illustration © James Scherrer 2014
conventional oil/gas reservoir

A pump extracts oil from a hole (oil well) drilled into the reserve.

Oil and gas accumulate to form a reserve in the trap. Hydrocarbons fill pore space in the reservoir rock.

Oil rises to float above groundwater. Gas floats above the oil.
Primary Oil Recovery

Uses natural pressure of the reservoir to push crude oil to the surface

Allows about 5% to 10% of the oil in the reservoir to be extracted
Secondary Oil Recovery

So after primary and secondary, ~50% oil remains in the ground

Injects water to drive the residual crude oil and gas remaining after the primary oil recovery phase to the surface wells

Allows additional 25% to 30% of the oil in the reservoir to be extracted

So after primary and secondary, ~50% oil remains in the ground
Tertiary “enhanced” Oil Recovery

Heat increases oil temperature;
Viscosity decreases;
Easier to pump out.

Liquid CO$_2$ forces oil out of tight pore spaces;

Tertiary recovery (average) about 25 %
Drill Conventionally

Jelly Donut

Conventional Drilling
Basic Vertical Penetration
Limited Formation Contact

East TX Field, WW II, 24 “big inch” pipe to City of Brotherly Love, and “thieves” 1930s, single wells > 20,000 b/day

Illustration © James Scherrer 2014
UNCONVENTIONAL RESERVOIR

How could one extract oil from these isolated pores filled with oil, gas and water?
A Pennsylvania historical marker near Titusville notes the 1865 demonstration of the invention by Union Col. E.A.L. Roberts.

Pouring nitroglycerin was risky enough in the late 19th century oil patch. Doing it for an illegal well “shooting” led to the term “moonlighting.”

patents for “Improvement in Exploding Torpedoes in Artesian Wells” on April 25, 1865…production from some wells increased 1,200 percent within a week of being shot – and the Roberts Petroleum Torpedo Company flourished…$100 to $200 per torpedo and a royalty of one-fifteenth of the increased flow of oil.
UNCONVENTIONAL RESERVOIRS REQUIRE “ENHANCED PERMEABILITY” FRACKING

Fracking engineered and used starting in the 1860’s to enhance permeability of vertical wells
What is Hydraulic Fracturing?
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.
Drill Conventionally

Jelly Donut

Conventional Drilling
Basic Vertical Penetration
Limited Formation Contact

Drill Unconventionally

Tiramisu

Unconventional Drilling
More Sophisticated Horizontal Penetration
Extensive Formation Contact

Illustration © James Scherrer 2014
The Geology of Conventional and Unconventional Oil and Gas

- Conventional Non-associated Gas
- Unconventional Oil or Gas Well
- Coalbed Methane
- Conventional Associated Gas
- Seal
- Sandstone
- Tight Sand Gas
- Oil and Gas-rich Shale

Lateral Wellbore with Multi-stage Hydraulic Fractures

Source: EIA
THEN

East TX Field, WW II, 24 “big inch” pipe to City of Brotherly Love, and “thieves” 1930s, single wells > 20,000 b/day

NOW
SEISMIC EXPLORATION
SEISMIC EXPLORATION

A ship is shown at the surface of the sea, with a cable extending down into the water. The cable is equipped with sound sensors and is positioned 20 - 40 feet deep. A seismic source, labeled as Airguns, is shown releasing sound waves. These sound waves travel through the water, reflected by different layers beneath the sea bed. The reflected sound waves are detected by the sensors on the cable, allowing for the creation of an image of the subsurface layers. These layers are referred to as Sedimentary Layers.
Figure 8. Seismic line L5034A and depth projection of well W-6. Seismic reflectors of sequence A appear to be in angular unconformity beneath SB2, and are cut by a strong acoustic reflector interpreted as a top-to-the-northwest detachment fault. This detachment is SB1 and juxtaposes the sedimentary sequence and crystalline basement. Note that sequences B and C flatten upwards.
Oil and natural gas are not sustainable because we consume them at a much faster rate than nature produces them.
Recoverable Reserves (billions bbl) and Number of Giant Oil Fields

**Recovered Reserves**

**Number of Giant Fields Discovered**
USA = 2.5 gallons of oil per person per day
World oil production significantly outpaced consumption in 2014, rising by 2.1 million b/d; all of the growth was in non-OPEC countries, which recorded a record increase. US output grew by 1.6 million b/d, its largest increase on record. OPEC production was essentially flat, with declines among African OPEC producers offset by rising Middle East output. Global consumption increased by 840,000 b/d, with emerging economies accounting for all of the growth; China saw a below-average increase but still accounted for the largest increment to consumption.
Total world proved oil reserves reached 1700.1 billion barrels at the end of 2014, sufficient to meet 52.5 years of global production. The largest addition to reserves came from Saudi Arabia, adding 1.1 billion barrels. The largest decline came from Russia, where reserves fell by 1.9 billion barrels. OPEC countries continue to hold the majority of the world’s reserves, accounting for 71.6% of the global total. South & Central America continues to hold the highest R/P ratio, more than 100 years. Over the past decade, global proved reserves have increased by 24%, or more than 330 billion barrels.