Fuel and Energy

Fossil Fuels

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- Types of Fuels
- Petroleum and Natural Gas
- Formation
- Recovery
- Demands
- Reserves
- Quality and Rating

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Types of Fuels

- **Solid** ⟶
  Coal
  Biomass
  - wood
  - peat
  - garbage
  - manure

- **Gaseous** ⟶
  natural gas
  town gas
  syngass
  petroleum-derived
  - propane
  - butane

- **Liquid** ⟶
  alcohol
  petroleum
  hydrocarbons
  plant/algae based oils
  whale oil
  black liquor
  shale oil (kerogen)
  tar sands (bitumen)

Types of Fuels

- Coal
- Oil (Petroleum)
- Natural Gas

Formation of Fossil Fuels – common conditions

- High Organic Production
- Burial of organic material
- Reducing conditions – little or no free oxygen
- Reducing conditions preserve organic matter
- Coal and Petroleum diverge from here

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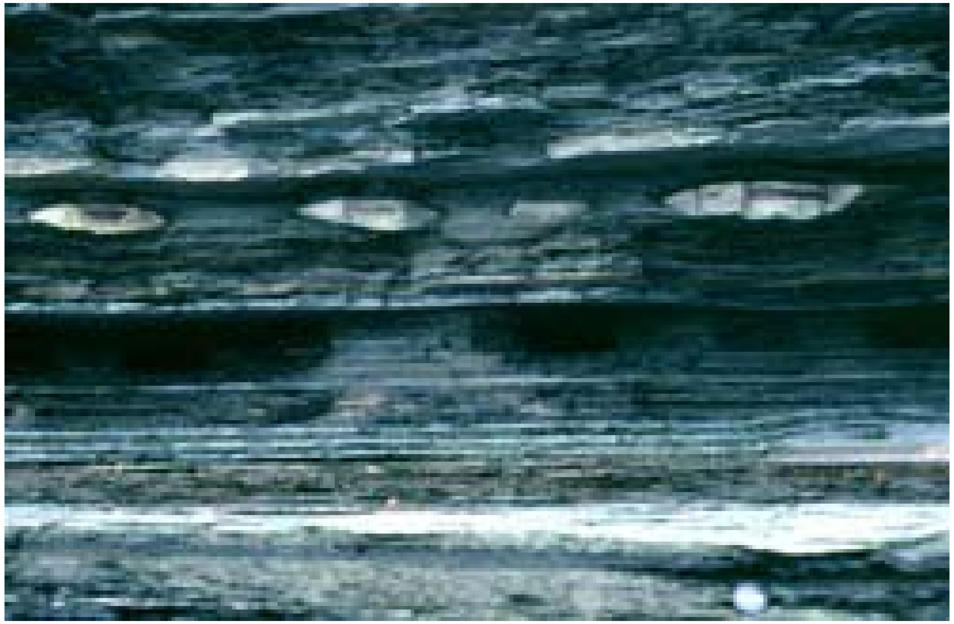
Petroleum

Crude Oil

- infinite number of hydrocarbons, C_nH_m
  - light gaseous (low-n)
  - heavy tar-like liquids & waxes (high-n), 83-87% C, 11-14% H_2
- sulfur, nitrogen, water, O_2, dirt, CO_2

Formation of Petroleum and Natural Gas

- Petroleum is called a fossil fuel because it is formed from the bodies of ancient organisms – primarily onecelled plants and animals.



Buried organic matter rich in hydrocarbons

- Accumulation of organic material – typically marine mud
- Burial and preservation of organic material – reducing conditions

- Reducing conditions in deep sea or on continental shelves during times of unusual oceanic circulation

- Only a tiny fraction (if any) of the molecules in crude oil are from dinosaurs.

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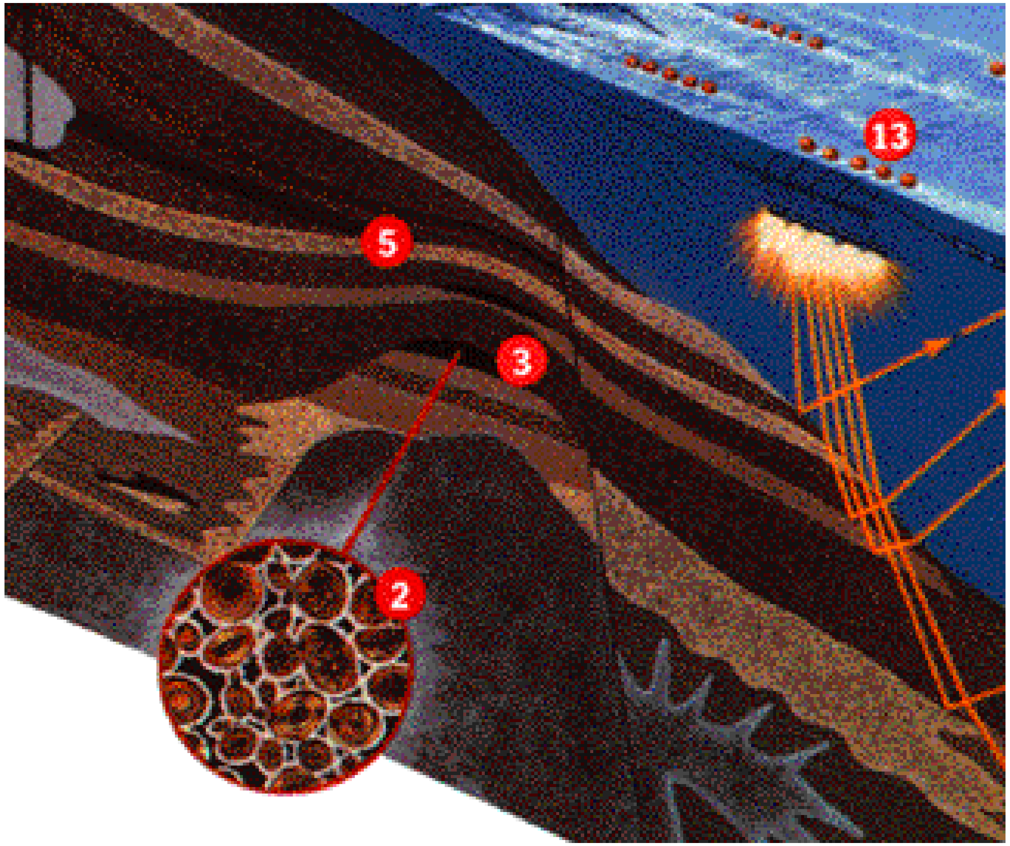
Formation of Petroleum and Natural Gas

- Black, organic-rich mud is buried deeper and converted to rock – shale
- With burial, the organic matter is heated
- When heat is sufficient (but not too great) – in the range of 100-300 degrees C – the organic matter is "cooked" and oil forms
- Process is called **thermal maturation**
- If heat is greater than 300 degrees C, the liquid petroleum is further broken down to form **natural gas**
- If heat is too great, even the natural gas is broken down to form **carbon dioxide**, which has no value as a fuel
- A combination of pressure, heat, and bacterial action transformed the deposits into sedimentary rock. The incorporated organic matter was transformed into simpler chemicals, such as hydrocarbons, water, carbon dioxide, hydrogen sulfide, and others

Migration and Concentration

- Petroleum must leave source rock
- Process is called **migration**
- **Migration** is essential because most source rocks are too fine-grained to enable easy extraction of the oil
- To be economically concentrated, petroleum must migrate to a **reservoir rock** with a **trap**

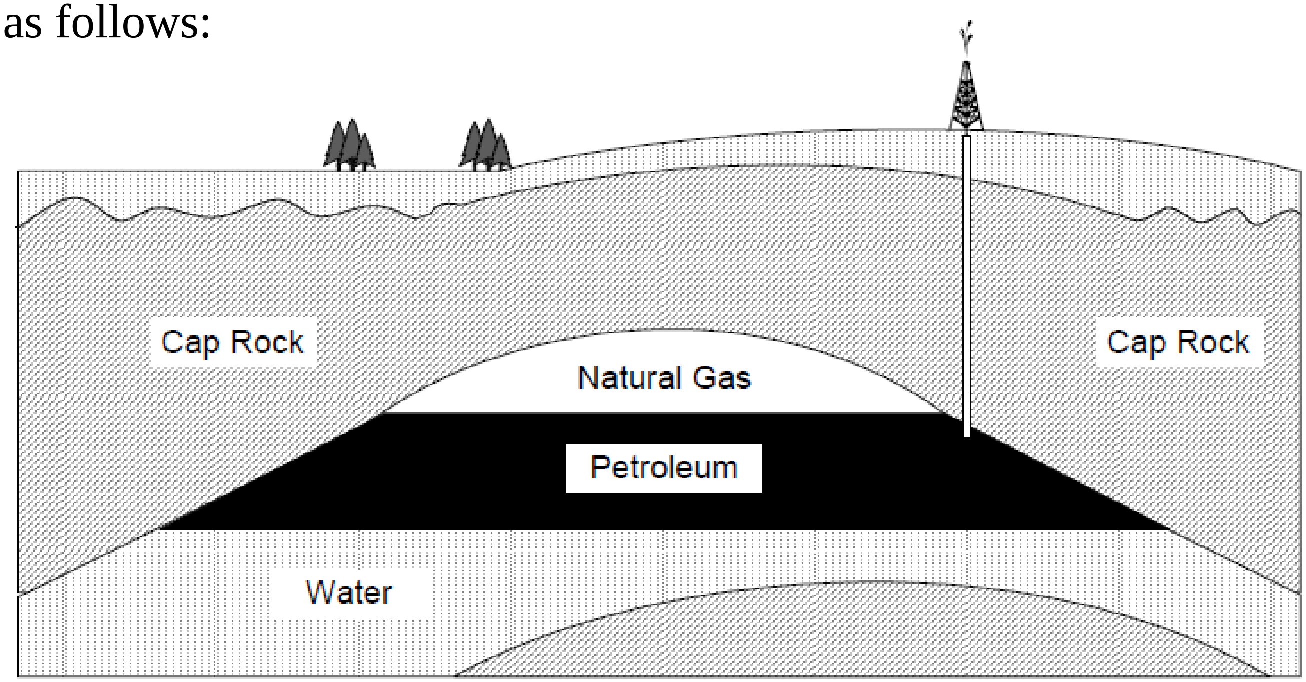


Examples of Petroleum Traps

Migration and Concentration

- If the surrounding rock was porous, liquids and gases could migrate, either up to the surface or into a reservoir that was capped by impermeable rock or a dome of salt

- Oil reservoirs can be classified on the basis of boundary type, which determines driving mechanism, and which are as follows:
  - Water-drive reservoir
  - Gas-cap drive reservoir
  - Dissolved-gas drive reservoir



Petroleum Reservoir

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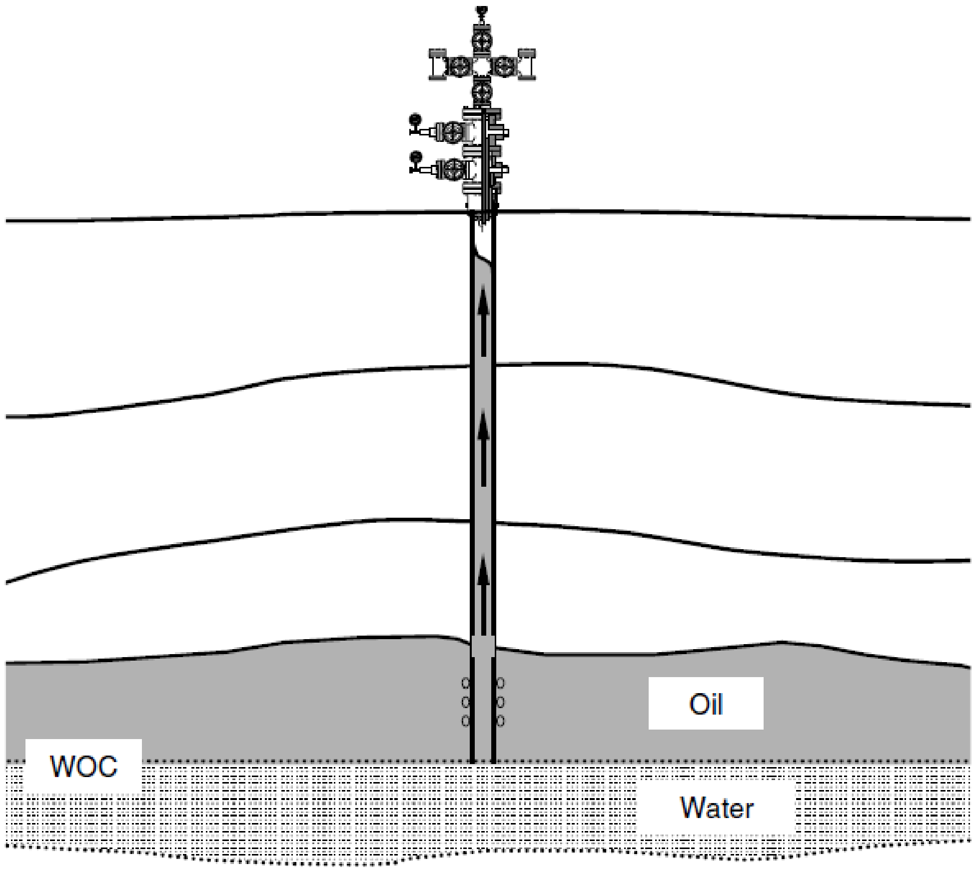
Water-Drive Reservoirs,

- The oil zone is connected by a continuous path to the surface groundwater system (aquifer).
- The pressure caused by the "column" of water to the surface forces the oil (and gas) to the top of the reservoir against the impermeable barrier that restricts the oil and gas (the trap boundary).
- This pressure will force the oil and gas toward the wellbore.
- With the same oil production, reservoir pressure will be maintained longer (relative to other mechanisms of drive) when there is an active water drive.



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Water-Drive Reservoirs,

- In bottom-water drive reservoir water is located beneath the oil accumulation, while in an Edgewater-drive reservoir, water is located only on the edges of the reservoir
- Edgewater drive reservoir is the most preferable type of reservoir compared to bottom-water drive.
- The reservoir pressure can remain at its initial value above bubble-point pressure so that single-phase liquid flow exists in the reservoir for maximum well productivity.
- A steady-state flow condition can prevail in a edge-water drive reservoir for a long time before water breakthrough into the well.
- Bottom-water drive reservoir is less preferable because of water-coning problems that can affect oil production economics due to water treatment and disposal issues.
- Oil recovery efficiency ranged between 28-84 %

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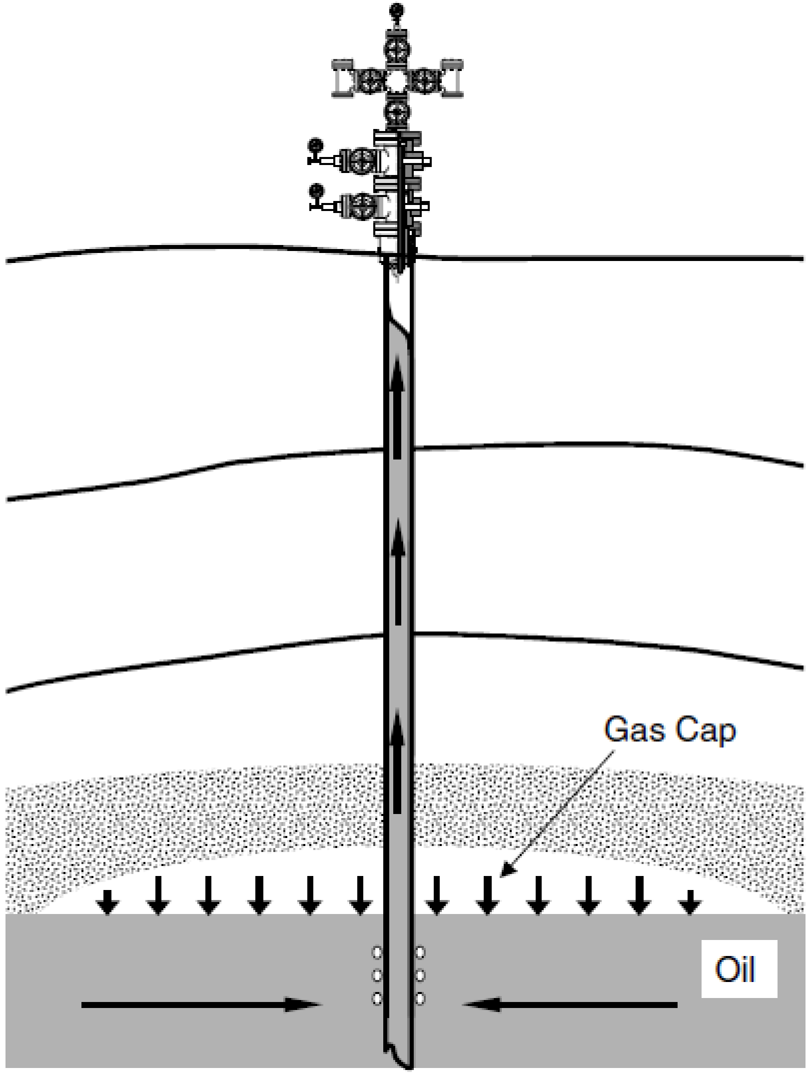
Gas-cap Drive Reservoir

- Gas-cap drive is the drive mechanism where the gas in the reservoir has come out of solution and rises to the top of the reservoir to form a gas cap.
- Thus, the oil below the gas cap can be produced.
- If the gas in the gas cap is taken out of the reservoir early in the production process, the reservoir pressure will decrease rapidly.
- Sometimes an oil reservoir is subjected to both water and gas-cap drive.



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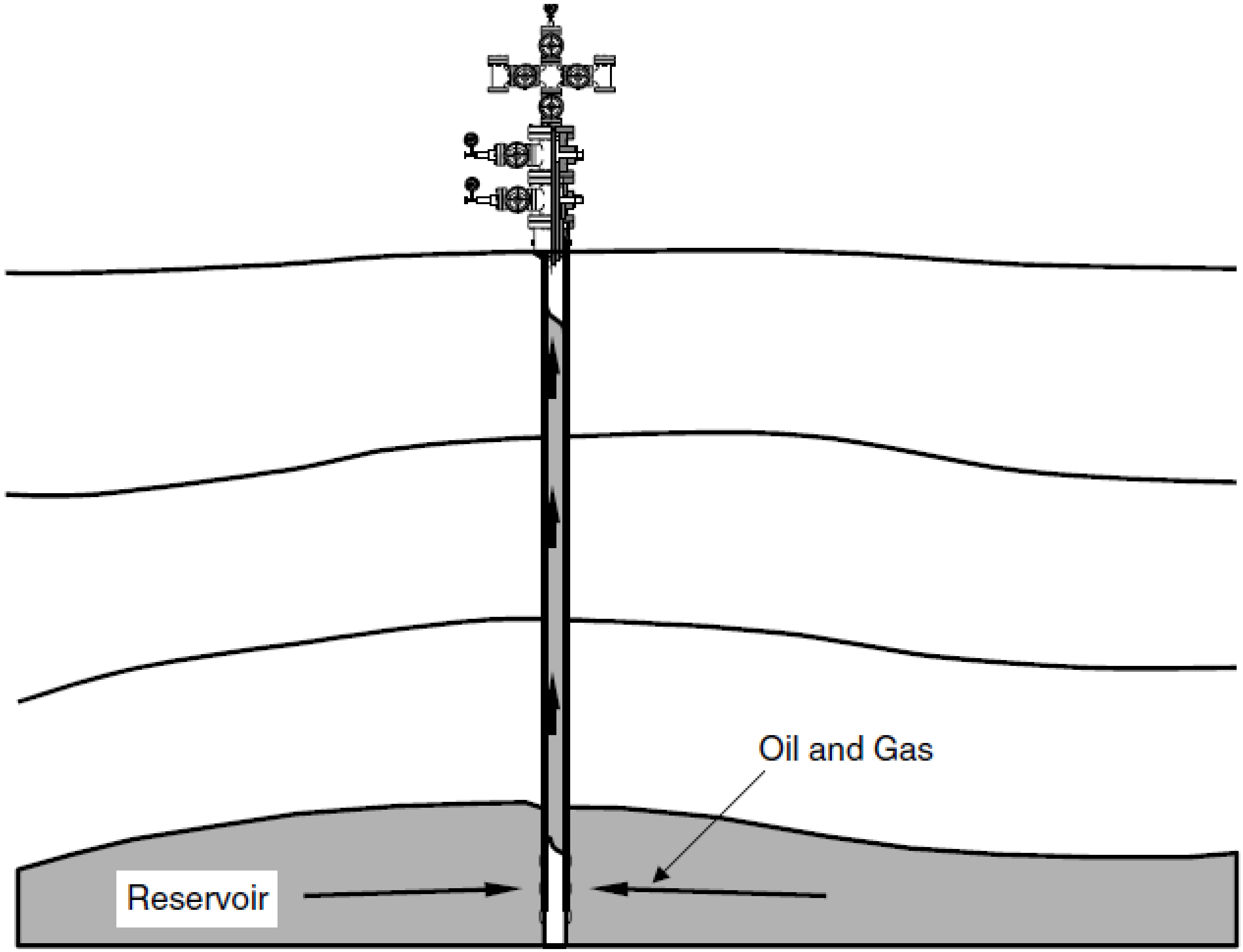
Dissolved-gas Drive Reservoir

- It is also called a "solution-gas drive reservoir" and "volumetric reservoir."
- The oil reservoir has a fixed oil volume surrounded by noflow boundaries (faults or pinch-outs).
- Natural gas dissolved in oil is a source of energy for this reservoir
- Dissolved-gas drive is the drive mechanism where the reservoir gas is held in solution in the oil (and water).
- The reservoir gas is actually in a liquid form in a dissolved solution with the liquids (at atmospheric conditions) from the reservoir.
- As oil is produced, the reservoir pressure drops.
- Once the bubble point pressure is reached, the NG dissolved in oil will come out of the solution and form bubbles which expands as the fluid pressure is reduced further.
- The bubbles will continue supporting production until they reach critical saturation when they join together and begin to flow as single continuous gas phase.

Dissolved-gas Drive Reservoir

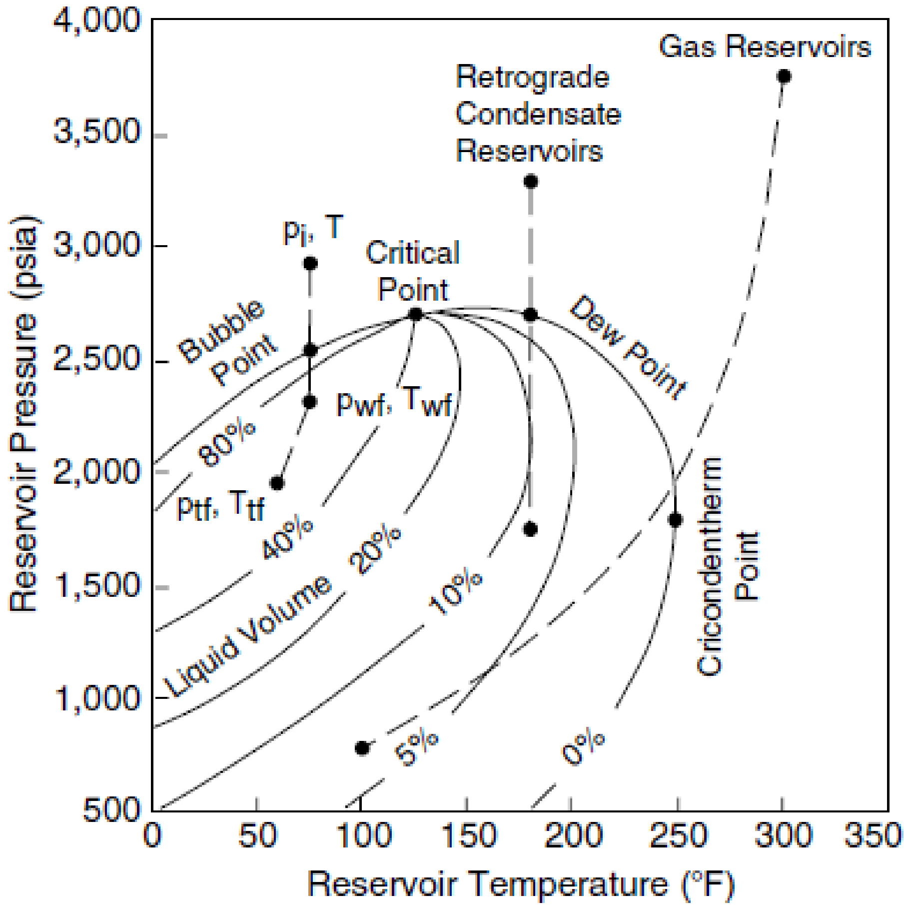
- Due to the low viscosity of the gas, it flows, much more rapidly than the oil. Hence more and more gas is produced with the crude oil.
- This causes the reservoir pressure to drop and hence the finite energy source is depleted .
- Oil recovery efficiency ranged between 12-37 %
- Reservoir managements may include:
  - Maintaining the reservoir pressure above the critical gas saturation pressure by injecting less expensive fluid
- Compared to the water- and gas-drive reservoirs, expansion of solution (dissolved) gas in the oil provides a weak driving mechanism in a volumetric reservoir.

Dissolved-gas Drive Reservoir



Hydrocarbon Accumulations

- Depending on the initial reservoir condition, hydrocarbon accumulations are classified as
  - Oil,
  - Gas condensate, and
  - Gas reservoirs.
- An oil that is at a pressure above its bubble-point pressure is called an ‘‘undersaturated oil’’ because it can dissolve more gas at the given temperature.
- An oil that is at its bubble-point pressure is called a ‘‘saturated oil’’ because it can dissolve no more gas at the given temperature.
- Single (liquid)-phase flow prevails in an undersaturated oil reservoir, whereas two-phase (liquid oil and free gas) flow exists in a saturated oil reservoir.



Petroleum Fuel Future

- The fossil fuel supply is expected to follow a bell shaped curve as developed by M. King Hubbert. The peak in the curve of yearly supply is the important point.
- World population growth is expected at 1% a year.
- Proven world oil reserves are about 2,000 billion barrels.
- Unproven reserves may boost this to 3,000-4,000 billion barrels.
- For world oil demand growing in the range between 0-2 percent a year, the year of the projected peak is shown in the next slide.
- The mean assessment of the reserves of the Artic National Wildlife Refuge (ANWR) is 6 billion barrels (if the price is greater than $25/barrel).

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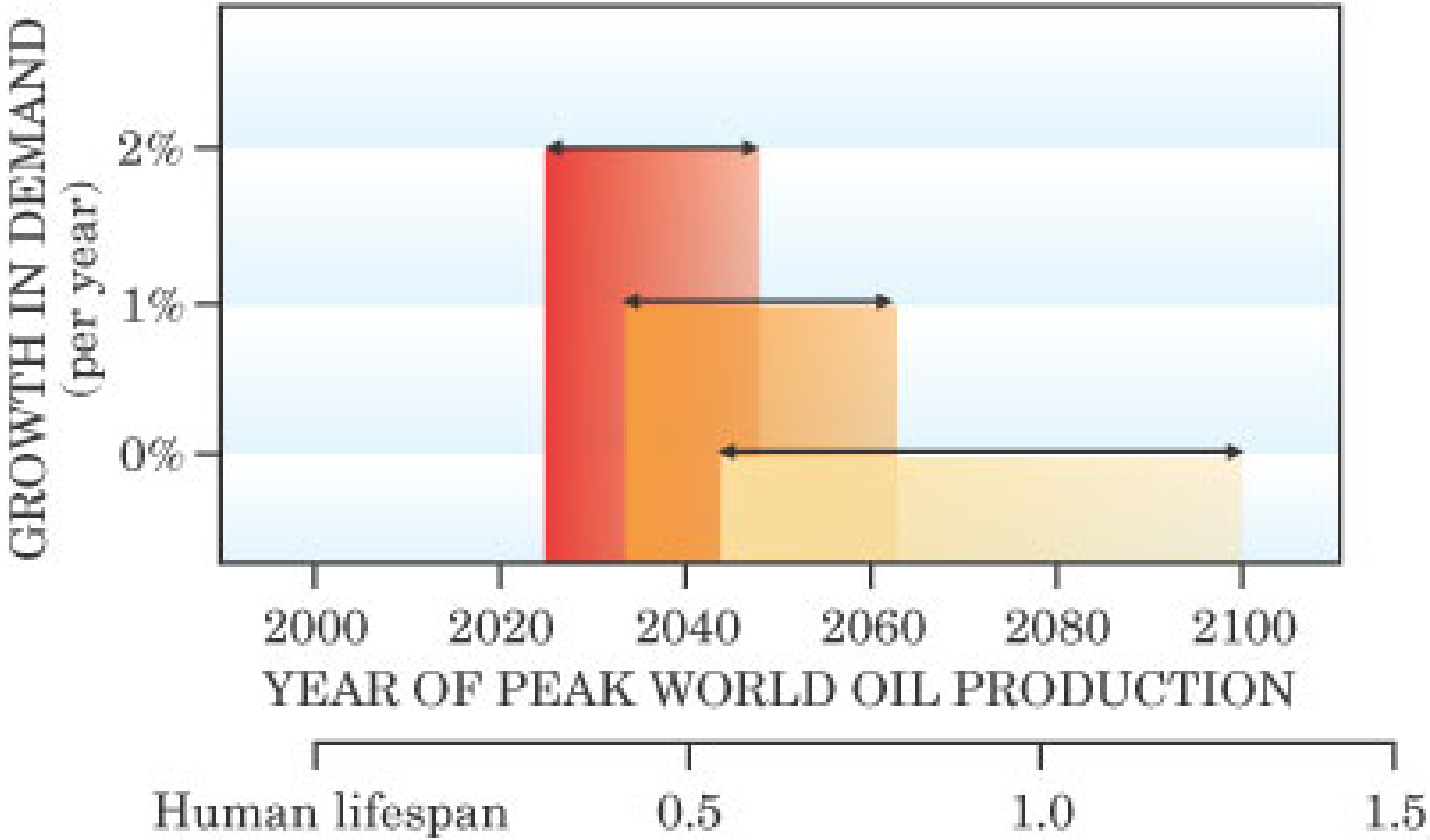
Petroleum Demands



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Some of the world's most productive sedimentary basins

- Saudi Arabia
- Kuwait
- Alaska – north slope
- Texas – Louisiana Gulf Coast
- Iraq and Iran
- Mexico
- Venezuela

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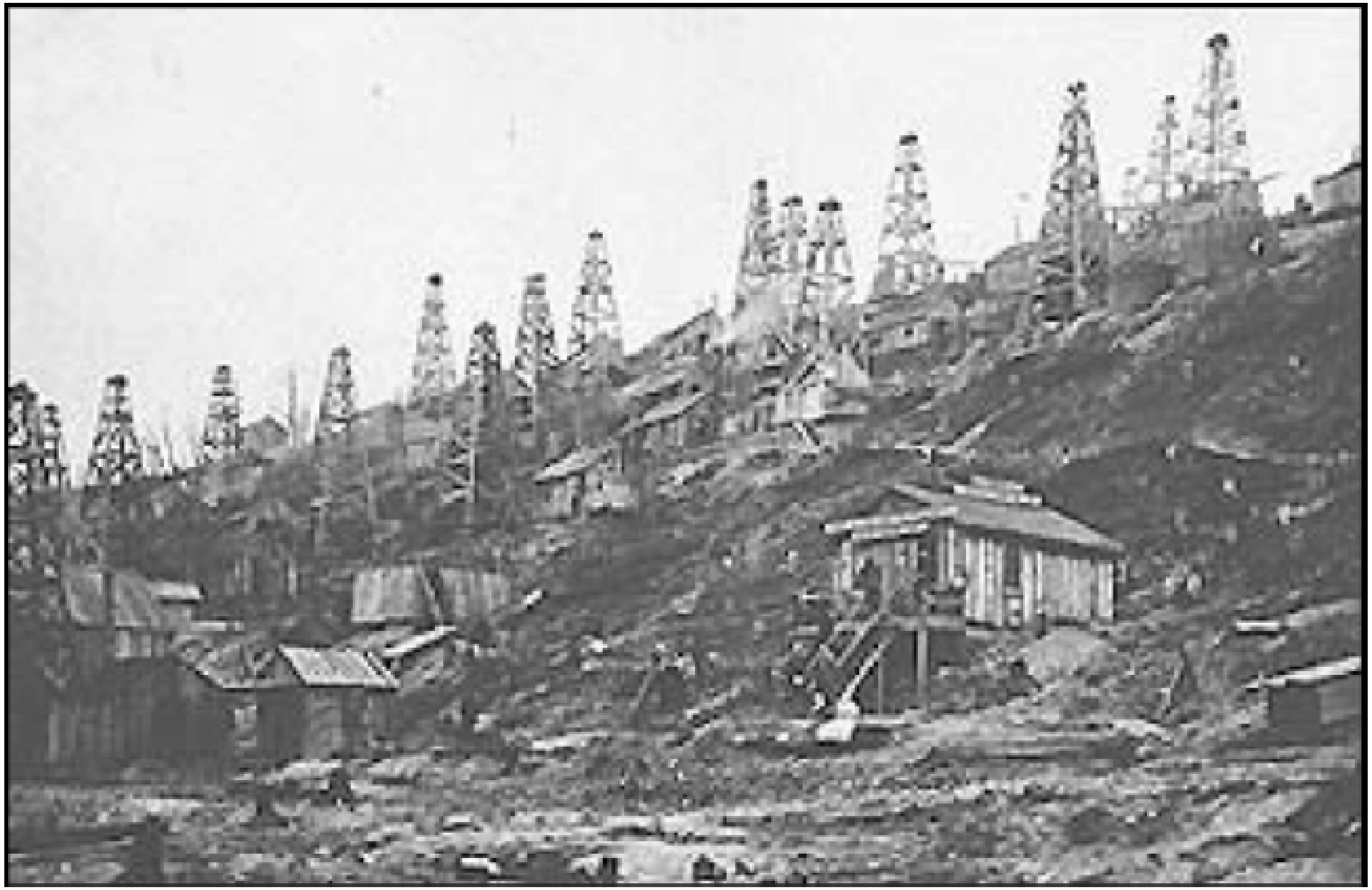
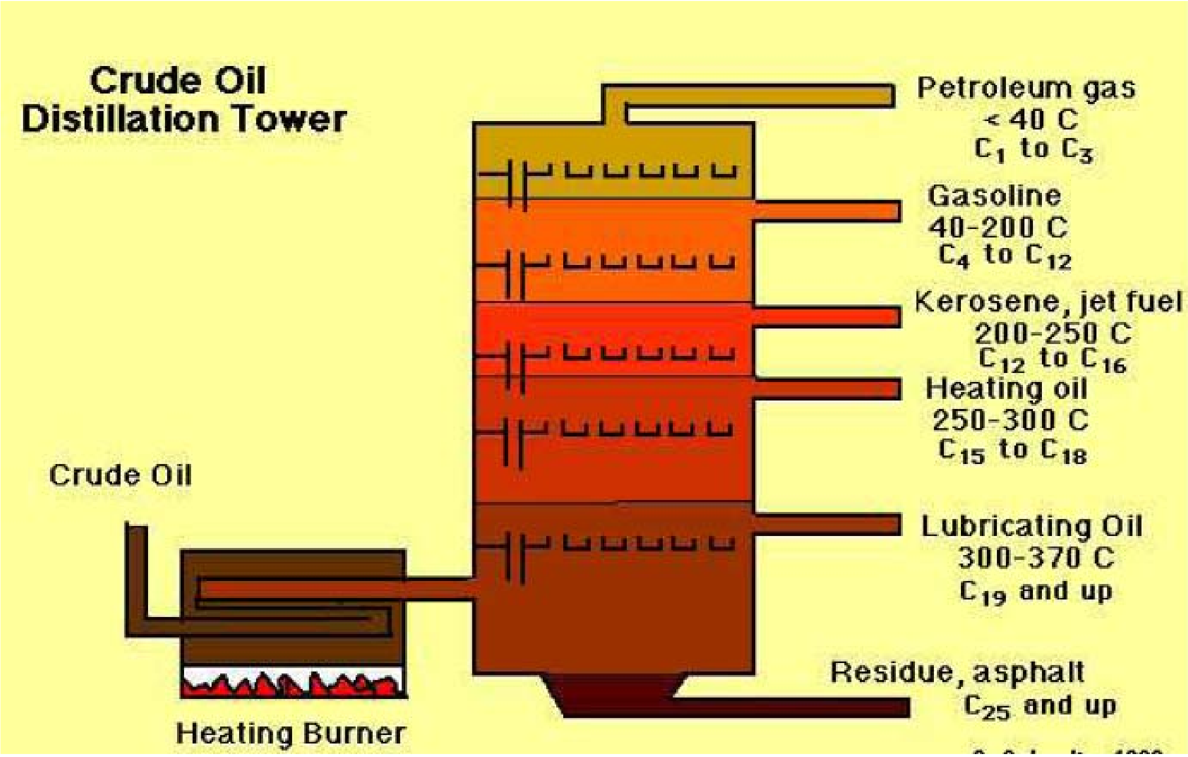
Petroleum Production



Pioneer Run oil field in 1859. Photo used with permission from the Pennsylvania Historical Collection and Musem Commission, Drake Well Museum Collection, Titusville, PA.

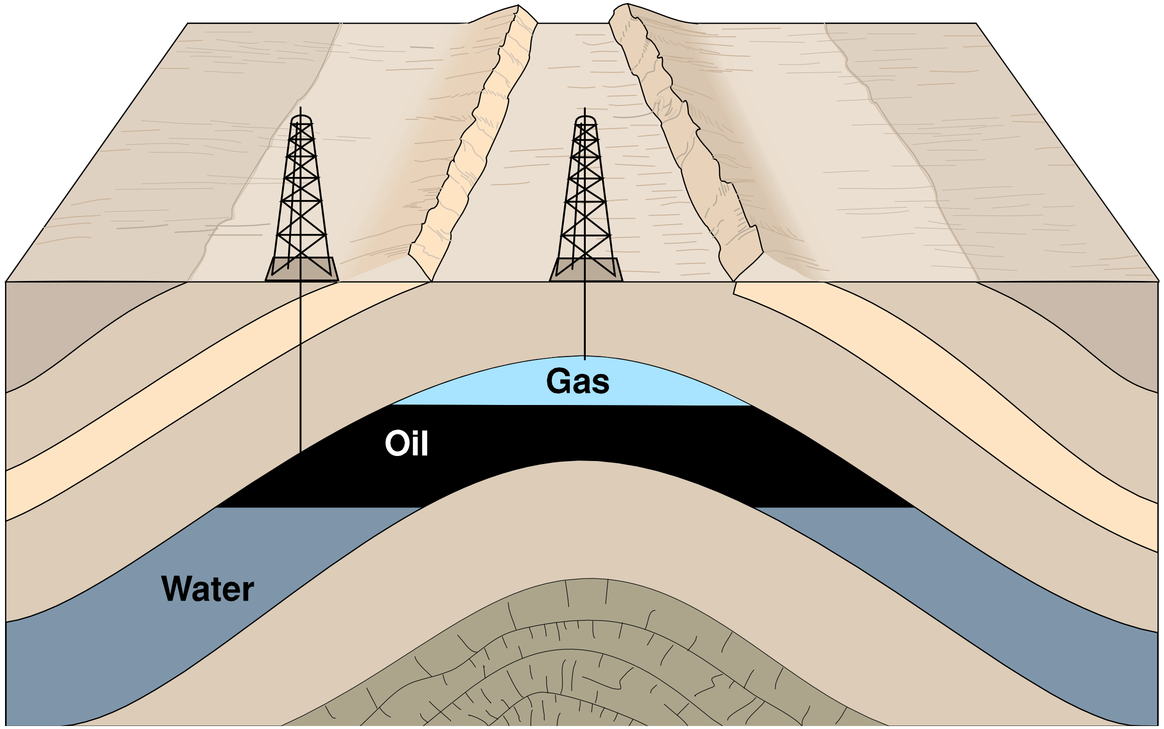
Refining of Petroleum

- Heat and/or chemical treatment to produce:
- Gasoline
- Diesel Fuel
- Kerosene
- Liquified Propane (LPG)
- Petroleum bases for plastics



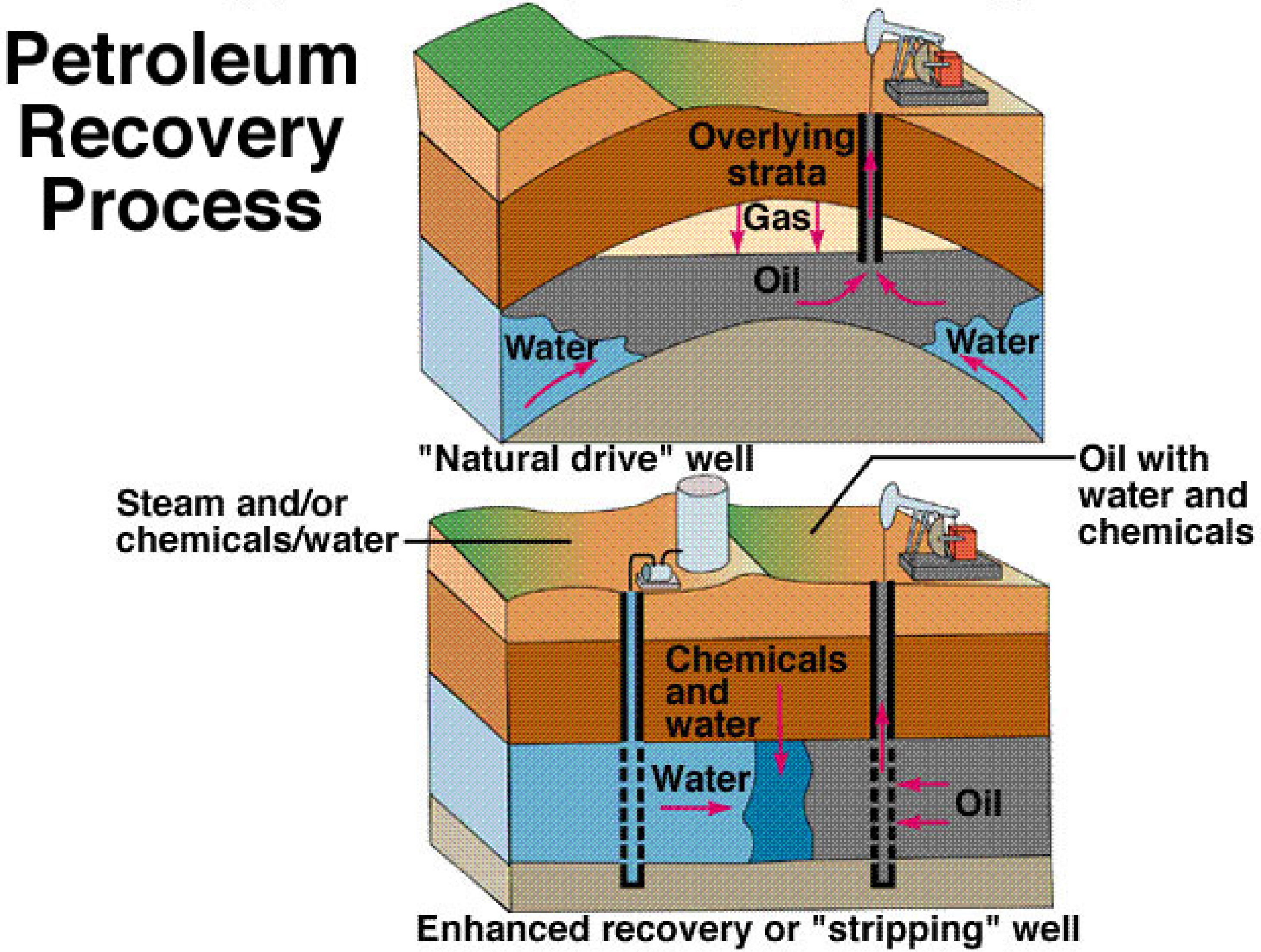
OIL and NATURAL GAS (Methane)

- Made from the decayed remains of sea creatures which died millions of years ago



- Even though it was not made from dead plants or animals, nuclear fuel is considered to be a fossil fuel because it comes from the ground and is running out.

Oil Recovery Process



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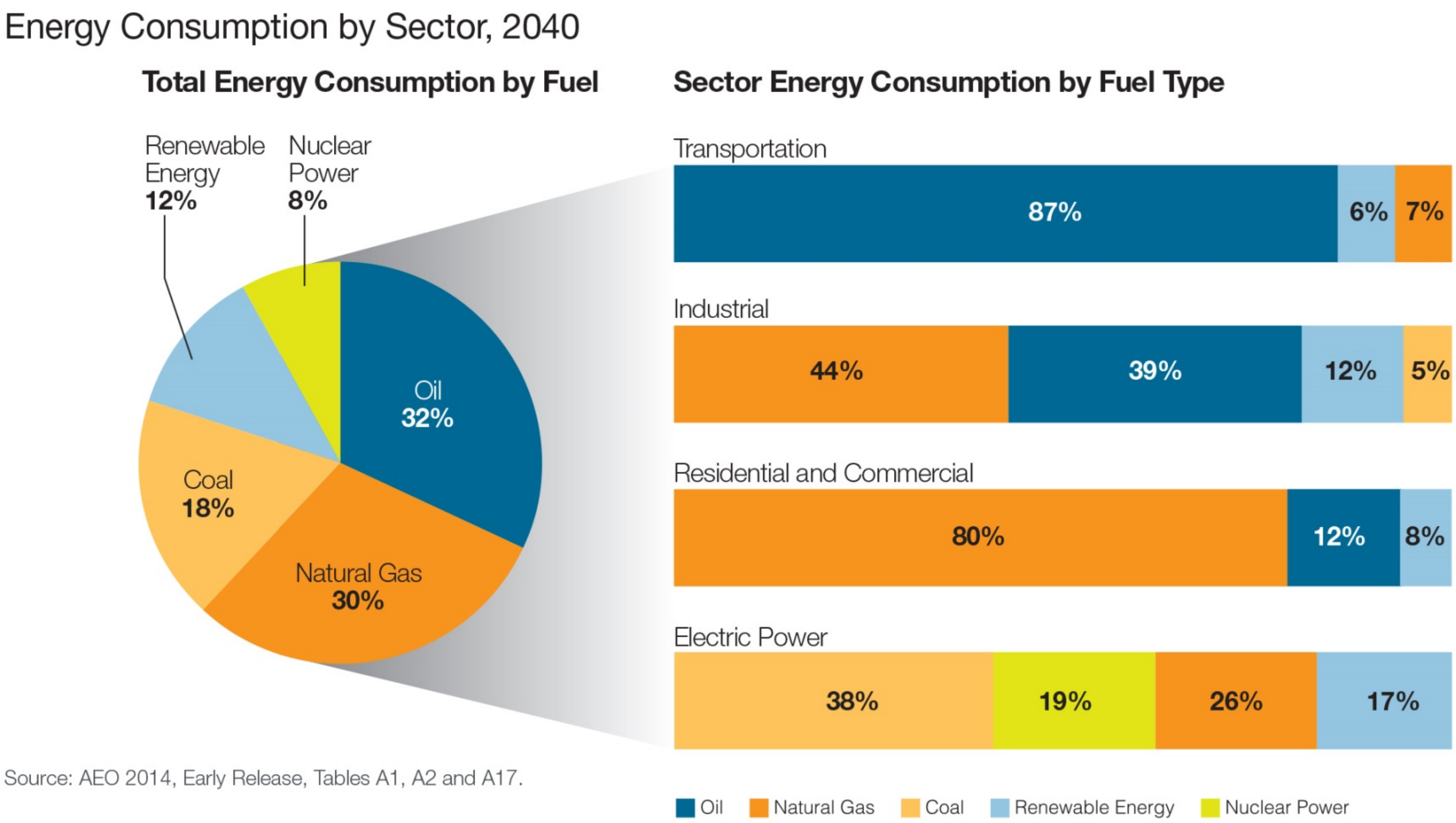
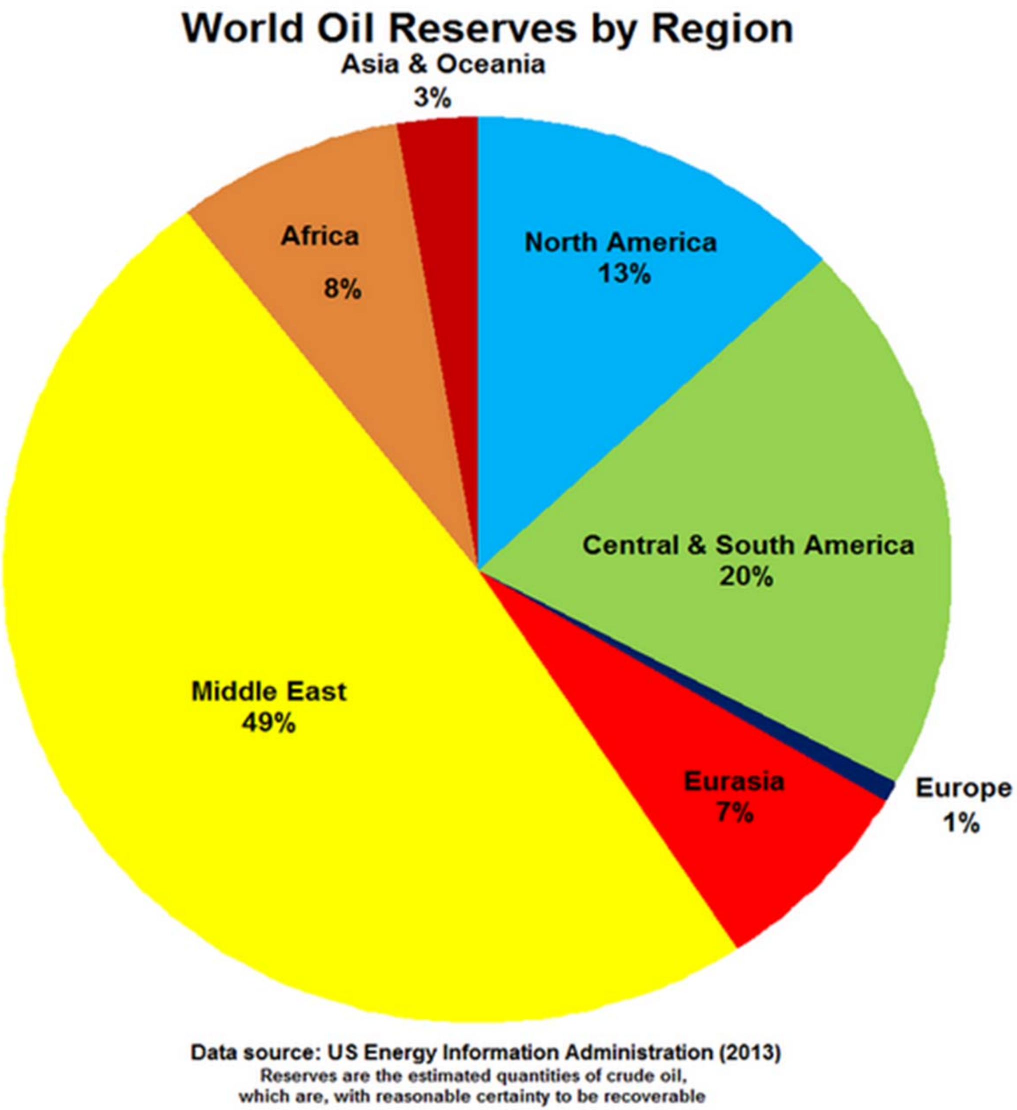
Oil Consumption by Sector



Oil Reserves



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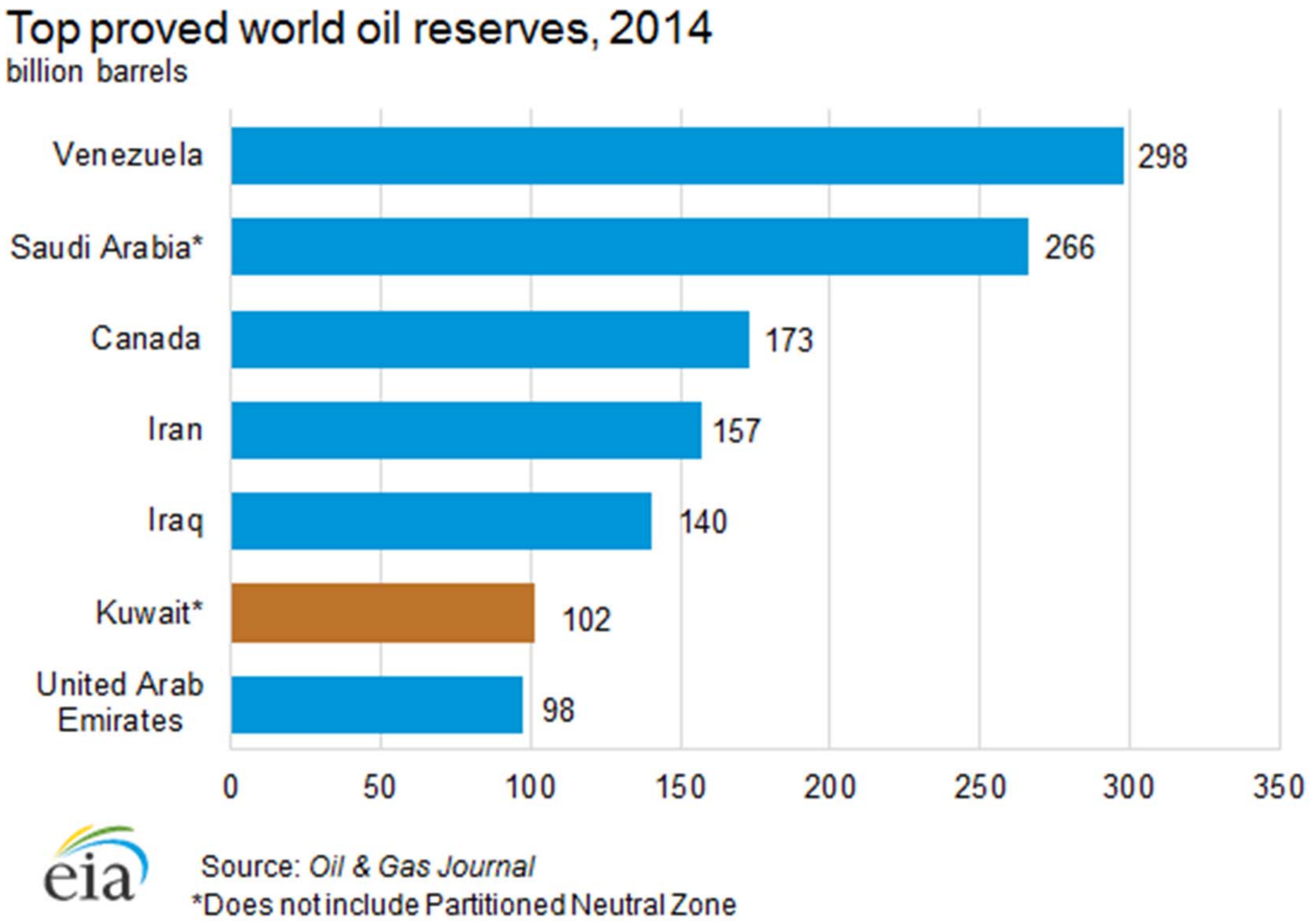
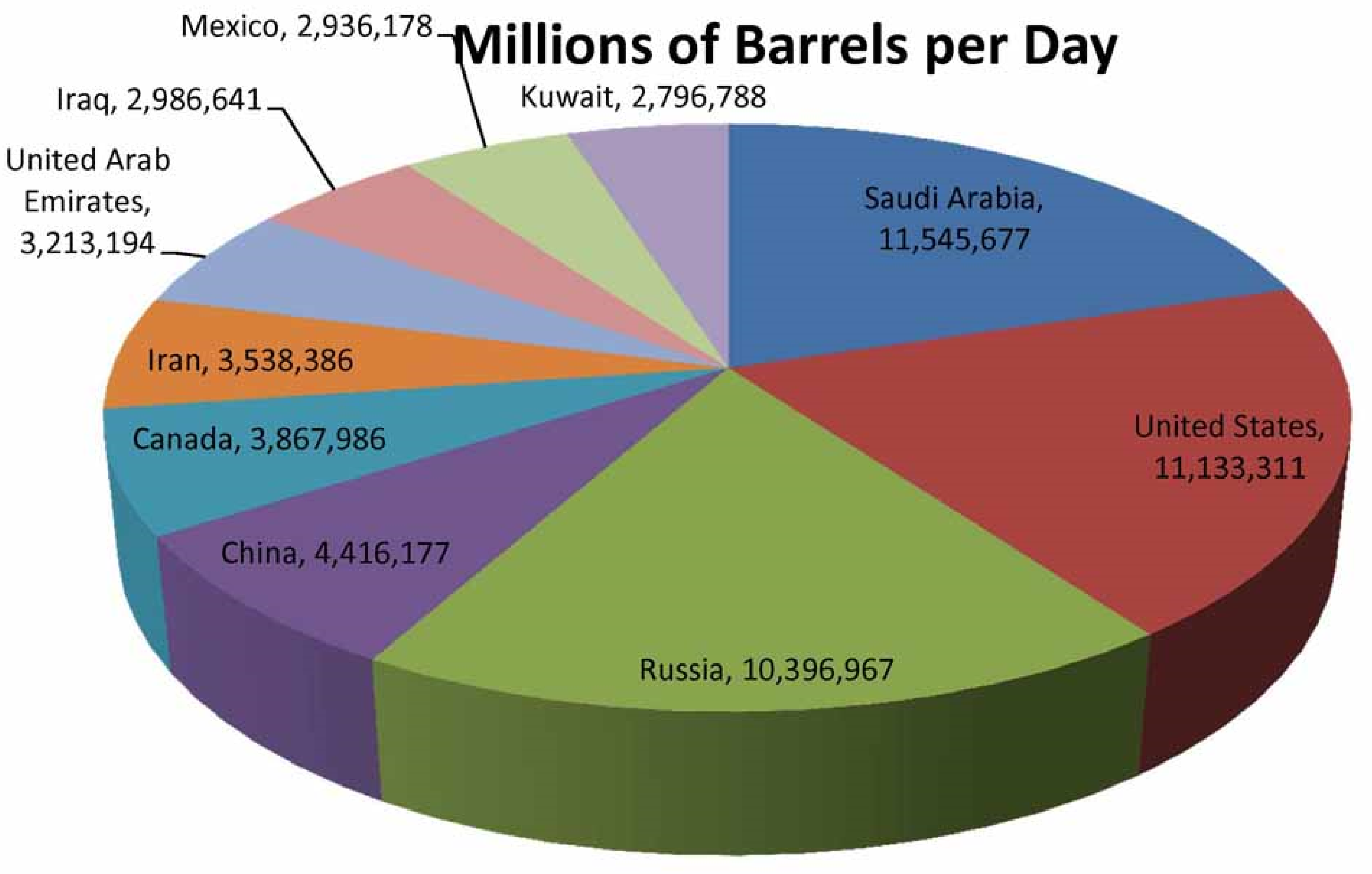
Oil Reserves



Oil Reserves



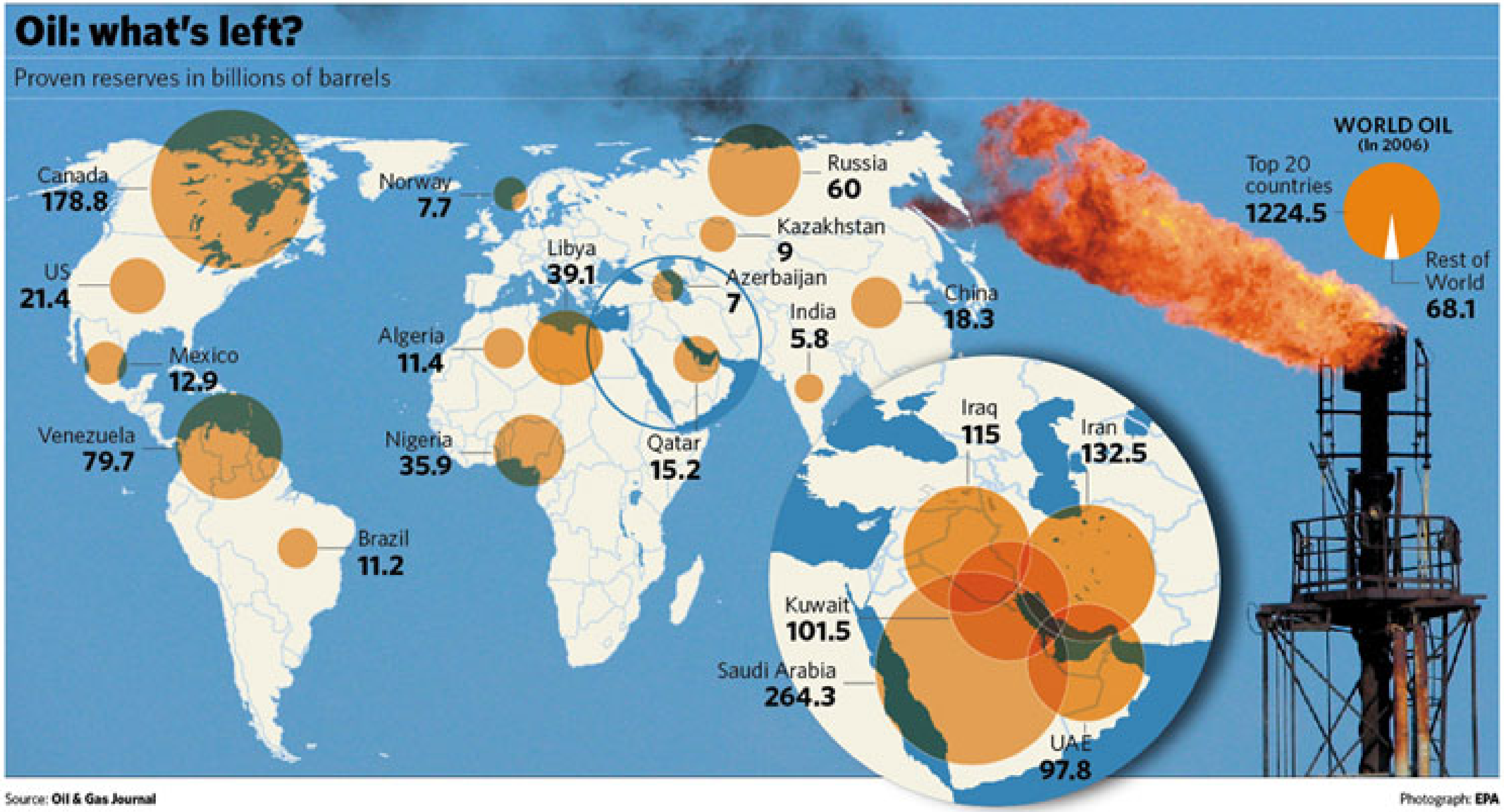
Oil Reserves

Leading Crude Oil Producers
First Quarter 2014

Rank	Country	Million Barrels per Day	Prospects
1	Russia	10.1	Decline
2	Saudi Arabia	9.8	Unstable
3	United States	8.1	Bubble
4	China	4.2	Flat; Decline?
5	Canada	3.5	Increase
6	Iraq	3.3	Unstable
7	Iran	3.3	Unstable
8	United Arab Emirates	2.8	Unstable
9	Kuwait	2.7	Unstable
10	Mexico	2.5	Decline

Based on EIA Data

Oil Reserves



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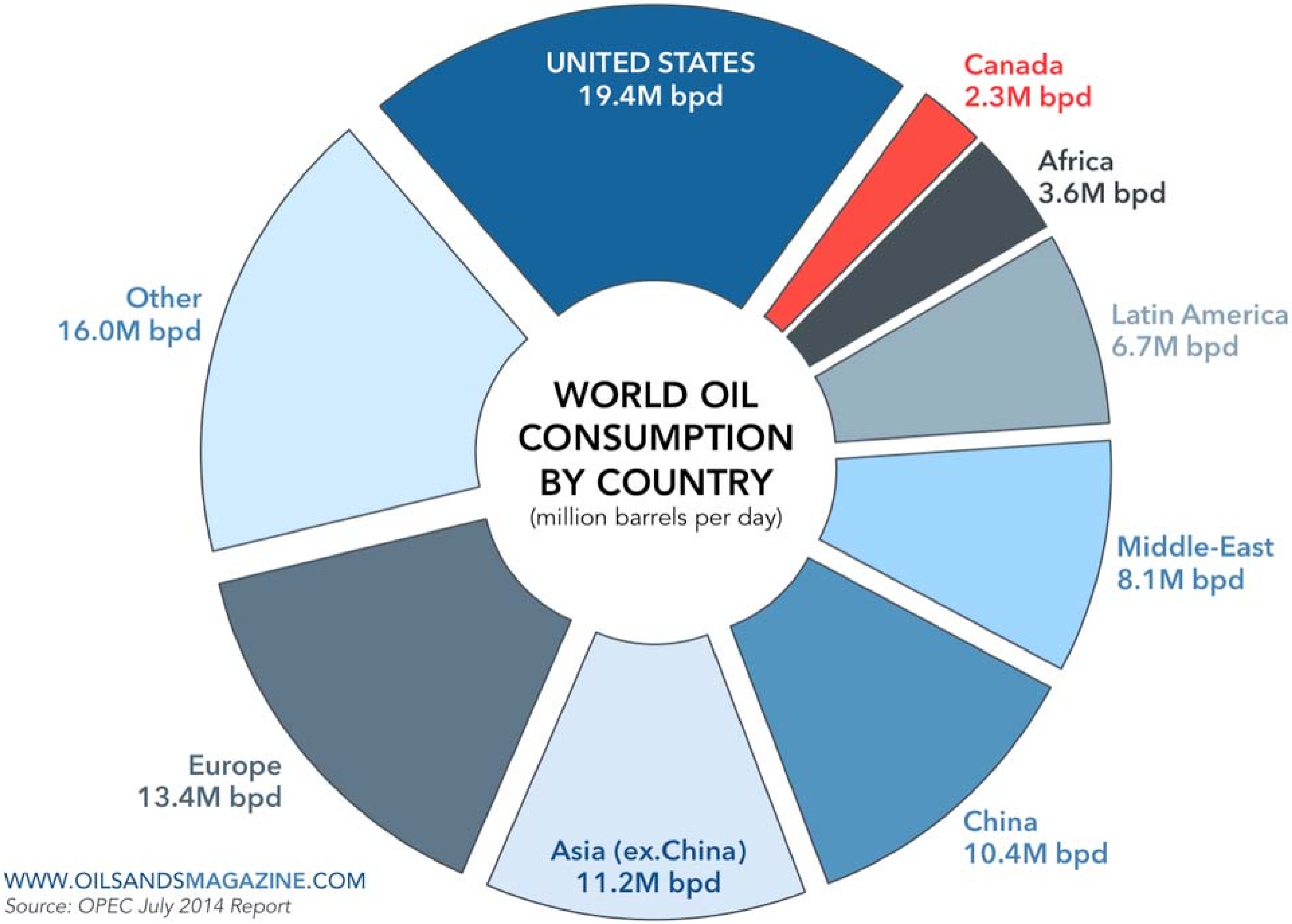
Oil Consumption



Proven oil reserves

- 465 billion barrels consumed
- 1 trillion barrels left
- 22 billion consumed a year
- 45 years to go! Party now!

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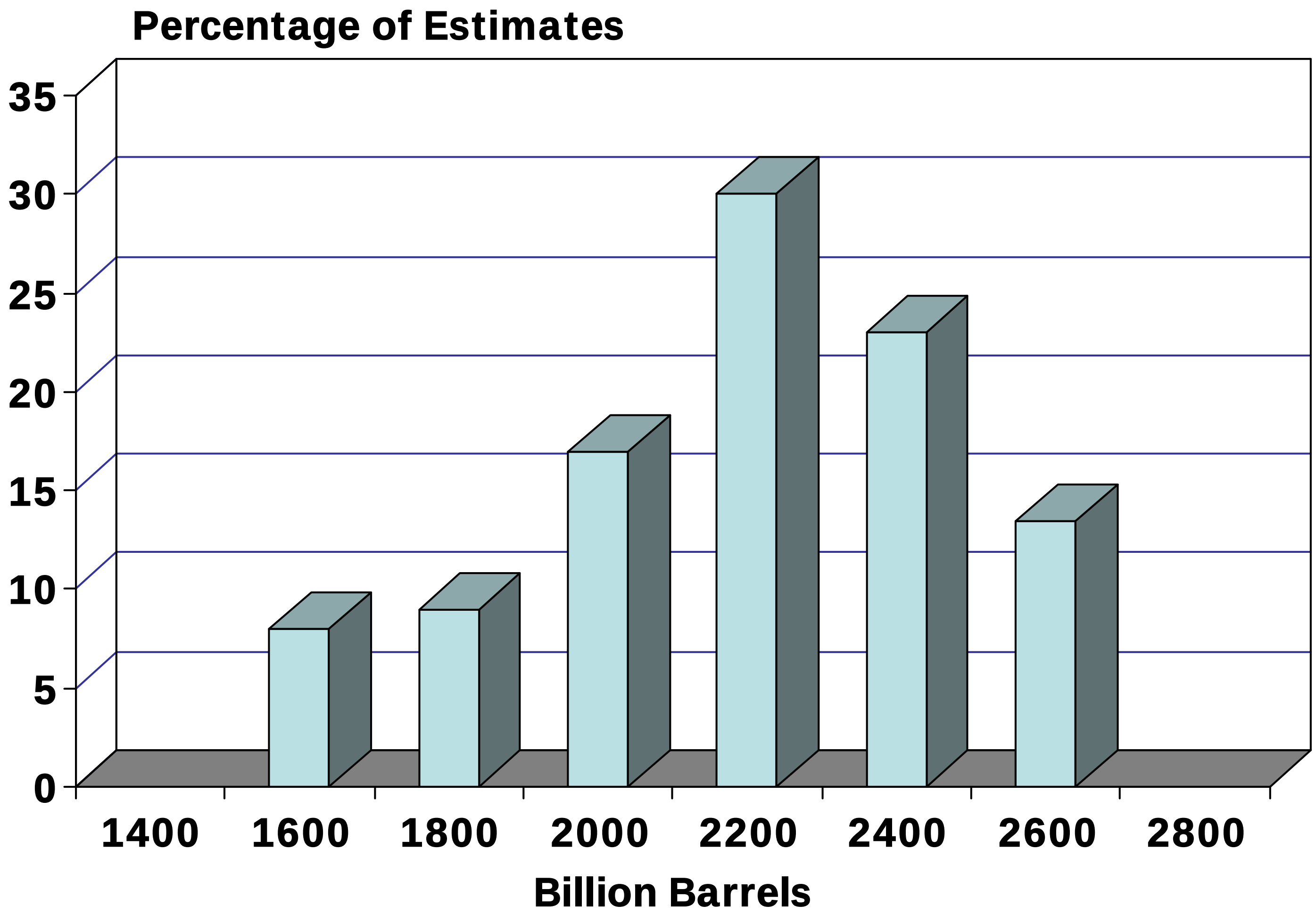
Distribution of Estimates of Ultimately Recoverable World Crude Oil (1975-1993)



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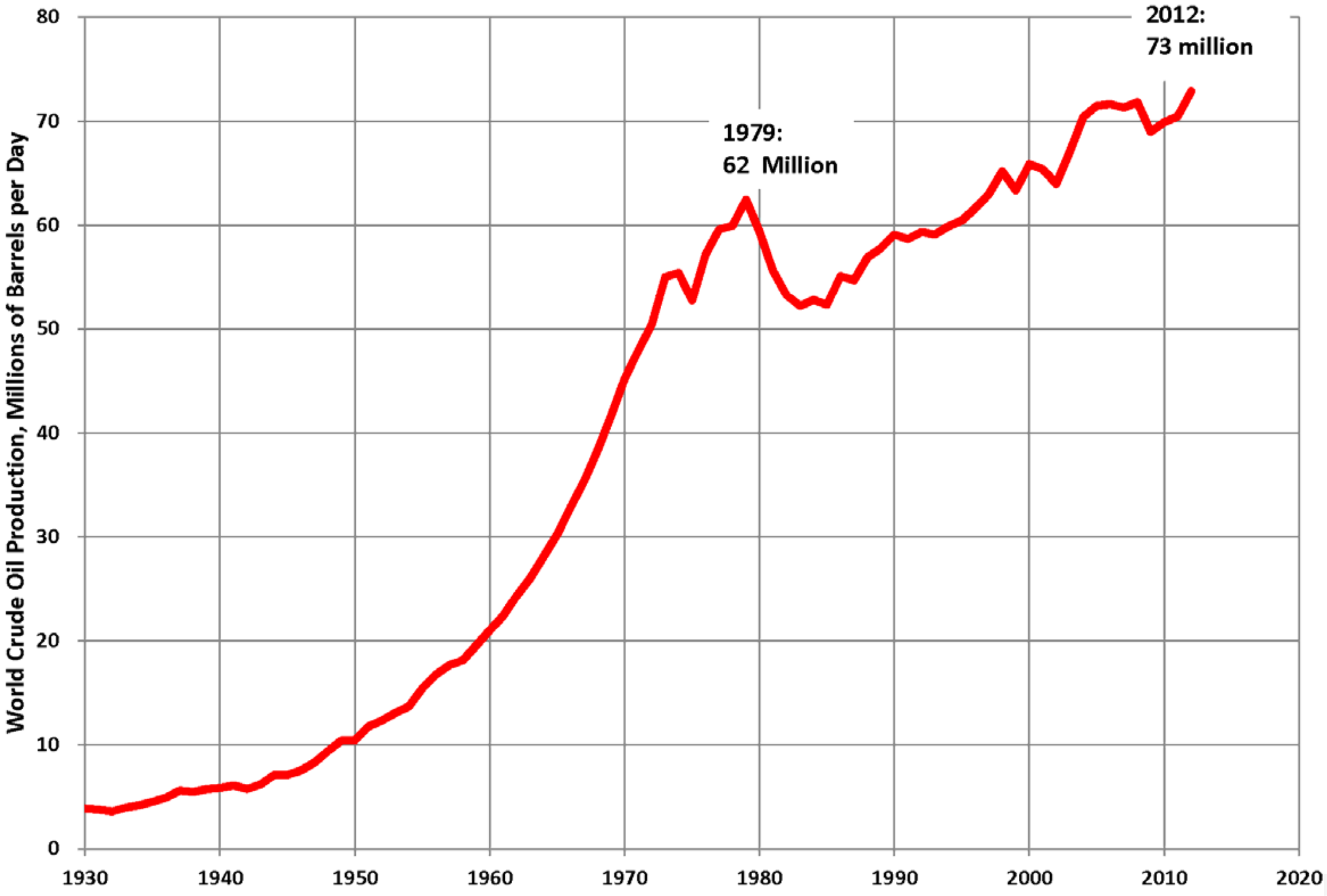
World Crude Oil Production



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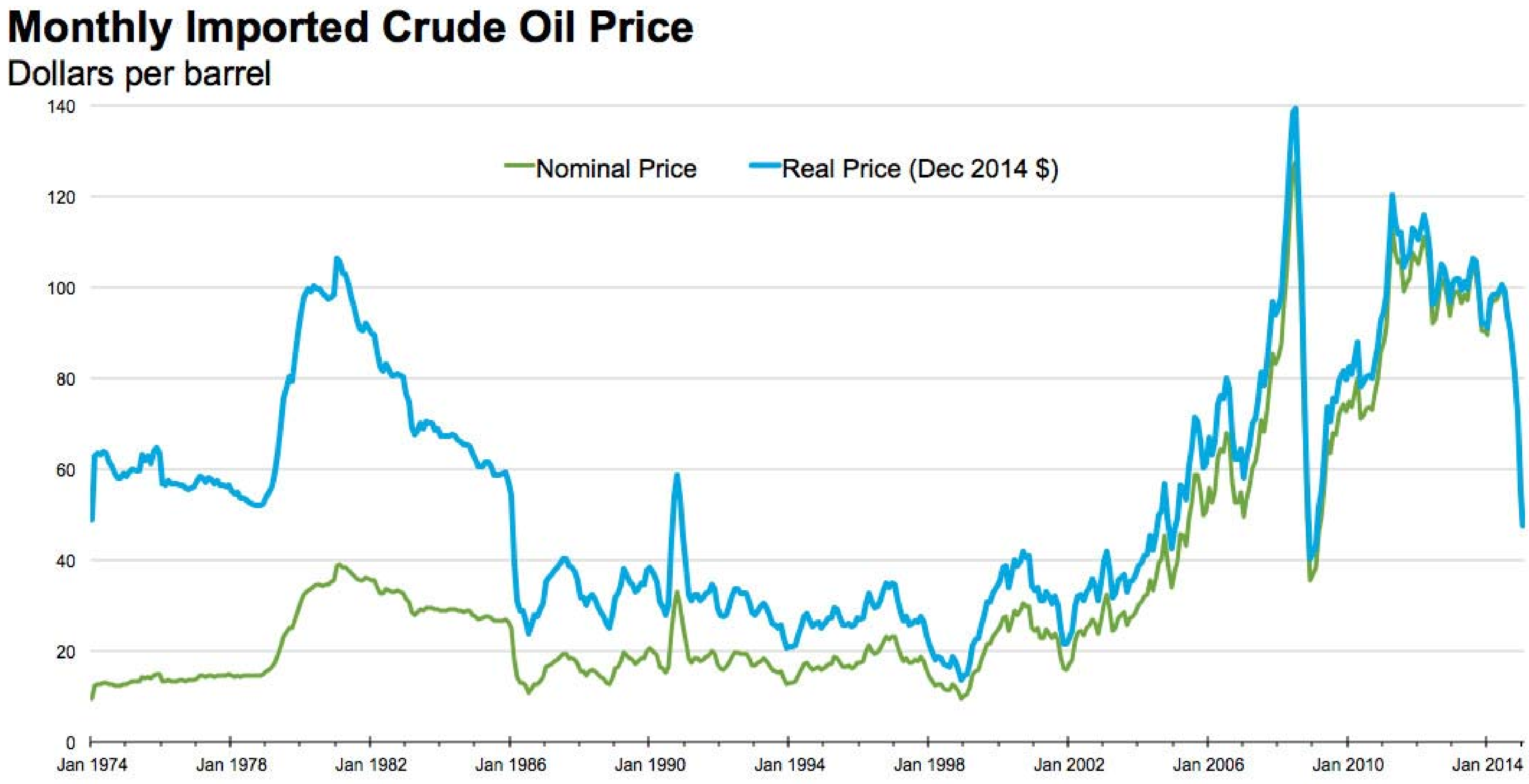
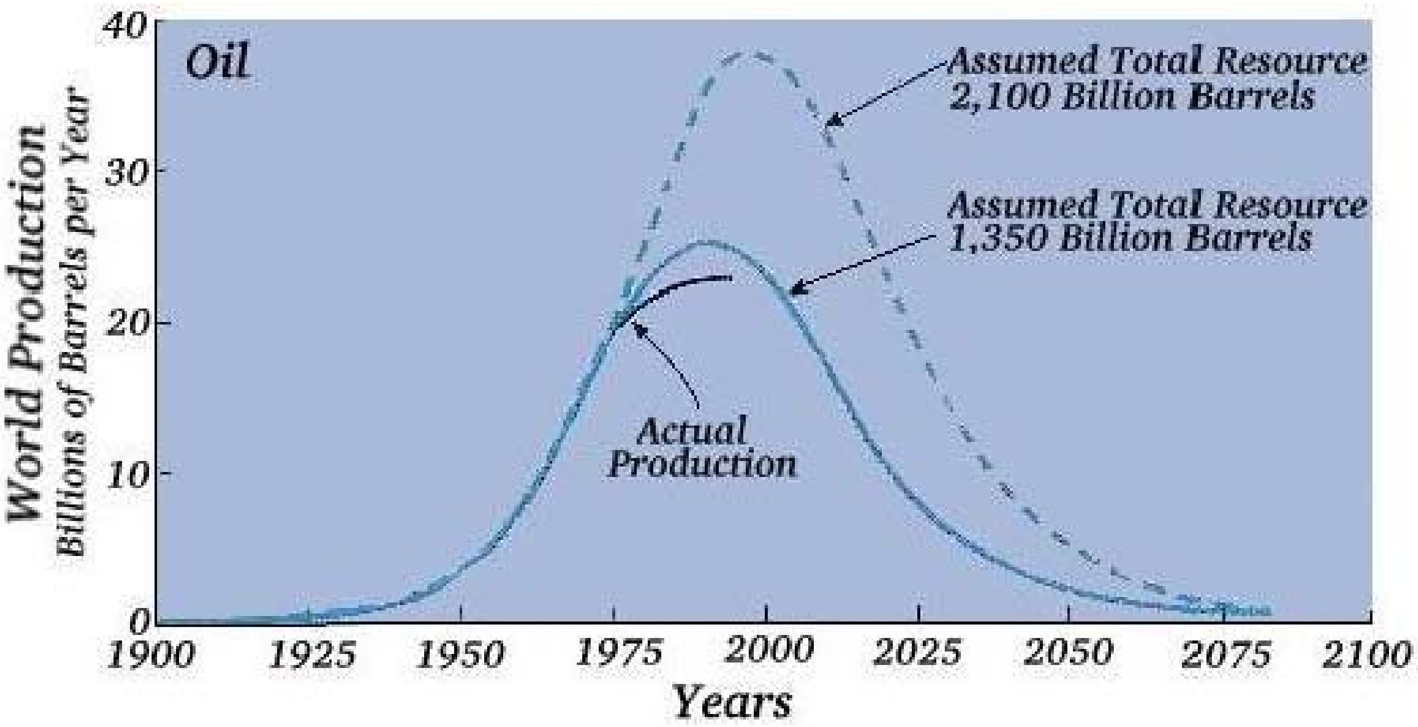
World Crude Oil Prices (economic crises in oil states)



Global trends in oil

- Growing use in China (+10%/year)
- Japan, Europe depend on Mideast
- New reserves around Caspian Sea
- Nearly size of Saudi Arabia
- Increasing source of major wars, human rights abuses

How long will the world oil supply last?



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Petroleum Oil

- Physical properties such as **boiling point, density (gravity), odor, and viscosity** have been used to describe oils.
- Petroleum may be called **light or heavy** in reference to the amount of low-boiling constituents and the relative density (specific gravity).
- **Odor** is used to distinguish between sweet (low sulfur) and sour (high sulfur) crude oil.
- **Viscosity** indicates the ease of (or more correctly the resistance to) flow.
- **Light petroleum** (often referred to as conventional petroleum) is usually rich in low-boiling constituents and waxy molecules
- **Heavy petroleum** contains greater proportions of higher-boiling, more aromatic, and heteroatom-containing (N-, O-, S-, and metal-containing) constituents.
- Heavy oil is more viscous than conventional petroleum.
- **Bitumen** is solid or near solid.

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Petroleum Oil

- **Heavy oil** (heavy crude oil) is more viscous than conventional crude oil and has a lower mobility in the reservoir but can be recovered through a well from the reservoir by the application of secondary or enhanced recovery methods.
- **Tar sand** is the several rock types that contain an extremely viscous hydrocarbon that is not recoverable in its natural state by conventional oil well production methods including currently used enhanced recovery techniques.
- **The term bitumen** (native asphalt and extra heavy oil) includes a wide variety of reddish brown to black materials of semisolid, viscous to brittle character that can exist in nature with no mineral impurity or with mineral matter contents that exceed 50% by weight.
- **Bitumen** cannot be recovered through a well by conventional oil well production methods including currently used enhanced recovery techniques; current methods involve mining.
- **Synthetic crude oil** is the hydrocarbon liquid that is produced from bitumen, by a variety of processes that involve thermal decomposition. It is a marketable and transportable product that resembles conventional crude oil.

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Petroleum Oil

Property	Athabasca Bitumen	Synthetic Crude Oil	Conventional Crude Oil
Specific gravity	1.03	0.85	0.85–0.90
Viscosity, cp			
38°C/100°F	750,000	210	<200
100°C/212°F	11,300		
Pour point, °F	>50	−35	ca. −20
Elemental analysis (wt%):			
Carbon	83.0	86.3	86.0
Hydrogen	10.6	13.4	13.5
Nitrogen	0.5	0.02	0.2
Oxygen	0.9	0.00	<0.5
Sulfur	4.9	0.03	<2.0
Ash	0.8	0.0	0.0
Nickel (ppm)	250	0.01	<10.0
Vanadium (ppm)	100	0.01	<10.0
Fractional composition (wt%)			
Asphaltenes (pentane)	17.0	0.0	<10.0
Resins	34.0	0.0	<20.0
Aromatics	34.0	40.0	>30.0
Saturates	15.0	60.0	>30.0
Carbon residue (wt%)			
Conradson	14.0	<0.5	<10.0

Petroleum Quality

- Petroleum composition is *site specific,* i.e., depends on regional and local variations in the proportion of the various precursors that went into the formation of the *protopetroleum* as well as variations in temperature and pressure to which the precursors were subjected.
- Thus the purely hydrocarbon content may be higher than 90% by weight for paraffinic petroleum and 50% by weight for heavy crude oil and much lower for tar sand bitumen
- The nonhydrocarbon constituents are usually concentrated in the higher-boiling portions of the crude oil.
- The atomic ratio of hydrogen to carbon increases from the low- to the high-molecular-weight fractions.

Petroleum Quality

- Petroleum *quality* (as a refinery feedstock) are assessed by
  - Measurement of physical properties such as relative density (specific gravity), refractive index, or viscosity or
  - Empirical tests such as pour point or oxidation stability that are intended to relate to behavior in service.
  - In some cases, the evaluation may include tests in mechanical rigs and engines either in the laboratory or under actual operating conditions.
  - Several properties may correlate well with certain compositional characteristics and are widely used as a quick and inexpensive means to determine those characteristics.
  - Complete elemental analysis and the general behavior of feedstock constituents

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Petroleum Quality

- The proportions of the elements in petroleum vary over fairly narrow limits

conventional petroleum,

Carbon, 83.0–87.0%
Hydrogen, 10.0–14.0%
Nitrogen, 0.1–2.0%
Oxygen, 0.05–1.5%
Sulfur, 0.05–6.0%
Metals (Ni and V), <1000 ppm

tar sand bitumen

Carbon, 83.5 ± 1.0%
Hydrogen, 10.5 ± 0.5%
Nitrogen, 0.5 ± 0.2%
Oxygen, 1.0 ± 0.5%
Sulfur, 5.0 ± 0.5%
Metals (Ni and V), >1000 ppm

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Chemical Composition

- Petroleum is not a uniform material.
- Its chemical and physical (fractional) composition can vary not only with the **location** and **age of the oil field** but also with the **depth of the individual well .**
- On a molecular basis, petroleum is a complex mixture of hydrocarbons with small amounts of organic compounds containing sulfur, oxygen, and nitrogen, as well as compounds containing metallic constituents, particularly vanadium, nickel, iron, and copper.
- The hydrocarbon content may be as high as 97% by weight in a lighter paraffinic crude oil or about 50% by weight in heavy crude oil and less than 30% by weight bitumen.
- The hydrocarbon components of petroleum into the following three classes:

i. ***Paraffins,*** which are saturated hydrocarbons with straight or branched chains, but **without** any ring structure.

ii. ***Naphthenes,*** which are saturated hydrocarbons containing one or more rings, each of which may have one or more paraffinic side chains (more correctly known as *alicyclic hydrocarbons).*

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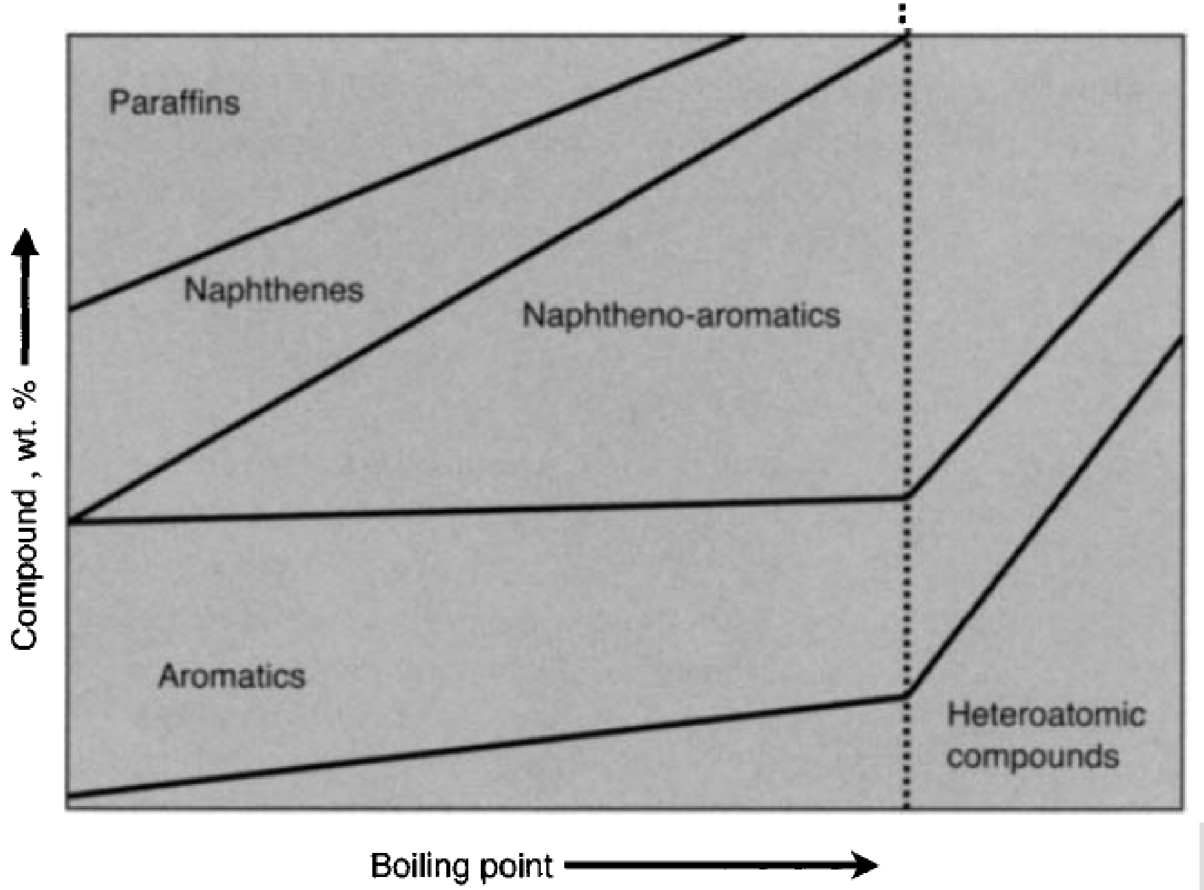
Chemical Composition

iii. ***Aromatics***, which are hydrocarbons containing one or more aromatic nuclei, such as benzene, naphthalene, and phenanthrene ring systems, which may be linked up with (substituted) naphthene rings and/or paraffinic side chains.

Distribution of various compound types throughout petroleum.



Hydrocarbon Chemistry

3 major groups

aliphatic hydrocarbons	⟶	carbon-atom "chains" (fossil fuels)
alicyclic hydrocarbons, aromatic hydrocarbons	⟶	"ring" hydrocarbons

saturated hydrocarbons	–	single bonds between carbon atoms
unsaturated hydrocarbons	–	two carbon atoms share multiple bonds

aliphatic hydrocarbons

Three subgroups of the aliphatic hydrocarbons: alkanes, alkenes, & alkynes.

alkanes (paraffins) are saturated hydrocarbons, C_nH_{2n+2}

Methane, CH_4	Hexane, C_6H_{14}	.
Ethane, C_2H_6	Heptane, C_7H_{16}	.
Propane, C_3H_8	Octane, C_8H_{18}	.
Butane, C_4H_{10}	Nonane, C_9H_{20}	Hexadecane, $C_{16}H_{34}$
Pentane, C_5H_{12}	Decane, $C_{10}H_{22}$	.

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Hydrocarbon Chemistry

alkane variations

"n-" (normal) ⟶ carbon atomes are connected in one long chain

"iso-" ⟶ carbon-atom branches; usually methyl groups (CH_3^-)

n-octane: C_8H_{18}

iso-octane: C_8H_{18}

If one H in an alkane is replaced by OH^-, the hydrocarbon becomes an alcohol.

methyl alcohol; methanol: CH_3OH
ethyl alcohol; ethanol: C_2H_5OH
propyl alcohol; proponal: C_3H_7OH

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alkenes (olefins) are unsaturated hydrocarbons with one double bond between two carbon atoms, C_nH_{2n}

ethylene, C_2H_4
propylene, C_3H_6 $\longleftrightarrow$
butene, C_4H_8
pentene, C_5H_{10}
hexene, C_6H_{12}

alkynes (acetylenes) are unsaturated hydrocarbons with one triple bond between two carbon atoms, $C_nH_{2(n-1)}$

acetylene, C_2H_2
ethylacetylene, C_4H_6 $\longleftrightarrow$

Hydrocarbon Chemistry

alicyclic hydrocarbons

Saturated carbon atom "rings", C_2H_{2n} (same as alkene subgroup of aliphatic hydrocarbons).

The alicyclic name is the same as the alkene group preceded by "cyclo"

cyclopropane, C_3H_6
cyclobutane, C_4H_8 $\longleftrightarrow$
cyclopentane, C_5H_{10}

aromatic hydrocarbons

Composed of benzene "rings"; 6 carbon atoms with a double bond every other atom.

C_2H_{2n-6} $\longleftarrow$ single-ring molecule
C_2H_{2n-12} $\longleftarrow$ double-ring molecule
C_2H_{2n} (same as alkene subgroup of aliphatic hydrocarbons).

The alicyclic name is the same as the alkene group preceded by "cyclo"

benzene, C_6H_6 $\longleftrightarrow$
toluene, C_7H_8
xylene, C_8H_{10}
naphthalene, $C_{10}H_8$

Compounds created by adding methyl groups to ring(s).

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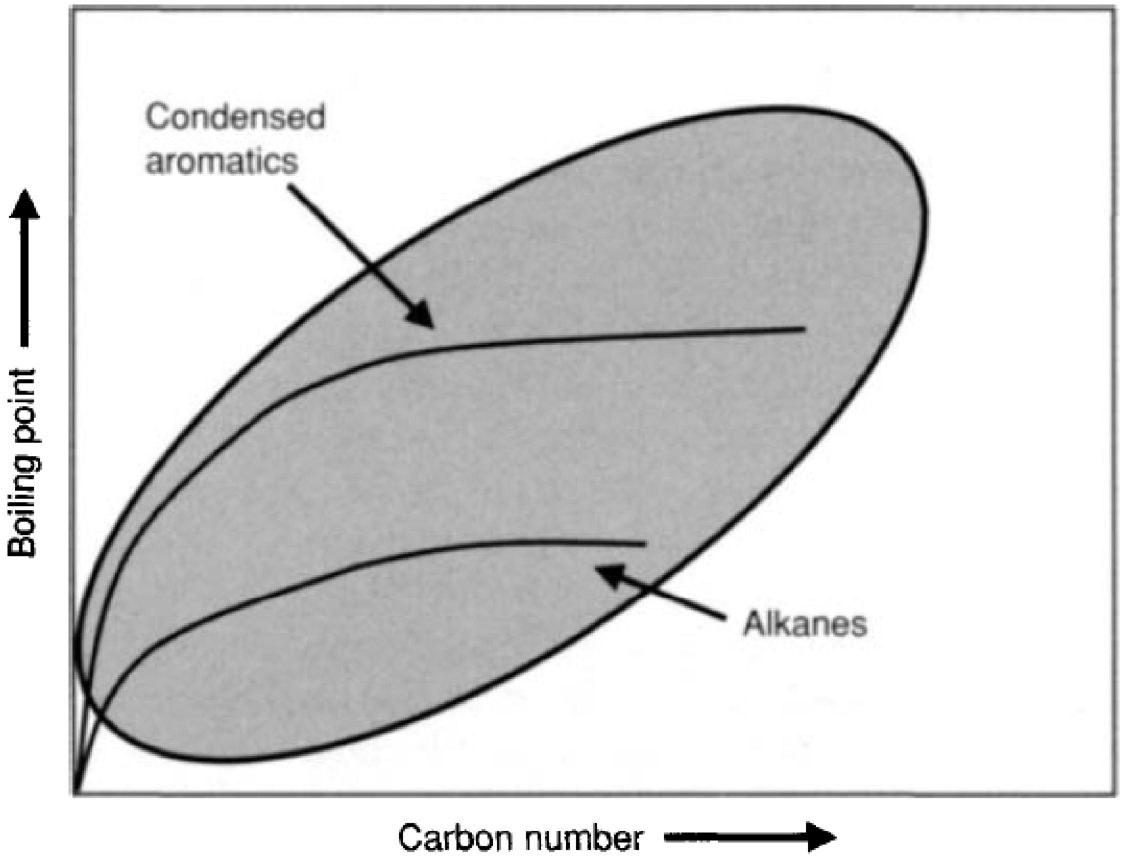
Boiling-point Distribution,

- The most important properties of a whole crude oil are **<u>its boiling-point distribution</u>**, its **<u>density</u>** (or API gravity), and its **<u>viscosity</u>**.
- The *boiling-point distribution, boiling profile,* or *distillation assay* gives the yield of the various distillation cuts.
- For heavy oil, bitumen, and residua, density and viscosity still are of great interest. But for such materials, hydrogen, nitrogen, sulfur, and metal content as well as carbon residue values become even more important



General boiling point-carbon number profile for petroleum (*petroleum map)*

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Distillation Products

PRODUCTS OF PETROLEUM DISTILLATION

Fraction	Molecular Size Range	Boiling Point Range Degrees Celsius	Typical Uses
Gas	C_1–C_5	−164 to 30	Gaseous fuel
Petroleum ether	C_5–C_7	30 to 90	Solvent, dry cleaning
Straight-run gasoline	C_5–C_{12}	30 to 200	Motor fuel
Kerosene	C_{12}–C_{16}	175 to 275	Fuel for stoves, diesel, and jet engines
Gas oil or fuel oil	C_{15}–C_{18}	Up to 375	Furnace oil
Lubricating oil	C_{16}–C_{20}	350 and up	Lubrication
Greases	C_{18}–up	Semisolid	Lubrication
Paraffin (wax)	C_{20}–up	Melts at 52–57	Candles
Pitch and tar	High	Residue in boiler	Roofing, paving

Source: Spencer L. Seager and H. Stephen Stoker, *Chemistry: A Science for Today* (San Francisco: Scott, Foresman, 1973), p. 299.

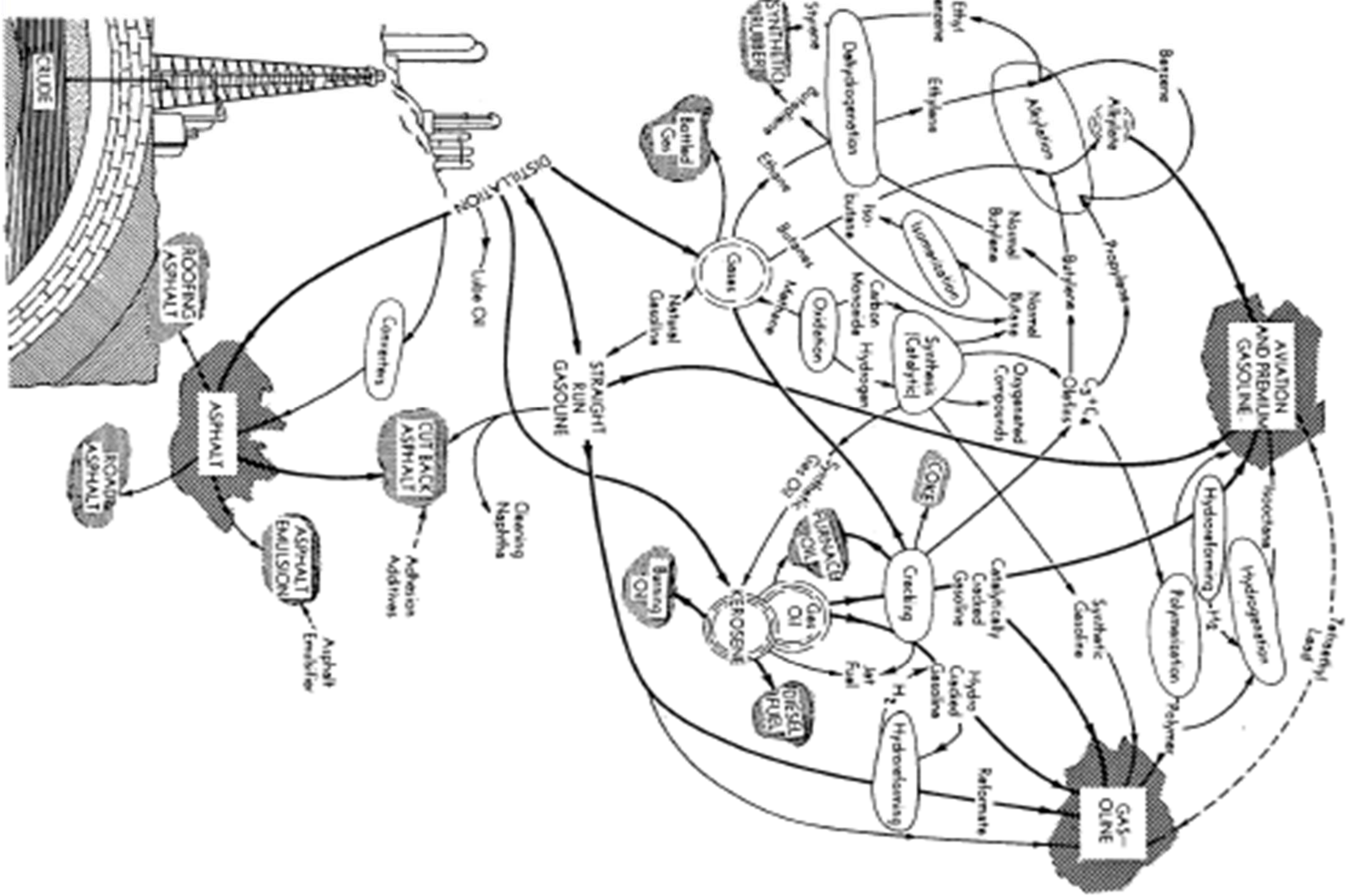
Distillation Products

THE ALKANE SERIES OF HYDROCARBONS[a]

n	Molecule	Name	Primary Use
1	CH_4	Methane	Natural gas
2	C_2H_6	Ethane	Natural gas
3	C_3H_8	Propane	Bottled gas
4	C_4H_{10}	Butane	Bottled gas
5	C_5H_{12}	Pentane	Gasoline
6	C_6H_{14}	Hexane	Gasoline
7	C_7H_{16}	Heptane	Gasoline
8	C_8H_{18}	Octane	Gasoline

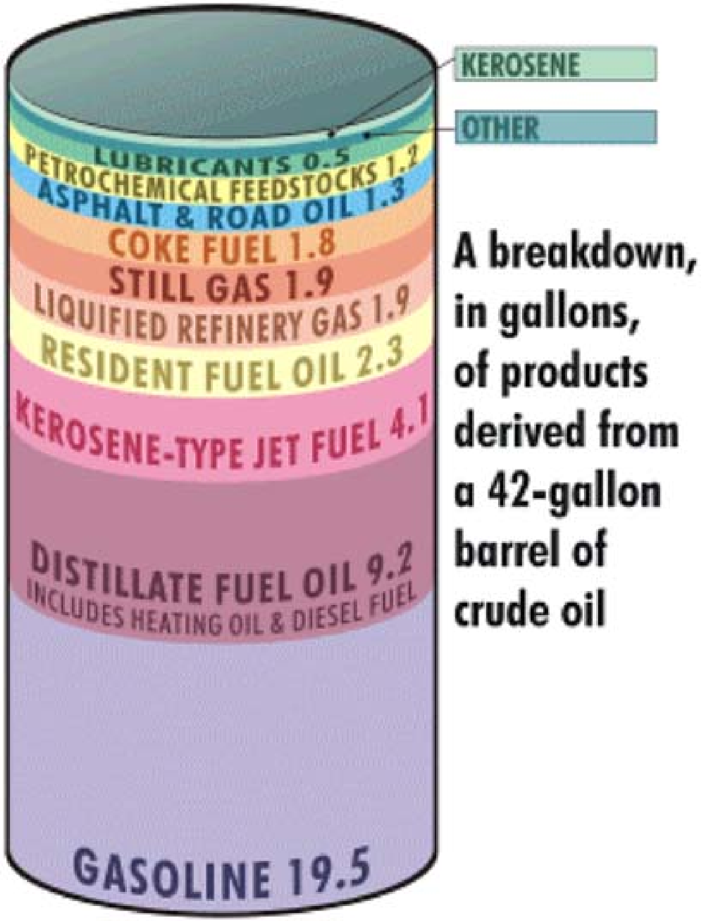
[a] The heat of combustion for these hydrocarbons ranges from about 53,000 Btu/kg for methane to 45,000 Btu/kg for octane.

Fuel technology.



So where does our petroleum go?

- Each barrel of crude oil goes into a wide variety of products
- Most goes into combustibles
- Some goes to lubricants
- Some goes to pitch and tar
- Some makes our plastics
- 40% of our energy comes from petroleum



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Liquid Fuel Ratings

After refining, liquid fuels are rated for combustion. The two most common ratings are the **Octane Number** used for spark-ignition engines and the **Cetane Number** used for compression-ignition engines.

Octane

100-octane fuel $\longrightarrow$ 2,2,4-trimethylpentane, C_8H_{18} (isooctane)
"hard to break" & resists detonation

0-octane fuel $\longrightarrow$ n-heptane, C_7H_{16}

The octane # of an unknown fuel is determined using a Cooperative Research Engine (CFR engine).

- single-cylinder with adjustable compression ratio from $r_v \approx 4{:}1$ to $\approx 14{:}1$
- burn unknown fuel in engine and increase r_v slowly until "knock" (detonation) is detected
- blends of standard fuels are burned at same r_v until same "knock" is obtained
- %∀ of 2,2,4-trimethylpentane is octaine # of fuel
- typical gasolines: 85 to 90 octane

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Liquid Fuel Ratings

Cetane

100-cetane fuel	$\longrightarrow$	n-hexadecane, $C_{16}H_{34}$ (n-cetane)
0-cetane fuel	$\longrightarrow$	alpha-methyl naphthalene, $C_{11}H_{10}$ 1 H atom in α-position; on one of 4 C-atoms closest to common C-atoms for both rings

The cetane # is the %$\forall$ of n-hexadecane which has the same combustion characteristics in a CFR engine.
- typical diesels: 30 to 60 cetane

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Natural Gas

- Natural gas is a subcategory of petroleum that is a naturally occurring, complex mixture of hydrocarbons, with a minor amount of inorganic compounds.

Natural gas accumulations

- Natural gas accumulations in geological traps can be classified as **reservoir, field, or pool**.
- **A reservoir** is a porous and permeable underground formation containing an individual bank of hydrocarbons confined by impermeable rock or water barriers and is characterized by a single natural pressure system.
- **A field** is an area that consists of one or more reservoirs all related to the same structural feature.
- **A pool** contains one or more reservoirs in isolated structures.

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Natural Gas

- Wells in the same field can be classified as **gas wells, condensate wells, and oil wells**.
- **Gas wells** are wells with producing gas-oil-ration (GOR) being greater than 100,000 scf/stb;
- **Condensate wells** are those with producing GOR being less than 100,000 scf/stb but greater than 5,000 scf/stb;
- **Oil wells** are those with producing GOR being less than 5,000 scf/stb.
- Stb; Stock tank barrel: One barrel of stabilized or dead oil at the surface after the gas has escaped

History

- China—first recorded use, piped through bamboo
- Europe-gas lights used in Belgium and England (this gas was distilled from coal, wood, and peat)
- William Murdoch: Scottish Engineer
  - Put coal gas lights in cotton mills
- 1821, Fredonia New York
- William Hart drilled a well 27’ deep and piped the gas to a local inn—where it lit 66 lights.
- Natural gas also found at Titusville in 1859
- 1872: long-distance pipelines made
- 1879: Thomas Edison

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Modern Use of Natural Gas

- Seamless pipes available in 1920's but it wasn't until after World War II that it became really important for heating
- Why is it a good fuel?
  - No refining
  - Burns cleanly
  - More heat/unit weight than any other fossil fuel

Formation

- Formed in the same manor as petroleum
  - Thermogenic-->4km and >150°C
- Formed during the petrogenesis of coal

Production

- Similar to oil but easier to release because it is much less viscous—

Composition of Natural Gas

- Mostly methane CH_4
- Some ethane C_2H_6
- Propane C_3H_8
- Butane C_4H_{10}
- Hydrogen H_2
- Some Nitrogen, carbon dioxide, hydrogen sulphide

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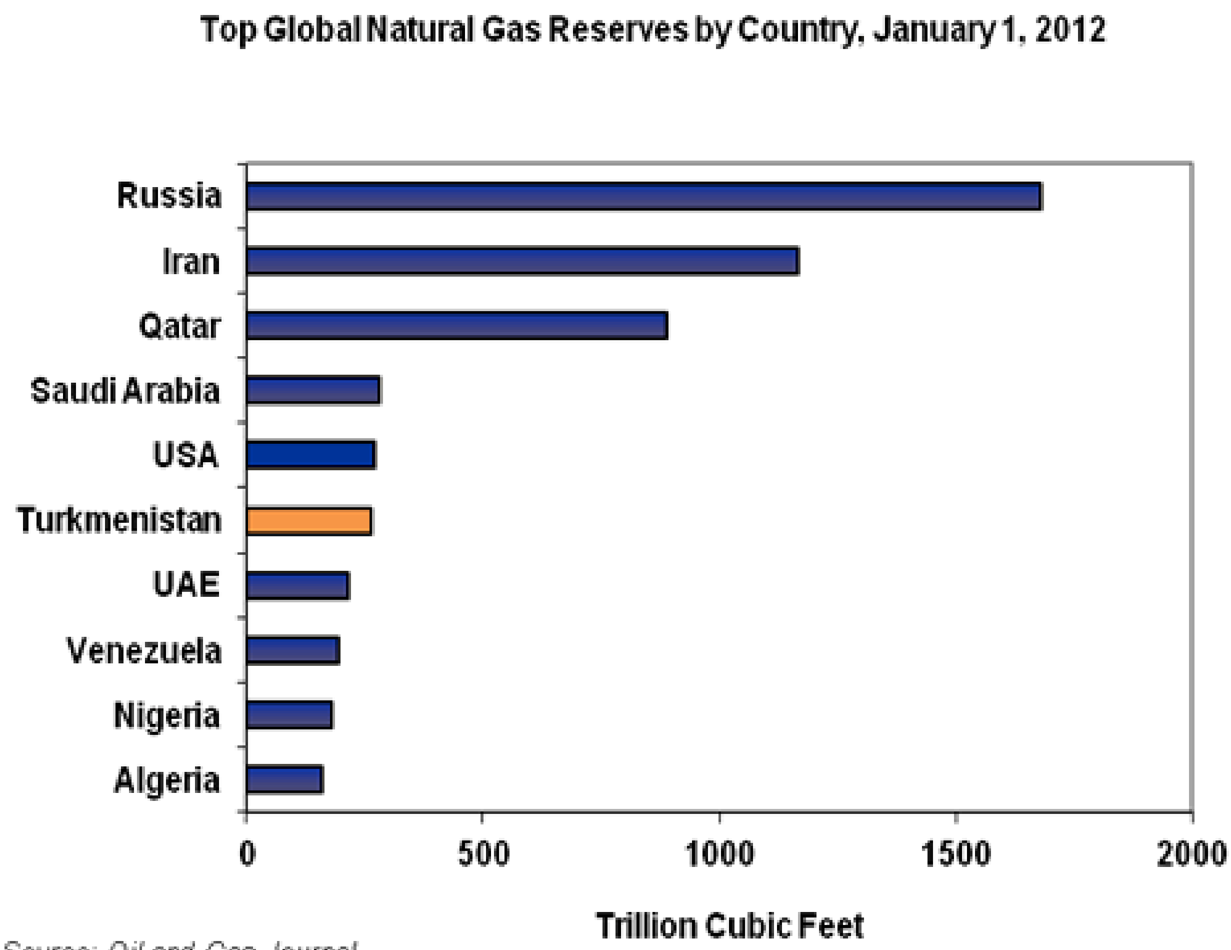
Reserves

- *Proved reserves* are those quantities of gas that have been found by the drill
- They can be proved by known reservoir characteristics such as production data, pressure relationships, and other data, so that volumes of gas can be determined with reasonable accuracy.

- *Potential resources* constitute those quantities of natural gas that are believed to exist in various rocks of the Earth's crust but have not yet been found by the drill.
- They are future supplies beyond the proved reserves.

Reserves



Source: *Oil and Gas Journal*

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Reserves

2013 Global Proved NatGas Reserves

Region/Country	Trillion Cubic Ft	% of Total
Iran	1192.9	18.2%
Russian Federation	1103.6	16.8%
Qatar	871.5	13.3%
Other Middle East	771.0	11.8%
Turkmenistan	617.3	9.4%
Asia Pacific	536.6	8.2%
Africa	501.7	7.7%
North America	413.7	6.3%
Other Europe & Asia	278.6	4.2%
S & Central America	270.9	4.1%
TOTAL	***6557.8***	***100.0%***
U.S.	330.0	5.0%

Source: Compiled by NGI's Daily GPI from BP data

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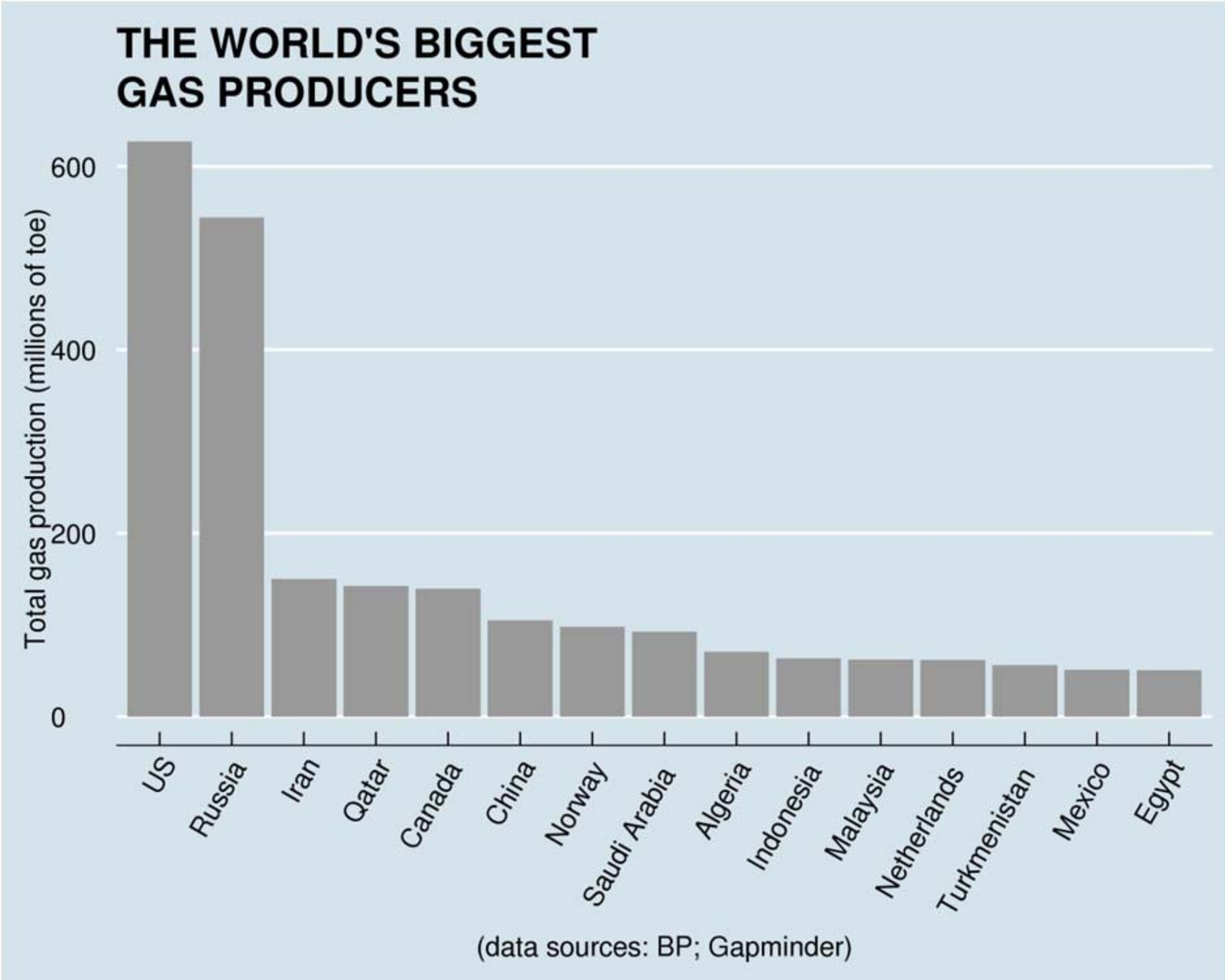
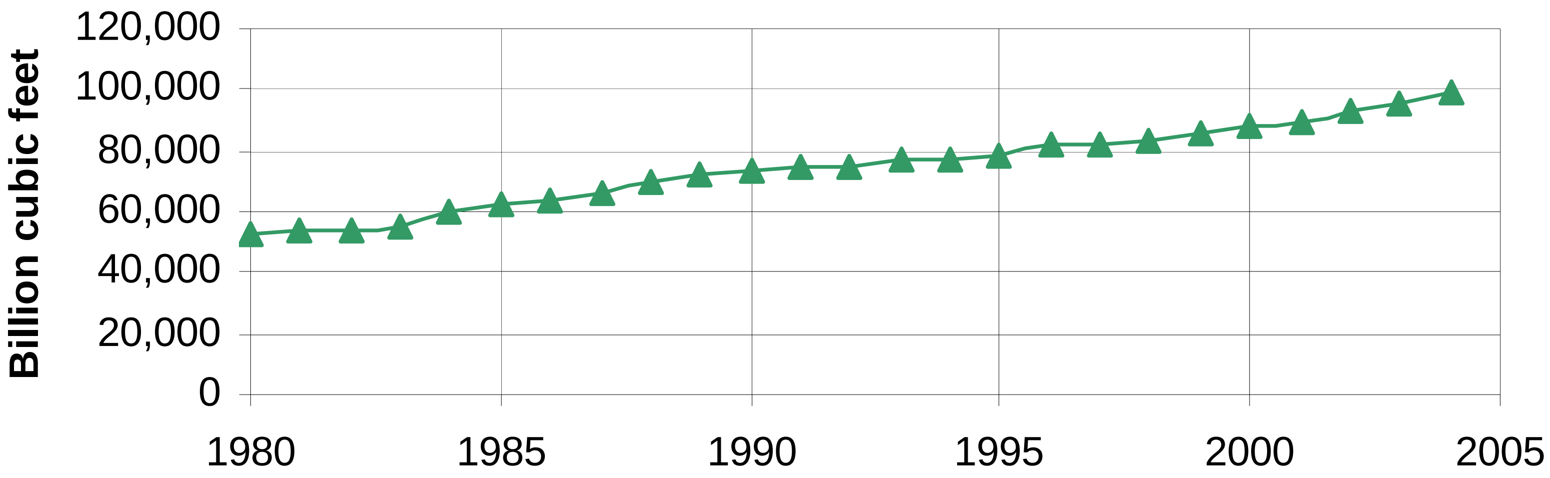
NG production



NG Consumption

In Billion cubic feet

World dry Natural gas consumption



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Reserves-countries with > 200 trillion cubic feet

- U.S.A. 204
- Russia 1688
- Iran 974
- Qatar 910
- Saudi Arabia 244
- United Arab Emigrates 214
  - These countries account for 67% of the world's reserves

➢ At the current rate?

  ➢ 100 trillion cubic feet per year—about 62 years

➢ At projected rates?

  ➢ About 150 trillion cubic feet per year—about 41 years

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Advantages of natural gas

- Cleaner to burn
  - Half as much CO_2 as coal

- More efficient
  - 10% energy lost

- 60-year supply at current rates

Disadvantages of natural gas

- Difficult to transport
  - o Pipelines
  - o Liquified Natural Gas (LNG) tankers

- Can be polluting, dangerous when extracted

- Methane bed drilling pollutes

Types of Natural Gas Resources

- The natural gases can be classified as conventional natural gas, gas in tight sands, gas in tight shales, coal-bed methane, gas in geopressured reservoirs, and gas in gas hydrates.
- Conventional natural gas is either associated or nonassociated gas.
- Associated or dissolved gas is found with crude oil.
- Dissolved gas is that portion of the gas dissolved in the crude oil and associated gas (sometimes called gas-cap gas) is free gas in contact with the crude oil.
- All crude oil reservoirs contain dissolved gas and may or may not contain associated gas.
- Nonassociated gas is found in a reservoir that contains a minimal quantity of crude oil.

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