PETROLEUM: Principal source of world's energy

33% of total energy use
90 Mbbbl/day, worth ~ $2 T/y (2017)

Most important commodity of international trade

Expensive energy: today’s price $55/bbl => $9/MBTU
cf. Coal ~ $1 to $3/MBTU
cf. Gas ~ $3/MBTU

Raw material for petrochemical industry
Plastics
Pharmaceuticals
Solvents
Resins
Paints
Lubricants
Feed
History of Use

Ancient Uses:
Middle East (Babylonia, etc.)
   Asphalt used for glue, mortar (e.g., Tower of Babel); Illumination, boats
   Egyptians: mummies, antiseptics
   Greek Fire: forerunner of flame-thrower, incendiary bombs, Napalm
   Oil production from hand dug pits & springs ever since

1000 AD    Arabs discovered distillation; made kerosene/ technology lost

1852       Abraham Gesner (Canadian geologist) rediscovered kerosene
   by distillation of oil & coal

1859       Edwin L. Drake     69' deep oil well, Titusville PA
   Steam operated drill   10-35 bbl/day

1865       1st pipeline   8 km

1874       97 km pipeline from oil fields to Pittsburgh
   Internal Combustion Engine:
   Nikolaus Otto (1862 ff) Karl Benz (1879) Rudolf Diesel (1900)

1901       Gulf Coast- Spindletop gusher   100,000 bbl/day

1859-1970  USA major world producer
2013-2017  ditto: also Russia & Saudi Artabia
Drake Oil Well, 1861

http://www.drakewell.org/librphoto.htm
Composition of Oil

Complex mixture of 100's of different liquid hydrocarbons

Mostly:
- Alkanes (paraffins; $C_nH_{2n+2}$)
- Cycloalkanes ($C_nH_{2n}$; saturated rings) Cyclopentane; Cyclohexane $C_6H_{12}$
- Aromates (e.g., benzene $C_6H_6$; unsaturated)
- Complex HC's

Typical Petroleum

<table>
<thead>
<tr>
<th></th>
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<th>Gas</th>
</tr>
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<tbody>
<tr>
<td>H</td>
<td>11.7 - 14.7</td>
<td>1-25</td>
</tr>
<tr>
<td>C</td>
<td>82.2 - 87.0</td>
<td>65-80</td>
</tr>
<tr>
<td>N</td>
<td>0.1- 1.5</td>
<td>1-15</td>
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<tr>
<td>O</td>
<td>0.1- 4.5</td>
<td>--</td>
</tr>
<tr>
<td>S</td>
<td>0.1- 5.5 (to &gt;10)</td>
<td>trace - 0.2</td>
</tr>
</tbody>
</table>

oil refining produces 55% of USA sulfur needs

Also, some porphyrins $=>$ chelated V, Fe, Ni, Cu...
Oil Consumption 2013

USA 19.0 Mbbl/d
China 10.3
Japan 4.5
India 3.5
Russia 3.5
Saudi Arabia 3.0
Brazil 3.0
Canada 2.4
Germany 2.3
S Korea 2.3

204 countries <0.5

http://www.eia.doe.gov
USA 2013
12.3 produced + 6.7 imported = 19 Mbbl/d consumed
World’s leading producer in 2013
Proved Oil Reserves  2013

<table>
<thead>
<tr>
<th>Country</th>
<th>Proved Oil Reserves (Bbl)</th>
</tr>
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<tbody>
<tr>
<td>Saudi Arabia</td>
<td>298</td>
</tr>
<tr>
<td>Venezuela</td>
<td>268</td>
</tr>
<tr>
<td>Canada</td>
<td>173</td>
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<tr>
<td>Iran</td>
<td>155</td>
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<td>Nigeria</td>
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<td>USA</td>
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<td>Kazakhstan</td>
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<td>Qatar</td>
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<tr>
<td>China</td>
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</tr>
<tr>
<td>Brazil</td>
<td>13</td>
</tr>
<tr>
<td>Algeria</td>
<td>12</td>
</tr>
<tr>
<td>Mexico</td>
<td>10</td>
</tr>
</tbody>
</table>

117 countries 0

http://www.eia.doe.gov/eia
Proven Oil Reserves 2016
1650 billion bbl

Venezuela
Saudi Arabia
Iran
Iraq
Kuwait
UAE
Other OPEC
Canada
Russia
United States
Kazakhstan
China
Brazil
Mexico
Norway
Other

OPEC Total
>73%
Distribution & Reserves (Table 5.6, p. 146)

Found on all continents, but very irregular distribution

Southern hemisphere has low share

Middle East very rich (65%)

>50% of reserves occurs in Middle East Megaprovine (626 billion bbl)

19% more of reserves occurs in 6 other Superprovinces (28-49 billion bbl ea.)

20% more of reserves occurs in 18 other Giant provinces (8-22 billion bbl ea.)

=> 6% of the explored sedimentary basins contain 90% of oil reserves

OPEC 73% (esp. Saudi Arabia + Venezuela = 34%)
Origin of Oil  
Most occurs in young sedimentary basins

Initially, organic matter is dispersed- need to form oil, then:

Source => Migration => Trap  
Oil preservation requires delicate timing

Source:

*Oil is derived from organic matter*, esp. marine phytoplankton:

i.e., Lipid rich; also proteins, carbohydrates

Evidence for organic origin

- $\delta^{13}C = -21$ to -32 PDB
- Optical activity

**Organic-rich marine shales + Heat (50 - 150°C) = OIL**

Migration:  Flushing of oil by water released during:

- Compaction (most water lost early)
- Smectite-Illite conversion (3000' to 15,000' @ Gulf Coast)

=> These processes of dewatering can cause overpressures

Trap:  Reservoirs are not underground "pools" of oil in solid rock

Reservoir rock must have high porosity ($F > 20\%$) and permeability ($k > 300$ mdarcy)

Oil floats: Lighter than water ($\pi \sim 0.86$)
Structural & Stratigraphic Traps

**Anticline**: 80% of traps this type: Classic trap (PA)
   - Gravity (buoyancy) trap
     - Porous sandstone with overlying impermeable shale

**Fault Traps**

**Salt Domes** (diapirs) find with gravity meters! Halite ($r \sim 2.17$)

**Stratigraphic traps**: sandstone lenses; unconformities; reefs...

Oil fields are mostly shallow

All "giant" fields $< 6500'$

Virtually no production $> 25,000'$
   - e.g. @ Gulf Coast most prod. @ 3000'-9000'; but wells now go to 35,000 ft.

Deeper, get only gas- oil not stable

Also, porosity and permeability decrease with depth
Figure 15.4 Types of petroleum traps. (A) A simple fold trap. (B) Petroleum accumulated in a fossilized ancient coral reef. (C) A fault trap. (D) Petroleum trapped against an impermeable salt dome, which has risen up from a buried evaporite deposit.
Elk Basin, WY
Horseheads above anticline
World Oil Reserves
after Craig et al. 2001

http://www.geo.ucalgary.ca/~macrae/timescale/timescale.html
**Production**: typically recover only **30 -35%** of oil

**Natural Drive & Pumping** (Water drive, gas expansion, vesiculation)
   => Get gusher if too much uncompensated pressure)

**Secondary recovery**: get up to **50%**
   Water & gas flooding to maintain reservoir pressure

**Tertiary Recovery**:
   Injection of water, steam, gas, or solvents & surfactants
   Hydrofracing
   Combustion of hydrocarbon @ margins of field

Oil Mining in future?
   e.g., dig drainage tunnels- very expensive!
Livermore Oil Field

“Pumpjack” or “Horsehead”
Monopod, Cook Inlet AK
32 wells
Endicott Oil Field, Prudhoe Bay
$1 B, 45 acre island; many wells
Problems:

**Blowouts**: main problem: (must use heavy muds & blowout preventers)

Early record
- Spindletop 1901- 60 m hi gusher- lost 100,000 bbl/day
- Lakeville Gusher (1910) 544 days- lost 9 million bbl

US Offshore 1964-1992
- Produced 13 billion bbl; only lost 450,000 bbl
- Santa Barbara spill, 1969 lost 77,000 bbl
- Deepwater Horizon 2010 lost ~ 5 M bbl

**Lake Peigneur** 1980 salt mine incident, LA

**Subsidence** (e.g., Long Beach, CA)

**Brines**- largest volume of liquid hazardous waste

**Gulf War** 8/90 to 2/91 Invasion of Kuwait (“19th province” of Iraq)
- >749 wells intentionally ignited,
- 2-11 x 10^6 bbl spilled
- 130 km-long oil slicks
Lakeview Gusher 1910
544 days
9 Mbbl
Old BLOWOUT
Rumsey Hills, California
SC 1

Conventional Pumping
~10 bbl H₂O/bbl oil produced
~15 bbl H₂O/MCF gas

Oil field brines
high TDS (to 400 g/l),
hi organics,
hi metals (Pb, Zn, Cd, Cu...)
Millions of wells; many abandoned

♀ 4500 cfs
= 70x other liquid hazardous waste
Kuwait, Jan 1991 > 1 B bbl burned

NOAA
Bergan oil field fire, Kuwait
Jan 1991
reflection of fire in oil pool

> 1 B bbl burned
Deepwater Horizon
April 21, 2010
11 fatalities 4.9 MBbl lost
Cost to BP by 11/2012:
$36B for cleanup + fines
+ penalties + reparations