Energy

The Mover of Output

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Energy

- For most of history, the main barrier for humans' output has been energy production.
- Even today. Fortune's Global 500 by revenue, 6 out of the top 10 companies are in the energy sector:
  2. State Grid.
  3. China National Petroleum.
  4. Sinopec Group.
  5. Royal Dutch Shell.
  6. Exxon Mobile.
  10. BP.
- Similar at a national level (for instance, 4 out of top 10 Spanish firms).

Energy: conflicts and challenges

- Furthermore, access to energy has been a key driver of conflicts.
- Indirectly, as struggles to control land and food sources.
- More recently, direct links:
  1. Japan's decision to go to war in 1941.
  2. 1953 coup d'état against Mohammad Mosaddegh in Iran.
  3. Gulf wars.
- Challenge of decarbonizing the economy **and** increasing energy consumption of much of the world population.

Energy units

a. 1 newton (N): unit of force = mass $*$ acceleration ($kg * m * s^{-2}$).

   Force required to accelerate 1 $kg * m * s^{-2}$.

   Given $g = 9.80665 m/s^2$, 1 newton is the weight on an apple.

b. 1 joule (J): unit of energy = force $*$ distance ($kg * m^2 * s^{-2}$).

   Work transferred to an object when a force of one newton acts on that object in 1 m (energy= force $*$ distance).

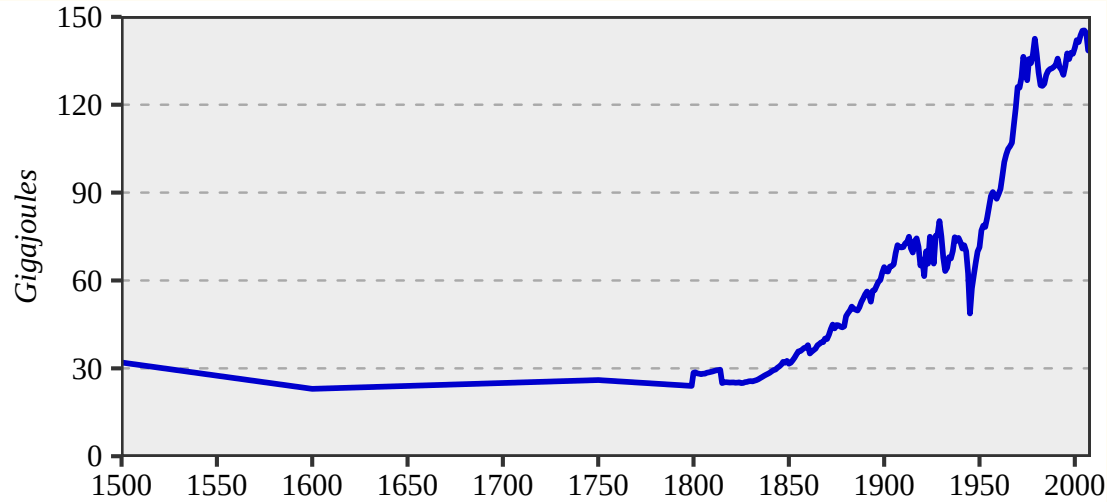
   1 joule is 1 apple lift 1 meter.

c. 1 watt (W): unit of power = work/time ($kg * m^2 * s^{-3}$).

   1 joule per second.

   Thus, 1 watt is 1 apple lift 1 meter in 1 second.

Energy consumed (history)



Energy consumed (US)

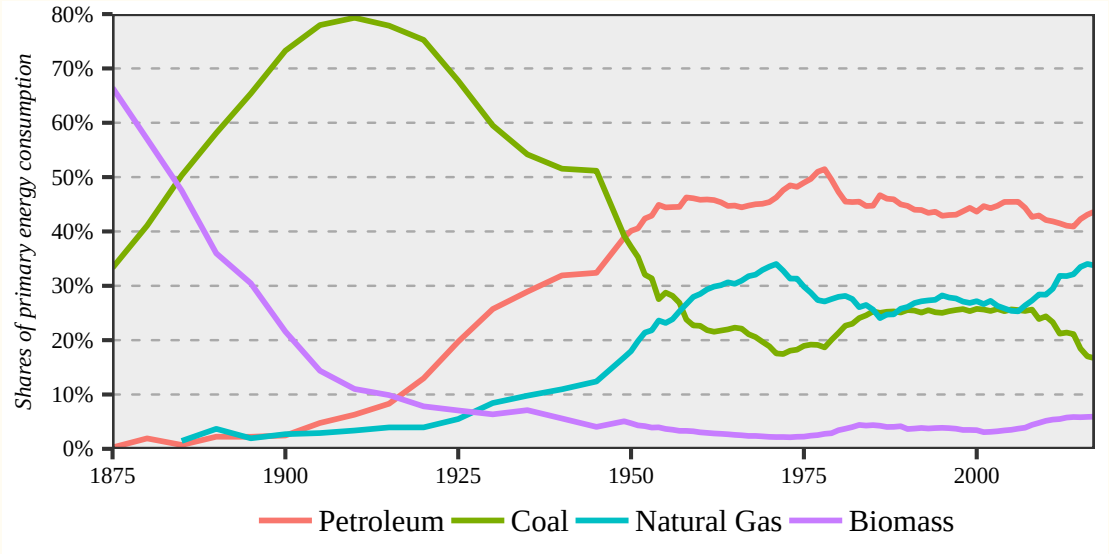
- Extraordinary amounts of energy consumed every second.
- Average U.S. person uses 11 kW ($11 * 10^3$ W).
- This is equivalent to:
  1. Running three clothes dryers or
  2. Using 100 laptops or
  3. Using 100 humans' full muscle effort or
  4. Consuming 1 barrel of oil every 5 days.
- U.S. uses 3.6 TW ($3.6 * 10^{12}$ W).
- And we use 50% less energy per 1$ produced than in 1980.

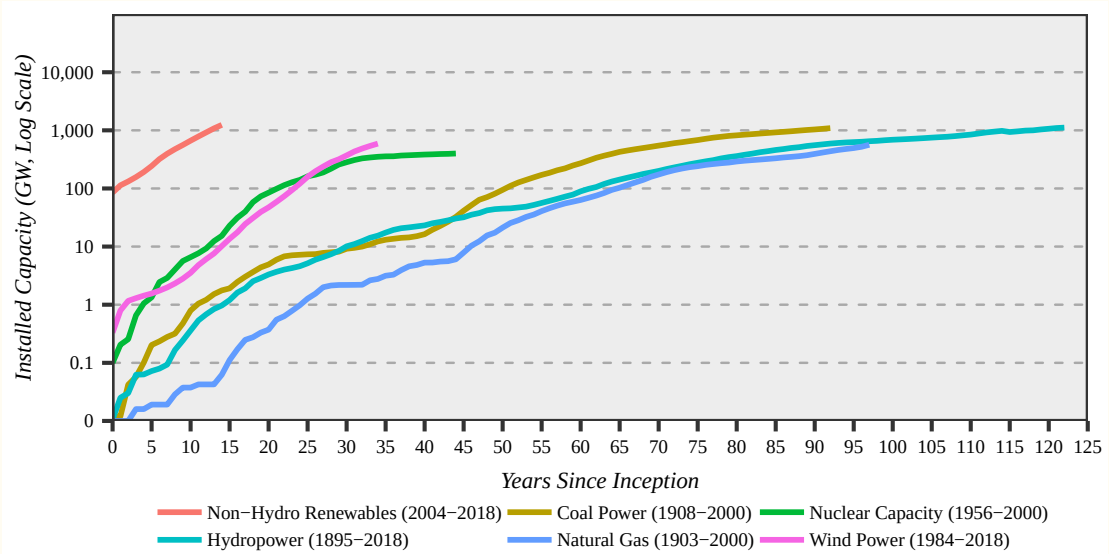
Energy consumed (world)

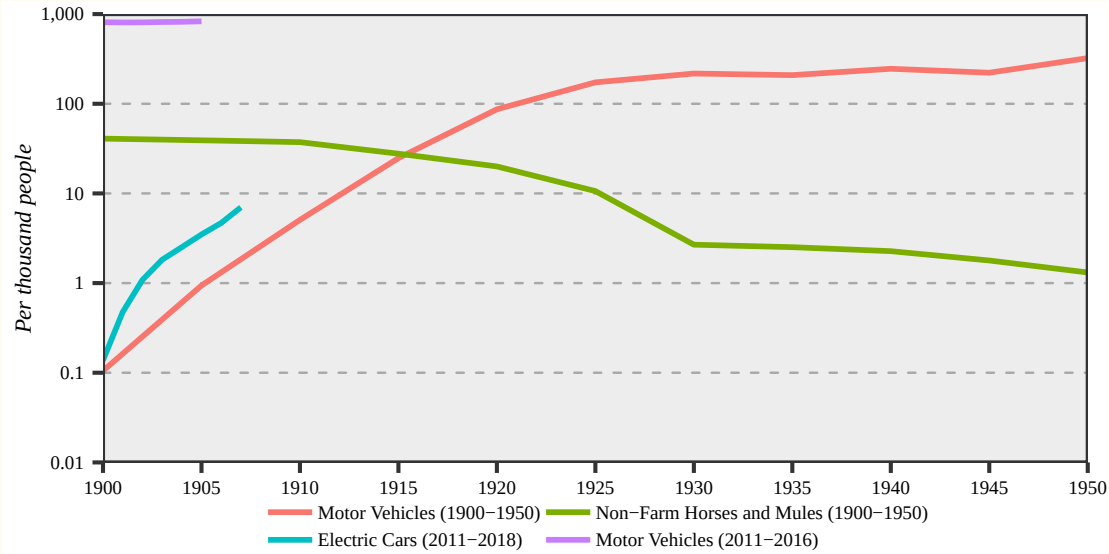
- World uses 18 TW.
- This is the equivalent of $18 * 10^{12}$ apples lift 1 meter in 1 second.
- Or the equivalent of lifting the USS Gerald R. Ford ($\approx 10^8$ kg) 18,367 meters into the air in 1 second (ignoring air friction).
- Or the equivalent of lifting an Imperial I-Class Star Destroyer ($\approx 4.44 * 10^9 kg$) 413 meters into the air in 1 second (ignoring air friction as well).

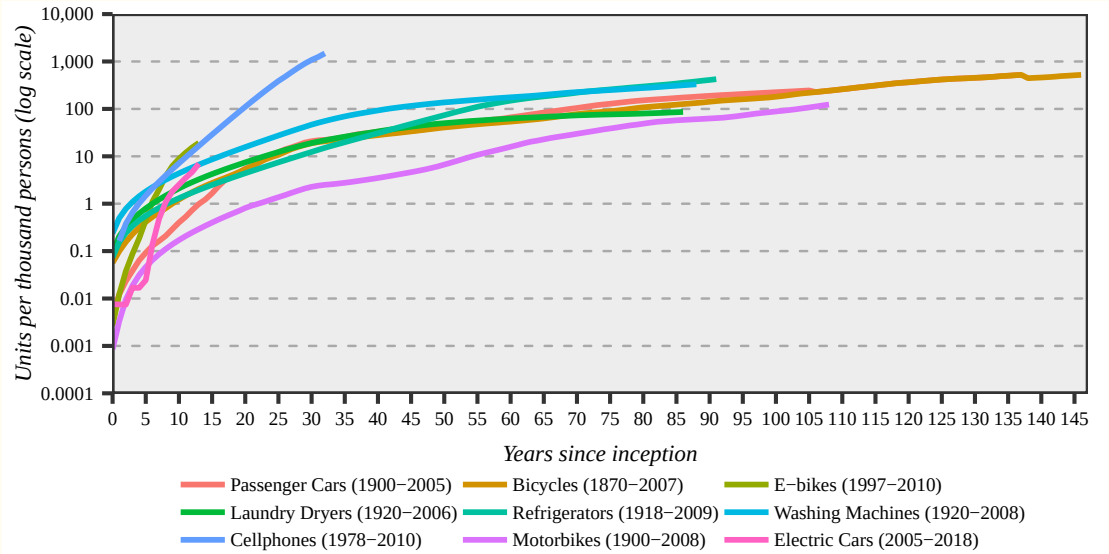
Three energy transitions

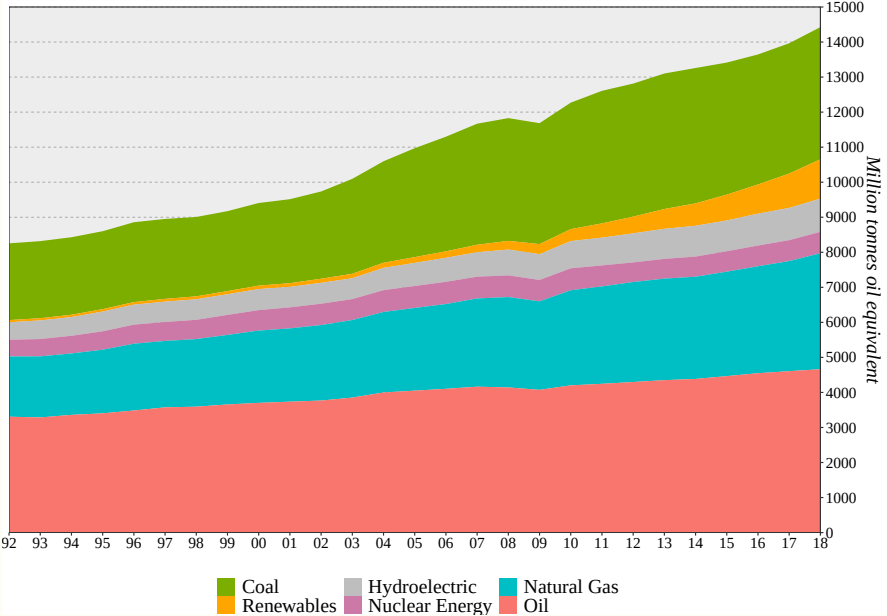
- From biomass, wind, and water to coal.
- From coal to oil and gas.
- From oil and gas to?

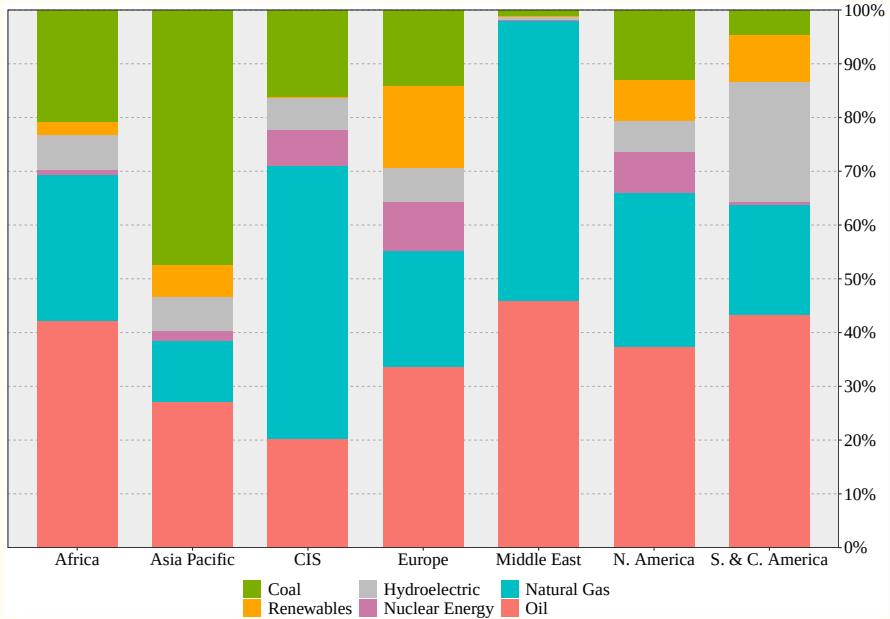

Shares of primary energy consumption
80%
70%
60%
50%
40%
30%
20%
10%
0%
1875
1900
1925
1950
1975
2000
Petroleum
Coal
Natural Gas
Biomass


Installed Capacity (GW, Log Scale)
10,000
1,000
100
10
1
0.1
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125
Years Since Inception
Non−Hydro Renewables (2004−2018)
Coal Power (1908−2000)
Nuclear Capacity (1956−2000)
Hydropower (1895−2018)
Natural Gas (1903−2000)
Wind Power (1984−2018)


1,000
100
10
1
0.1
0.01
Per thousand people
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
Motor Vehicles (1900−1950)
Non−Farm Horses and Mules (1900−1950)
Electric Cars (2011−2018)
Motor Vehicles (2011−2016)


Units per thousand persons (log scale)
10,000
1,000
100
10
1
0.1
0.01
0.001
0.0001
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145
Years since inception
Passenger Cars (1900−2005)
Bicycles (1870−2007)
E−bikes (1997−2010)
Laundry Dryers (1920−2006)
Refrigerators (1918−2009)
Washing Machines (1920−2008)
Cellphones (1978−2010)
Motorbikes (1900−2008)
Electric Cars (2005−2018)


15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Million tonnes oil equivalent
92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18
Coal
Renewables
Hydroelectric
Nuclear Energy
Natural Gas
Oil


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Africa
Asia Pacific
CIS
Europe
Middle East
N. America
S. & C. America
Coal
Renewables
Hydroelectric
Nuclear Energy
Natural Gas
Oil

Biomass

- The sun provides earth all the energy that humans use in a year in $\approx$ 75 min.
- Photosynthesis in plants, algae, and cyanobacteria transforms light energy into chemical energy.
- The chemical energy becomes biomass (wood, animals, etc.).
- Fossil fuels are transformed solar energy as well.
- In fact, only nuclear and geothermal are sources of energy not (directly) linked with the sun.

Using the biomass (I)

- Humans traditionally got their energy either from food or from fuel (wood, vegetable, animal, or rock oil, coal...).
- Before internal combustion engine, fuel is used mainly for fire.
- The ability of homo species to create and control fire appears for sure $\approx$ 250,000 BCE, probably $\approx$ 800,000 BCE in evidence from South Africa and Israel.
- Ability to create and control fire is *unique* to home species, *cultural* and, as far as we can tell, *universal* to all anatomically modern humans.

Using the biomass (II)

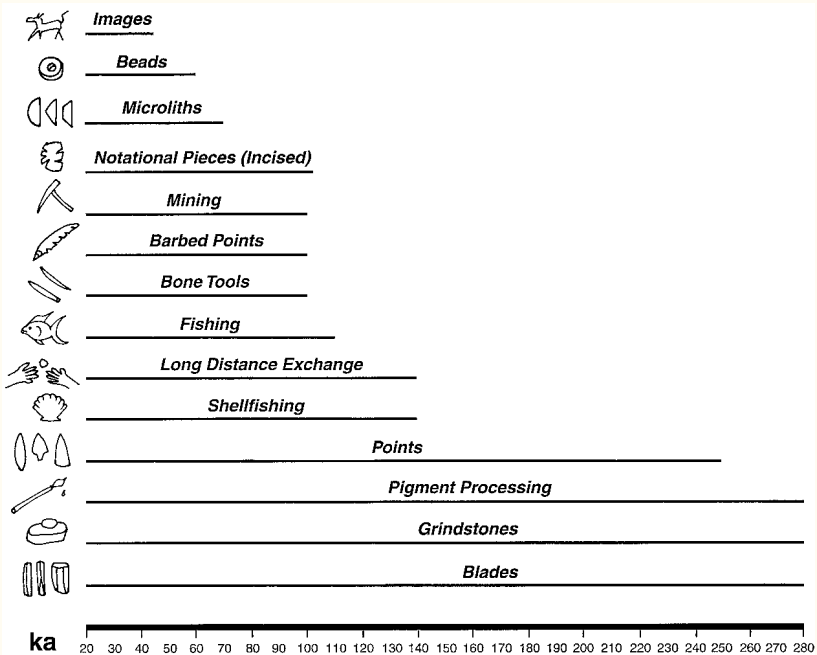
- The ability of homo species to create and control fire was also probably was crucial for evolution.
- For example, cooking led to smaller jaws and gastrointestinal tracts. Perhaps (but disputed) to bigger brains.
- More importantly, it led to better survival chances, better defenses, and to the ability to populate harsher environments.
- Think about our ability to cook grains such as wheat and rice.
- *Catching Fire: How Cooking Made Us Human* by Richard Wrangham.

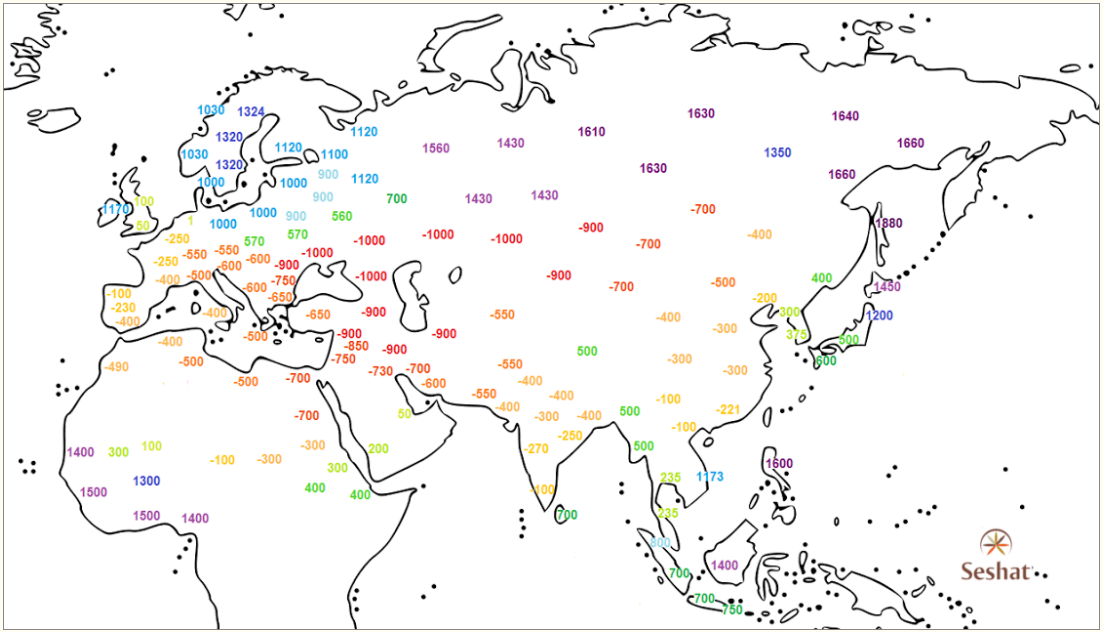
Using the biomass (III)

- Deep changes in the landscape over millennia.
- For example, eucalyptus trees forest in Australia.
- It also probably led to the first forms of gender-related division of labor.

Using the biomass more intensely

- Neolithic revolution ($\approx$ 10,000 BCE): domestication of plants and animals.
- Culmination of a relatively fast process of behavioral innovations.
- Use land to produce much more biomass than before:
  1. Hunter-gatherers require $\approx 26\ km^2$ of land per person.
  2. Farmers require $\approx 0.26\ km^2$ of land per person.
- Dramatic change in population size. $\approx$ 10,000 BCE only between 2-4 million humans.
- Additional uses. Example: the spread of cavalry.
- Changes in environment: germs, dogs, etc.

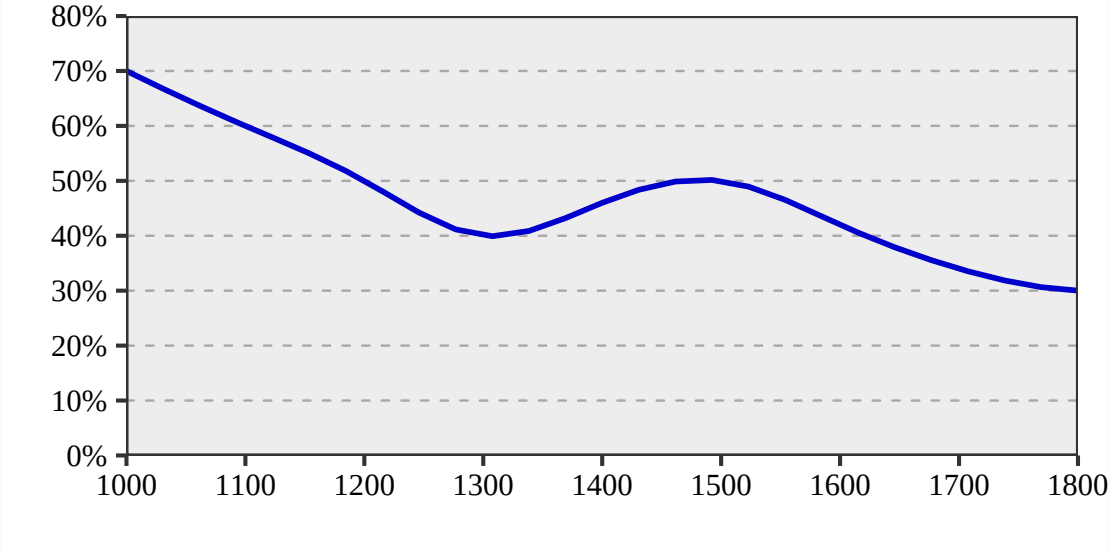

Images
Beads
Microliths
Notational Pieces (Incised)
Mining
Barbed Points
Bone Tools
Fishing
Long Distance Exchange
Shellfishing
Points
Pigment Processing
Grindstones
Blades
ka
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280

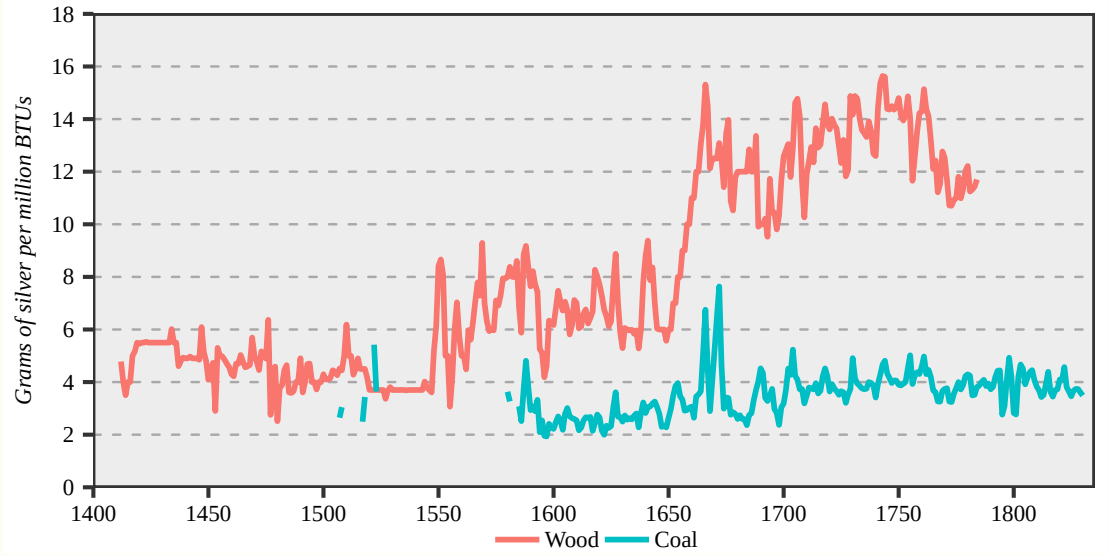

Seshat

	%
Sweden	80.0
Netherlands	38.2
England & Wales	4.3
Germany	49.6
France	65.4
Italy	60.0
Spain	46.3
Portugal	57.4
Western Europe	*50.0*

Wind and water

- We already discussed the importance of mills and watermills before the industrial revolution.
- However, by early 18th century, we had reached as far as we could use wind and water without modern science and technology.
- Even wood was becoming a binding constraint in Western Europe and China.
- For example, the wood price in London grows quickly after 1550.


80%
70%
60%
50%
40%
30%
20%
10%
0%
1000
1100
1200
1300
1400
1500
1600
1700
1800

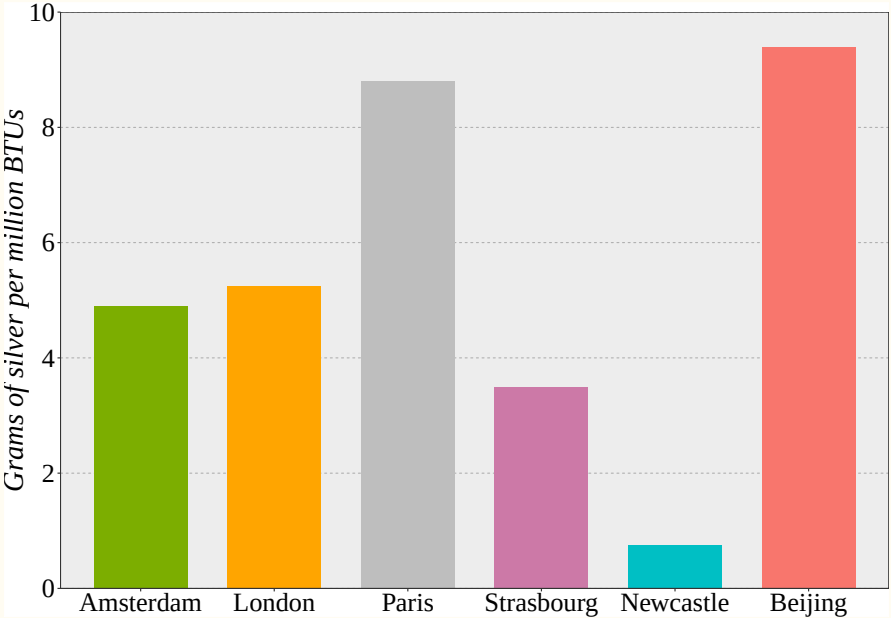

Grams of silver per million BTUs
18
16
14
12
10
8
6
4
2
0
1400
1450
1500
1550
1600
1650
1700
1750
1800
Wood
Coal

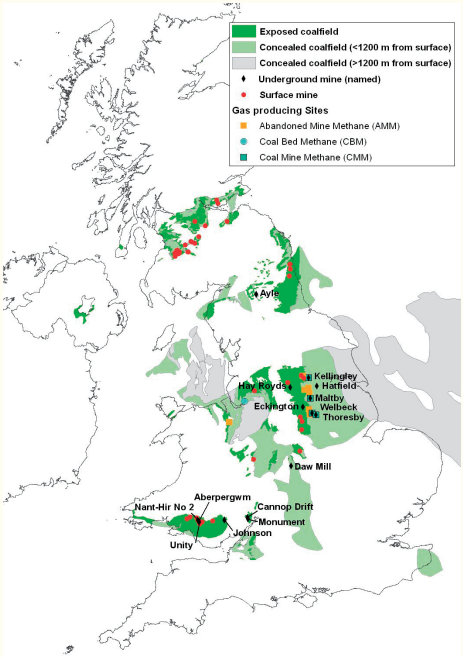
Coal

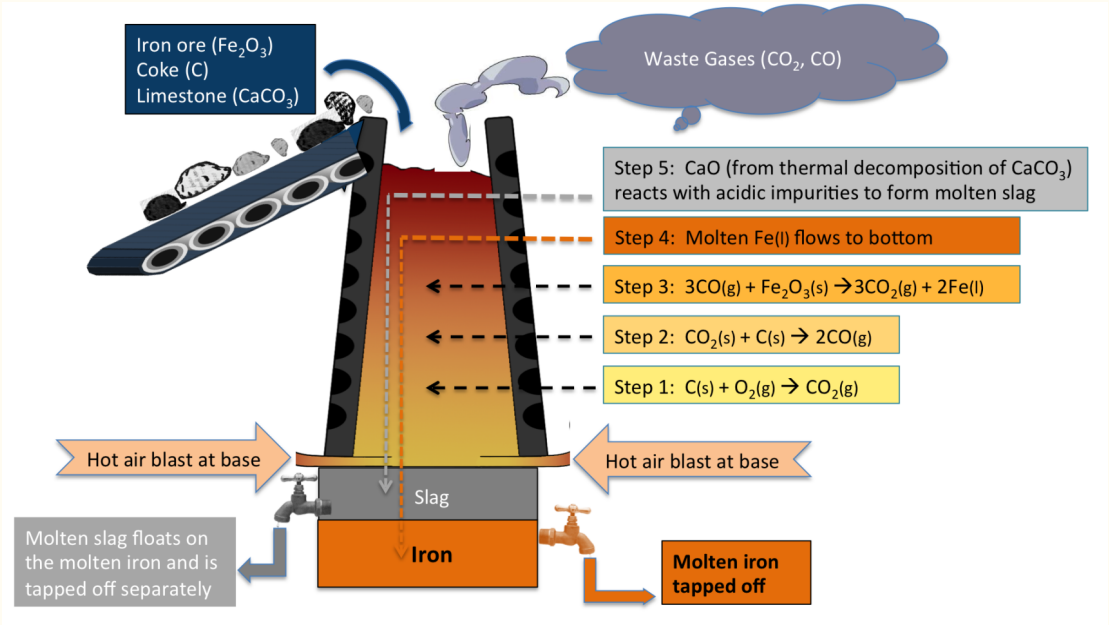
- Types:
  1. Peat.
  2. Lignite.
  3. Sub-bituminous.
  4. Bituminous.
  5. Anthracite.
- Coal used in China for copper smelting and heating already by 1,000 BCE.
- In Europe, coal from geological outcrops used for metalworking around 300 BCE.
- Romans extensively mined the coal in present-day England and Wales.

Coal and the industrial revolution

- Coal booms in Britain in the 18th and 19th century and fuels the industrial revolution.
- Relative price of energy with respect to wages in North England was strikingly low in early 17th century.
- Incentives for energy-intensive, labor-saving technological developments.
- Linked with crucial technological advances: steal production, heat, steam engine, and train.
- Oil only surpassed coal as the main source of primary energy in the U.S. in 1950.
- Coal is still more three times more important than oil as a source of primary energy in China ($\approx 60\%$ vs. $\approx 20\%$).


Grams of silver per million BTUs
10
8
6
4
2
0
Amsterdam
London
Paris
Strasbourg
Newcastle
Beijing

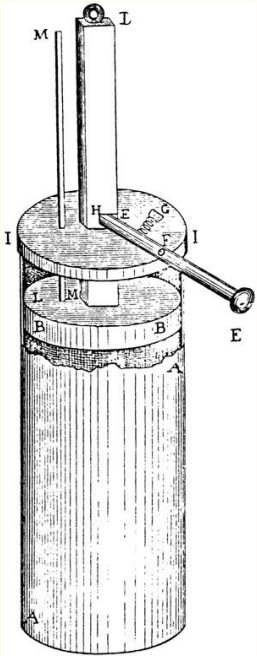

Exposed coalfield
Concealed coalfield (<1200 m from surface)
Concealed coalfield (>1200 m from surface)
Underground mine (named)
Surface mine
Gas producing Sites
Abandoned Mine Methane (AMM)
Coal Bed Methane (CBM)
Coal Mine Methane (CMM)
Ayle
Kellingley
Hatfield
Hay Royds
Maltby
Eckington
Wellbeck
Thoresby
Daw Mill
Aberpergwm
Nant-Hir No 2
Cannop Drift
Monument
Johnson
Unity

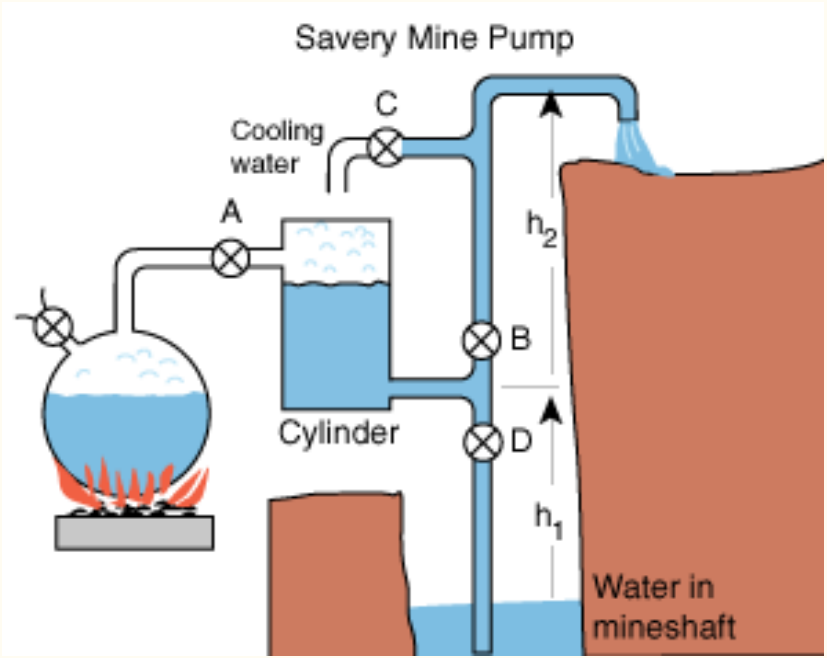

Iron ore (Fe_2O_3)
Coke (C)
Limestone ($CaCO_3$)
Waste Gases (CO_2, CO)
Step 5: CaO (from thermal decomposition of $CaCO_3$) reacts with acidic impurities to form molten slag
Step 4: Molten Fe(l) flows to bottom
Step 3: $3CO(g) + Fe_2O_3(s) \rightarrow 3CO_2(g) + 2Fe(l)$
Step 2: $CO_2(s) + C(s) \rightarrow 2CO(g)$
Step 1: $C(s) + O_2(g) \rightarrow CO_2(g)$
Hot air blast at base
Hot air blast at base
Slag
Iron
Molten slag floats on the molten iron and is tapped off separately
Molten iron tapped off

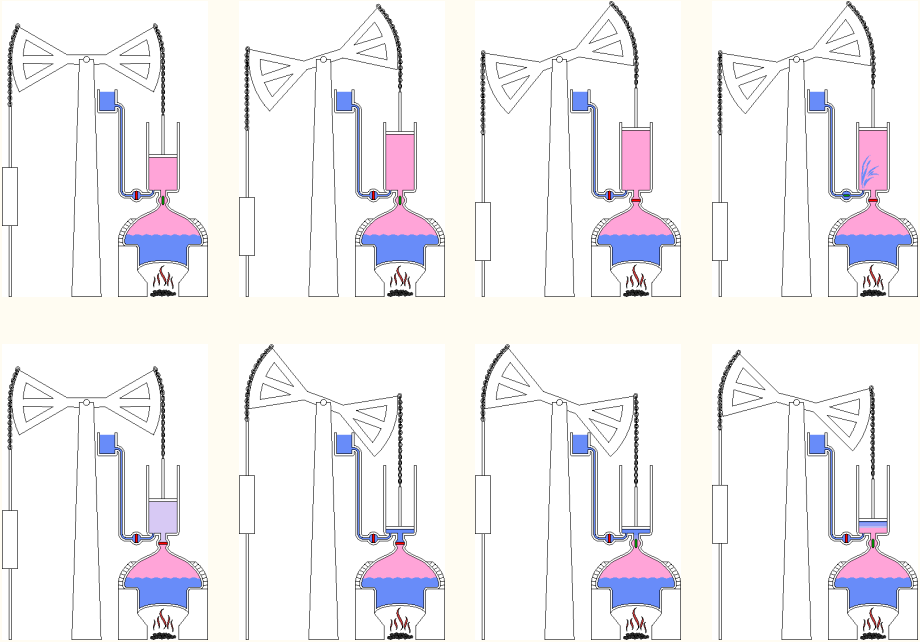
Steam engine

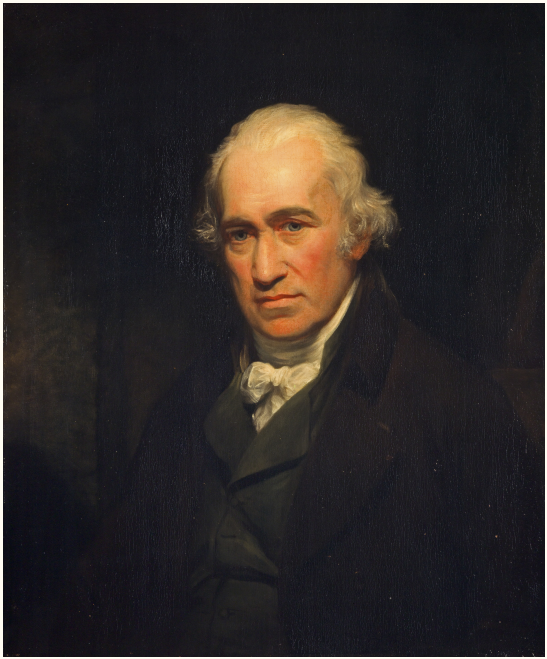
- Aeolipile.
- Otto von Guericke discovers the physics of vacuum in 1654-1657.
- Denis Pepin's steam digester in 1679.
- Thomas Savery's engine in 1698.
- Thomas Newcomen's atmospheric engine in 1712.
- James Watt's separate condenser from 1763 to 1775.
- Double-acting Piston.
- Richard Trevithick's 1804 Locomotive.
- Cornish engine in the 1820s and 1830s.

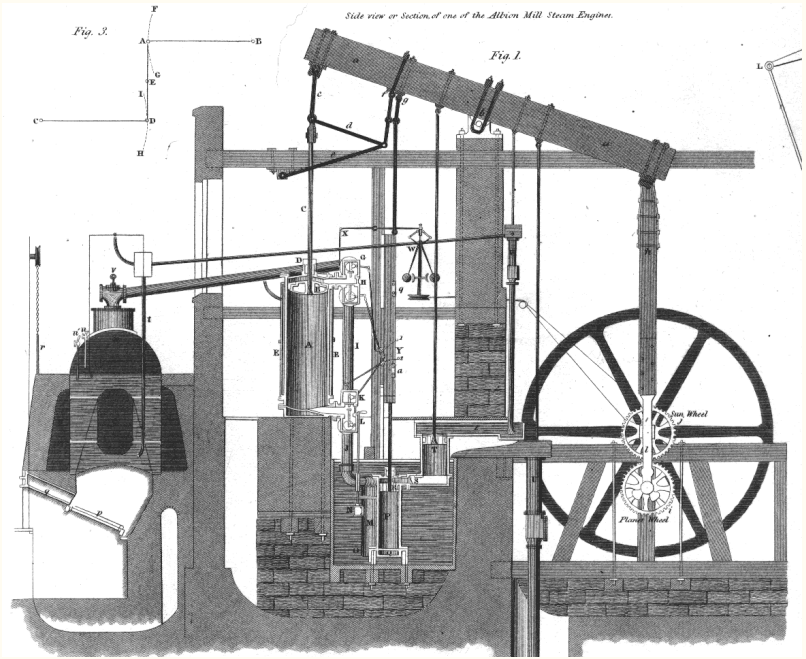

ICONISMUS XI
Fig I.
A
B
Fig IV.
Fig V.
Fig II.
D


M
L
H
E
G
F
I
I
L
M
B
B
E
A
A

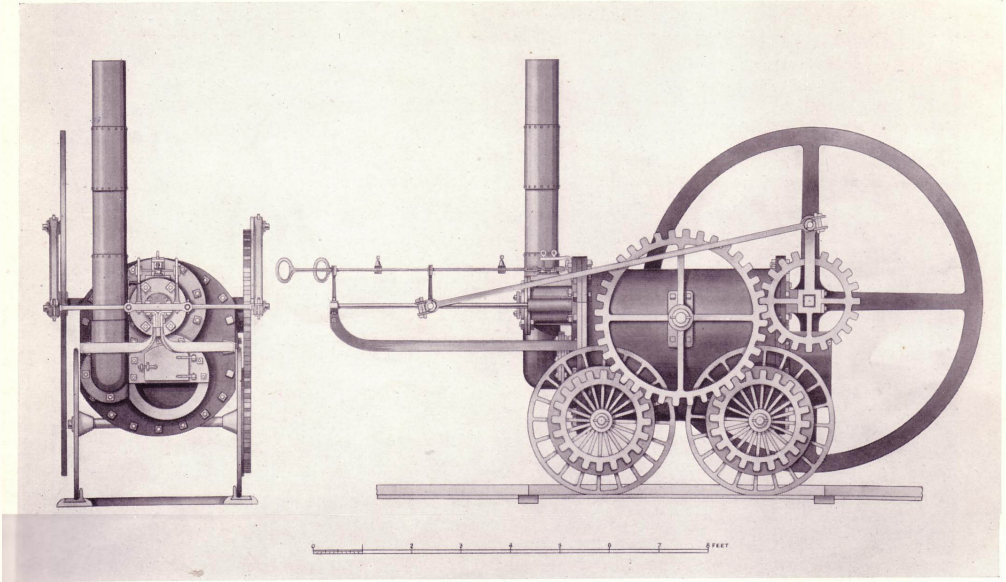

Savery Mine Pump
Cooling water
C
A
B
D
Cylinder
h_2
h_1
Water in mineshaft

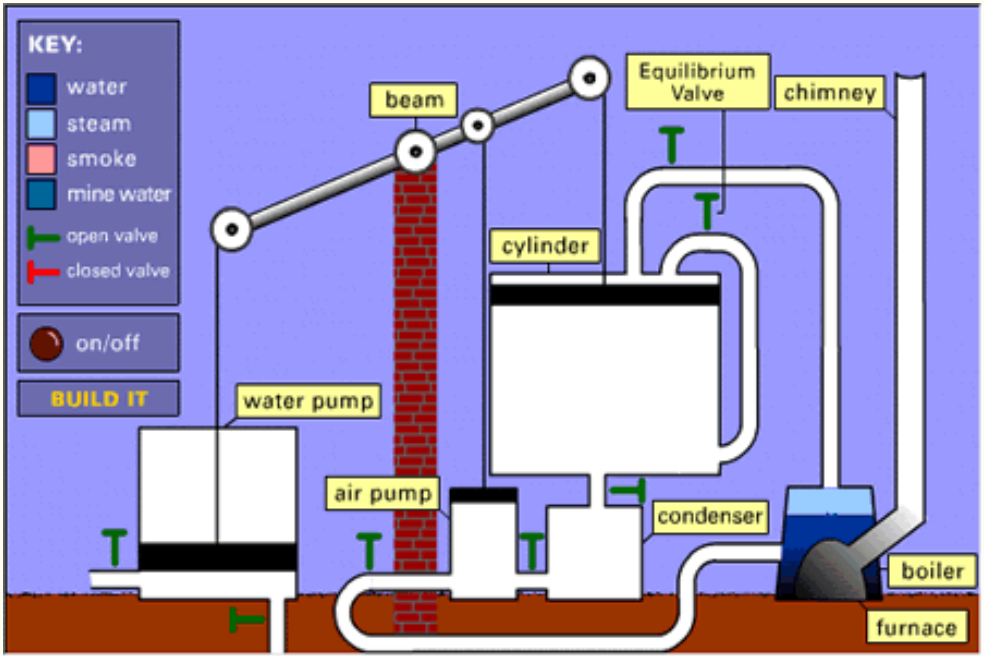


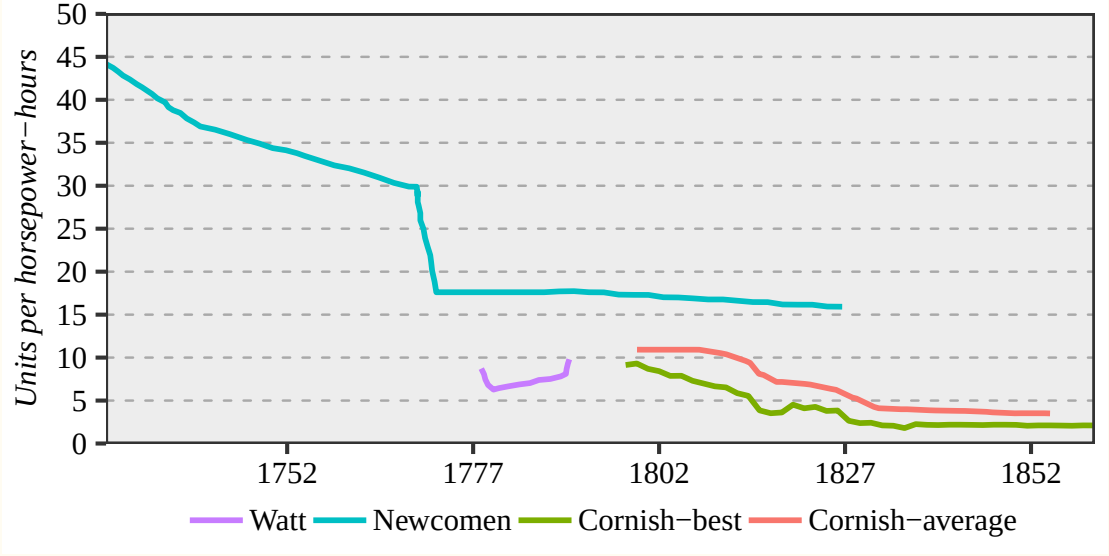


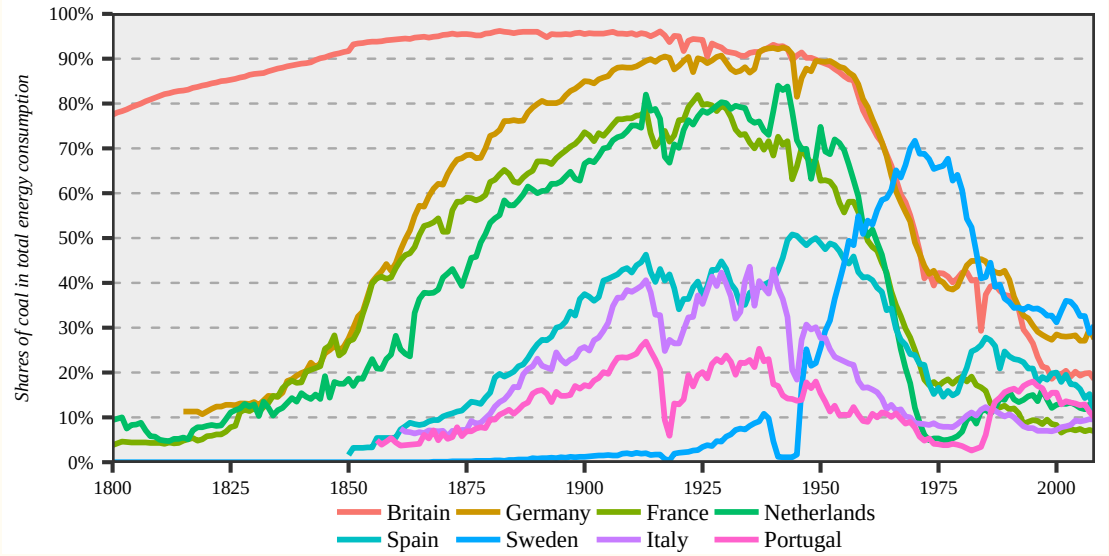

Side view or Section of one of the Albion Mill Steam Engines.
Fig. 1.
Fig. 3.
Sun Wheel
Planet Wheel

c. 1803




KEY:
water
steam
smoke
mine water
open valve
closed valve
on/off
BUILD IT
beam
Equilibrium Valve
chimney
cylinder
water pump
air pump
condenser
boiler
furnace


Units per horsepower−hours
50
45
40
35
30
25
20
15
10
5
0
1752
1777
1802
1827
1852
Watt
Newcomen
Cornish−best
Cornish−average


Shares of coal in total energy consumption
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1800
1825
1850
1875
1900
1925
1950
1975
2000
Britain
Germany
France
Netherlands
Spain
Sweden
Italy
Portugal

Oil

- Oil (petroleum: rock oil) was known since ancient times.
- Bitumen used to attach flint arrowheads to arrows, caulking boats, boiling off water to obtain salt, mummification, "greek fire," medicinal purposes.
- However, it was always a niche industry.
- Need for illumination. By the mid-19th century, whale oil was becoming too expensive.
- Also, growing interest in having high-quality lubricants that can substitute traditional lubricants such as lard.

Kerosene

- Distilling kerosene using an alembic was already known by the 9th century.
- Muhammad ibn Zakariya al-Razi (854 CE-925 CE) describes it in one of his works.
- However, the modern process starts when Abraham Gesner distills kerosene from coal (1846).
- Ignacy Łukasiewicz develops both technique to distill oil from petroleum seep (first refinery in 1856) and the kerosene lamp (1853).
- Roughly, at the same time (1851), Samuel Kier in the U.S. also develops a technique to refine kerosene and a lamp (less successful).

First oil boom

- George Bissell puts together two key observations:
  1. He notices oil deposits in Western Pennsylvania and ascertains their usefulness for refining.
  2. He realizes that you can derrick drill for oil.
- Bissell creates the Pennsylvania Rock Oil Company, hires Edwin Drake, and sends him to drill around Titusville, PA.
- Drake finds oil on August 27, 1859.
- He and his coworkers' store in 42-gallons barrels (standard since 1872).
- Industry quickly booms all across the region. Chaotic and "rule of capture."
- By January 1862, the U.S. is exporting oil to the UK. Oil compensates cotton export losses during Civil War.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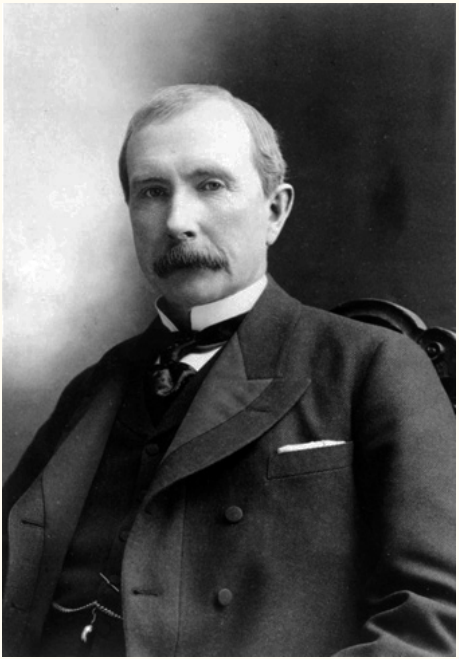
PENNSYLVANIA
POPULATED PLACES
1,000,000 and over
Philadelphia
100,000 – 499,999
Pittsburgh
25,000 – 99,999
Easton
24,999 and less
Somerset
State capital
Harrisburg
Urban areas
TRANSPORTATION
Interstate; limited access highway
Other principal highway
Railroad
PHYSICAL FEATURES
Streams
Lakes
Highest elevation in state (feet)
+3213
The lowest elevation in Pennsylvania is sea level (Delaware River).
CANADA
Lake Erie
NEW YORK
OHIO
WEST VIRGINIA
VA
MARYLAND
DE
NEW JERSEY
APPALACHIAN MTS
Erie
Edinboro
Corry
Warren
Bradford
Allegheny Res
Meadville
Titusville
Kane
Coudersport
Mansfield
Wellsboro
Sayre
Towanda
Honesdale
Carbondale
Scranton
Pittston
Wilkes-Barre
Williamsport
Jersey Shore
Lock Haven
Emporium
St Marys
Greenville
Franklin
Oil City
Sharon
Clarion
Grove City
New Castle
Du Bois
Clearfield
Punxsutawney
Butler
Kittanning
Beaver Falls
Aliquippa
Pittsburgh
Mt Lebanon
Bethel Park
Monroeville
New Kensington
Indiana
Altoona
Tyrone
State College
Bellefonte
Lewistown
Huntingdon
Raystown Lake
Johnstown
Greensburg
Washington
Connellsville
Somerset
Waynesburg
Uniontown
Mt Davis
+3213
Bedford
Chambersburg
Gettysburg
Hanover
York
Columbia
Lancaster
Harrisburg
Carlisle
Lebanon
Reading
Pottstown
Norristown
West Chester
Chester
Philadelphia
Levittown
Doylestown
Bethlehem
Allentown
Easton
Pottsville
Stroudsburg
Hazleton
Bloomsburg
Berwick
Sunbury
Shenandoah
West Branch Susquehanna
Susquehanna River
Delaware River
Allegheny River
Ohio R
Chesapeake Bay
Delaware Bay
N
MILES
0 10 20 30 40 50 60
Albers equal area projection

Why the U.S.?

- The U.S. rejected English common law, which reserved the mineral right to the crown.
- Instead, it applies the principle of *Cuius est solum, eius est usque ad coelum et ad inferos* to its latest consequences.
- Later clearly reaffirmed by courts: *Grimes v. Goodman*.
- Free entry and competition.
- High potential demand.

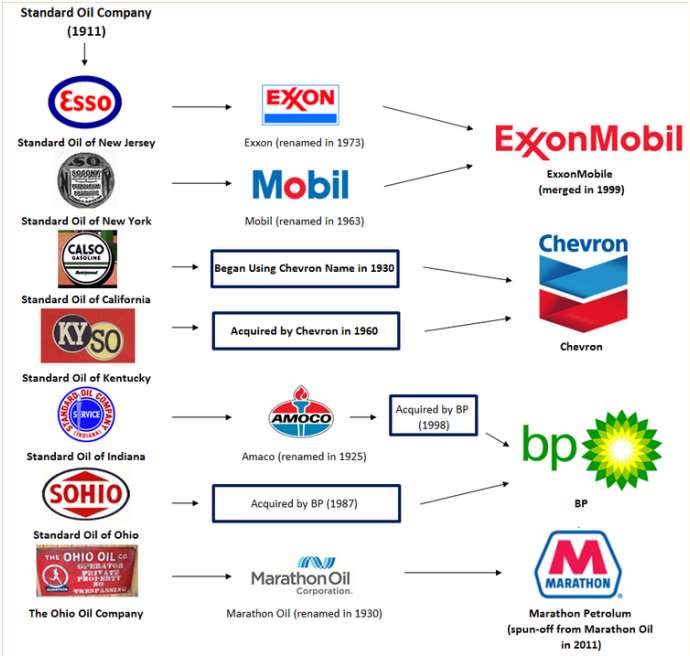
Standard Oil

- But it would be John D. Rockefeller who came to dominate the industry.
- Rockefeller is a merchant in Cleveland.
- He understands that the real money is to be made in refining and distribution.
- He founds Standard Oil in 1870.
- Through a combination of business acumen (mainly, cost control and the search for economies of scale) and predatory tactics (pricing wars, transportation rebates,...), Standard Oil becomes the near monopolist of the U.S. oil market ($\approx 90\%$ of market share).
- John D. Rockefeller becomes fabulously wealthy and deeply hated.



Breakdown of Standard Oil and new rivals

- Growing antitrust sentiment in the U.S.
- Ida Tarbell: The History of the Standard Oil Company (1904).
- Sherman Antitrust Act of 1890.
- Eventually, Standard Oil is broken down in 1911 by SCOTUS ("rule of reason").
- By 1911, Standard Oil only controlled $\approx$ 60-65 % of refining capacity.


Standard Oil Company (1911)
Standard Oil of New Jersey
Exxon (renamed in 1973)
ExxonMobile (merged in 1999)
Standard Oil of New York
Mobil (renamed in 1963)
Standard Oil of California
Began Using Chevron Name in 1930
Chevron
Standard Oil of Kentucky
Acquired by Chevron in 1960
Standard Oil of Indiana
Amaco (renamed in 1925)
Acquired by BP (1998)
BP
Standard Oil of Ohio
Acquired by BP (1987)
The Ohio Oil Company
Marathon Oil (renamed in 1930)
Marathon Petrolum (spun-off from Marathon Oil in 2011)

Breakdown of Standard Oil and new rivals

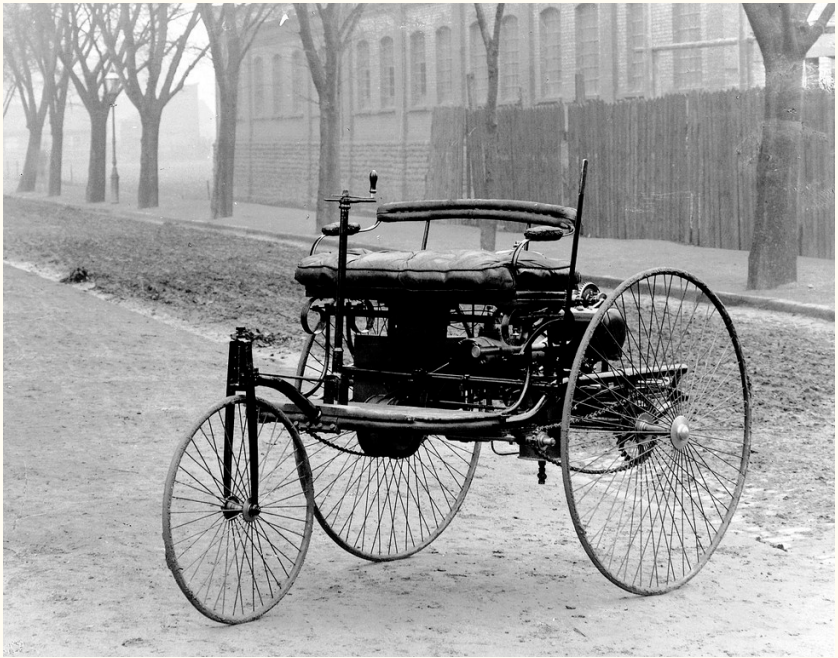
- Perhaps irrelevant:
  1. In Texas, Gulf Oil (Mellon family) and Texaco created in 1901 to exploit the Spindletop discovery (both in present-day Chevron).
  2. In California, Unocal was growing quickly.
  3. In Pennsylvania, Sunoco (Pew family) and Pure were becoming significant competitors.
  4. A few years later, in 1917, Phillips Petroleum founded (present-day ConocoPhillips).
  5. Standard Oil management was becoming old and tired.
- Independents will have more political clout than the majors (particularly important in the quota and tariff system created in 1959).
- Production in Texas (Permian Basin and the East Texas Oil Field), California, Oklahoma, and Illinois.

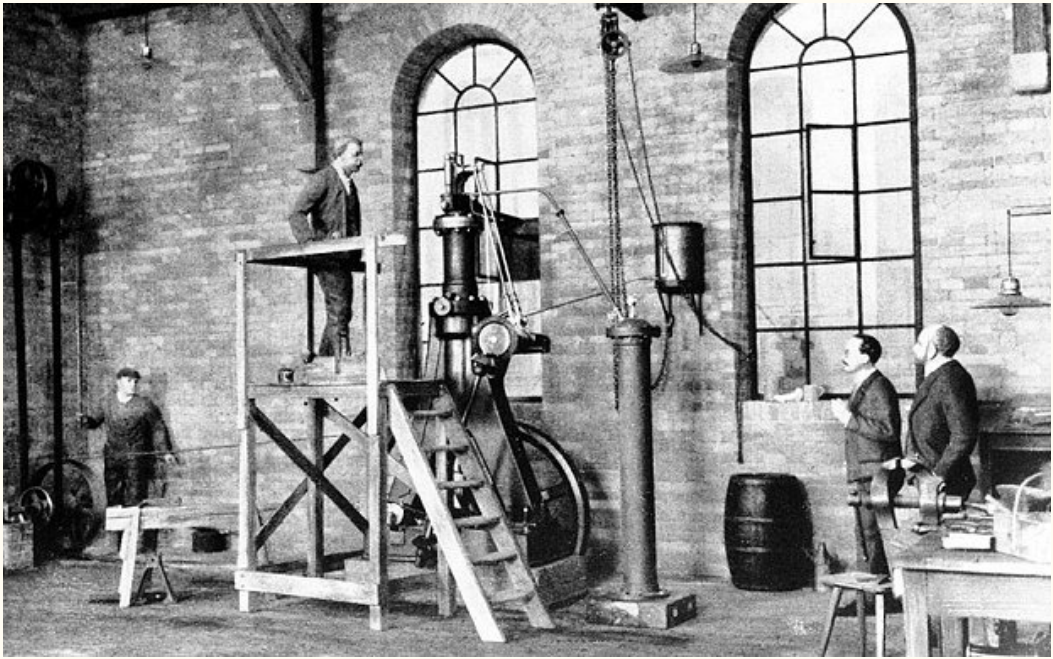
From illumination to transportation (I)

- A potentially more significant risk for the industry: incandescent light bulb.
- Long development, but critical breakthroughs by Joseph Swan (1828-1914) and Thomas Edison (1847-1931).
- Start expanding after 1879. Much better and reliable than kerosene lamps. Their use today is residual.
- Incandescent light bulbs create the modern electric power industry.
- Electricity soon extends:
  1. Industry with electric motors.
  2. Electric trains.
  3. Electro-chemicals (aluminium, chlorine, ...).

From illumination to transportation (II)

- Alternative for the industry: internal combustion engine.
- Again, long history of development, but critical breakthroughs by Gottlieb Daimler and Carl Benz. First real automobile in 1886.
- Rudolph Diesel in 1892 invents an alternative, more efficient and durable engine (originally designed to run on peanut oil!).
- Gas turbines:
  1. 1930: Frank Whittle's patent a centrifugal gas turbine.
  2. 1963 Pratt and Whitney commercializes the GG4/FT4 turbine.
- Vaclav Smil has called the diesel engines and the gas turbine the prime movers of globalization.





From illumination to transportation (III)

- Soon, the internal combustion engine becomes essential for transportation:
  1. Automobile, motorbikes, and trucks.
  2. Farming equipment.
  3. Ships.
  4. Trains.
  5. Planes.
- By 1911, for the first time, Standard Oil's sales of gasoline exceed those of kerosene.
- Up to present day, transportation is the primary use of oil and still the hardest to substitute.
- Fuel-oil was (mostly) phased-out for heating and electricity generation in rich countries after the 1970s oil crises.

Non-fossil fuel electricity

- Percentage of electricity generation, 2015:

Source	Sweden	France	Norway
Nuclear	34.3	76.6	0
Hydropower	46.7	10.7	95.8
Renewables	10.5	4.9	1.8
Fossil	8.5	7.8	2.4

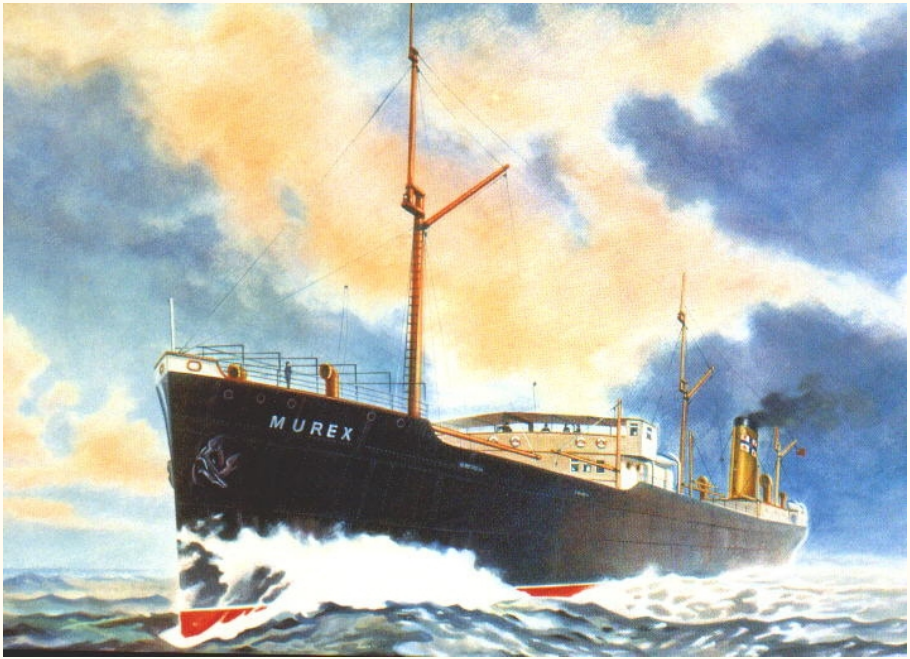
- And yet, France has to import 1.2 million oil bbl/day.
- Low energy density and cost of electric batteries.
- High cost of producing hydrogen.

Cracking

- Bottleneck: gasoline production from distilling.
- William M. Burton (1865-1954) develops thermal cracking for Standard of Indiana.
- Cracking increases gasoline output from $\approx$ 15-20% of a barrel to up to 45%.
- Opened the door to the role of chemistry in the industry.

International industry growth, I

- Oil in Baku (present-day Azerbaijan, back then part of Russian Empire):
  1. Large production starts in 1872.
  2. Largely controlled by the Nobel brothers and the Rothschilds.
- Marcus and Samuel Samuel decide to ship Russian oil to the Far East, where they have ample experience as traders.
- Key innovation: fleet of dedicated tankers: *SS Murex* (1892), which can cross the Suez Canal.
- Since the family had started their business selling shell boxes, the Samuel brothers call their company Shell.
- In 1907, Shell mergers with the Royal Dutch Petroleum Company that had operated oil wells in Sumatra. One the first transnational mergers.
- Royal Dutch/Shell directed by Henry Detrending for several decades.


MUREX

International industry growth, II

- Oil is also found in Mexico:
    1. Pan American Petroleum.
    2. Mexican Eagle.
- Mexico is the first major producing country to nationalize oil industry on 1938.
- And Venezuela. By 1929, Venezuela is second world producer.
- Smaller fields in Romania. Importance in WWI and WWII.


O. DE POTRERO DEL LLANO
POZO Nº 4
1910.

Standard Oil of New Jersey (Esso)

Royal Dutch Shell (Anglo-Dutch)

Anglo-Persian Company (APOC)

Standard Oil Co. of New York (Socony)

Standard Oil of California (Socal)

Gulf Oil

Texaco

The final seventh sister

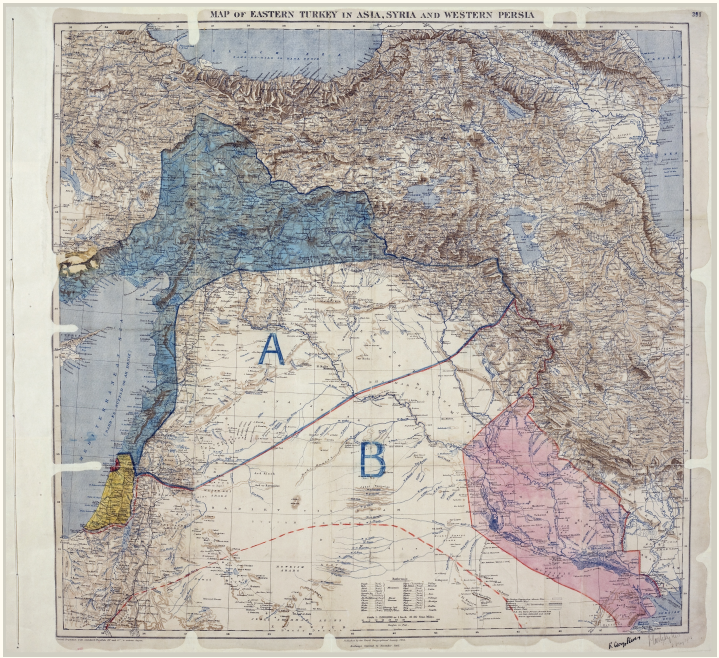
- Name coined by Enrico Mattei to refer to the companies that dominated the oil industry for much of the 20th century.
- We have already described the origins of 6 of them.
- The final sister was Anglo-Persian Company (present-day BP).
- Anglo-Persian was created in 1908 to exploit oil in Iran found by George Reynolds (who later developed Venezuelan's oil as well).
- 1914, the British government takes control of Anglo-Persian to ensure oil supplies to the Royal Navy.
- Anglo-Persian expanded to Iraq and Kuwait.

Cartelizing the world oil market

- Arrival of Persian, Russian, and Romanian oil lowers world prices.
- Achnacarry Agreement or "As-Is" Agreement signed on 17 September 1928.
- "Understanding" with Russia in February 1929.
- Export Petroleum Association by American independents (excepted from antitrust legislation by the Webb-Pomerene Act of 1918).
- Heads of Agreement for Distribution in December 1932.
- Draft Memorandum of Principles, 1934.
- All agreements collapse rather quickly. Esso withdraws in early 1938.

The biggest prize in the world

- Harold Macmillan (Prime Minister of the UK) called the oil reserves of the Middle East "the biggest prize in the world."
- Ottoman empire collapses in WWI and the UK and France divide the spoils among themselves in the Sykes-Picot agreement.
- Turkish Petroleum Company (TPC).
- French interest in creating a French oil company (CFP), directed by Ernest Mercier (present-day Total, together with Petrofina and ELF Aquitaine).
- San Remo agreement in 1920 transfers 25% German stake in TPC to France in exchange for Britain controlling Mosul region.


MAP OF EASTERN TURKEY IN ASIA, SYRIA AND WESTERN PERSIA
A
B

Red line agreement

- US opposes Anglo-French arrangement and defends an open doors policy.
- Widespread concerns about oil reserves within the U.S.
- Key person: Calouste Gulbenkian, “mister 5%.”
- Red line agreement of 1928.


MIDDLE EAST
RUSSIA
Black Sea
Caspian Sea
KAZAKHSTAN
UZBEKISTAN
TURKMENISTAN
TURKEY
Ankara
GREECE
Athens
BULGARIA
Sofia
Bucharest
CYPRUS
Nicosia
Mediterranean Sea
SYRIA
Beirut
Damascus
IRAQ
Baghdad
IRAN
Tehran
JORDAN
Amman
Kuwait
EGYPT
Cairo
SAUDI ARABIA
Riyadh
QATAR
Doha
Abu Dhabi
Muscat
OMAN
YEMEN
Sanaa
Aden
Arabian Sea
Gulf of Aden
SUDAN
Khartoum
ERITREA
Asmara
DJIBOUTI
Djibouti
ETHIOPIA
Addis Ababa
SOMALIA
Scale 1:21,000,000

Arabian oil changes it all

- Immense oil fields discovered in Saudi Arabia after 1933.
- After several years of exploration, Socal and Texaco create the Arabian-American Oil Company (Aramco) in 1944.
- When the large size of oil fields is understood, Socal and Texaco are joined by Socony and SoconyMobil to provide more capital.
- Similar moves with Kuwait Oil Company.
- This breaks the red line agreement.

Developments in the Middle East

- "Fifty-fifty" agreements pioneered by Venezuela extend to Saudi Arabia and other countries in the region.
- J. Paul Getty gets into the Neutral Zone.
- Mohammed Mossadegh and Iran's failed oil nationalization. Coup d'état in 1953.

Other post-war developments

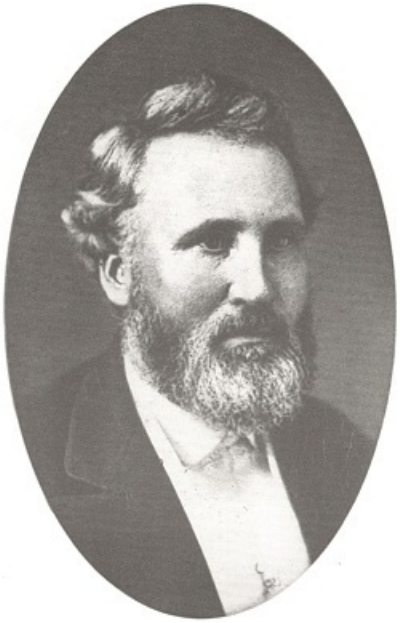
- Kerr-McGee develops know-how for off-shore drilling: November 14, 1947, on "Kermac 16."
- Start of generalized use of natural gas (Big Inch and Little Inch pipelines opened in 1947).
- ENI in Italy.
- Thus, we have present-day private western supermajors ($>$ \$100 bn. revenue in 2015): ExxonMobil, Royal Dutch Shell, BP, Total, Chevron, ENI, and Valero.
- Big boom of independents (1950s and 1960) and national oil companies (1970s and later).

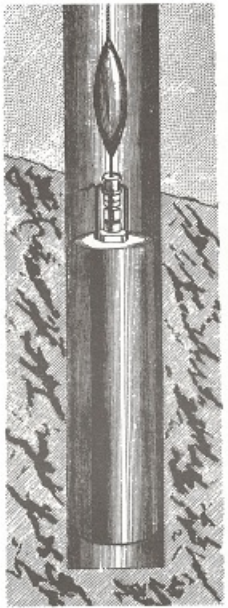
Shale oil and gas revolution

- In 2016, the U.S. produced 4.6 MMb/d of tight oil (52% of total oil production; total crude supply is 16.30 MMb/d).
- In 2016, the U.S. produced 26.58 Tcf of natural gas (consumed 27.68 Tcf).
- EIA's *Annual Energy Outlook 2017* forecasts that, by 2025, the U.S. will be a net exporter of energy.
- Tremendous increase in productivity (finding rates, recovery rates, reservoir stimulation, production costs, ...).
- How did the industry develop?

Origins, I

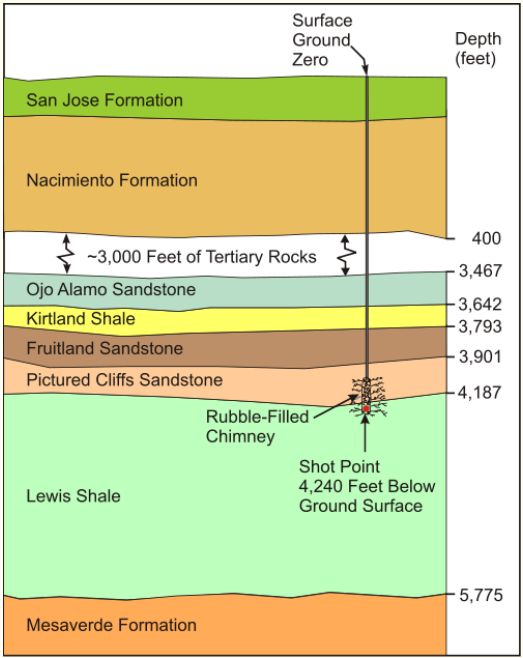
- Understanding that oil and gas can be trapped inside rocks and not being able to flow into easily-accessed reservoirs is old.
- Torpedo by Edward A. L. Roberts.
- "Moonlighters."
- Dow Chemical starts using hydrochloric acid to dissolve rocks in 1932.
- Big pressure to increase production during WWII without drilling new wells that need too much scarce steel.
- Riley Floyd Farris and Bob Fast discovered that cement fractures rocks. In November 1946, Fast intentionally fracks rock in Kansas with over-stocked napalm from WWII.





Origins, II

- Operation Plowshare: detonate nuclear bombs to frack (Project Gasbuggy in New Mexico, and Projects Rulison and Rio Blanco in Colorado).
- Federal policy:
  1. Natural Gas Policy Act of 1978.
  2. R&D support (Unconventional Gas Research Program).
- Large number of independents: Mitchell Energy and Chesapeake Energy (Aubrey McClendon).


Surface
Ground
Zero
Depth
(feet)
San Jose Formation
Nacimiento Formation
400
~3,000 Feet of Tertiary Rocks
3,467
Ojo Alamo Sandstone
3,642
Kirtland Shale
3,793
Fruitland Sandstone
3,901
Pictured Cliffs Sandstone
4,187
Rubble-Filled
Chimney
Shot Point
4,240 Feet Below
Ground Surface
Lewis Shale
5,775
Mesaverde Formation

Historical regulators of oil prices

- Three regulators:
  1. Standard Oil.
  2. Interstate Oil Compact Commission (mainly the Railroad Commission of Texas, the Oklahoma Corporation Commission, and the Louisiana Conservation Commission) to regulate the big oil boom generated by the Black Giant field.
  3. OPEC (conceived by Juan Pablo Pérez Alfonzo, founded in 1960).
- Sparse capacity to control markets by changing supply at short notice.
- Inelastic supply and demand.