Energy and Civilization

Waseda University, SILS,
Science, Technology and Society (LE202)

The concept of *Energy*

- Our modern worldview is constructed around the central concept of *Energy*. We conceive of the universe as made up of matter and energy, and from a strictly physical perspective, energy appears to be prior. Moreover, under the right conditions, they are interchangeable. ($E = mc^2$, where E is energy, m is mass and c is the speed of light).
- But this concept of energy is much broader than physics. Our entire modern civilization is founded on the consumption of vast quantities of what we call *energy*.
- We can quite easily take a reductionist stance and reduce everything in history and culture to talk about energy. (There are, in fact, limits to how useful such an approach can be.)
- Finally, we use the concept of energy loosely to talk about our social relations, art and culture in general.

The laws of thermodynamics

This central place of energy is a result of 19th-century thermodynamics and the worldview that it implies. The laws of thermodynamics: 1. You can't win (energy). 2. You can't even break even (entropy). 3. You can't get out of the game (no absolute zero).

Richard Feynman, on the 1st law of Thermodynamics:

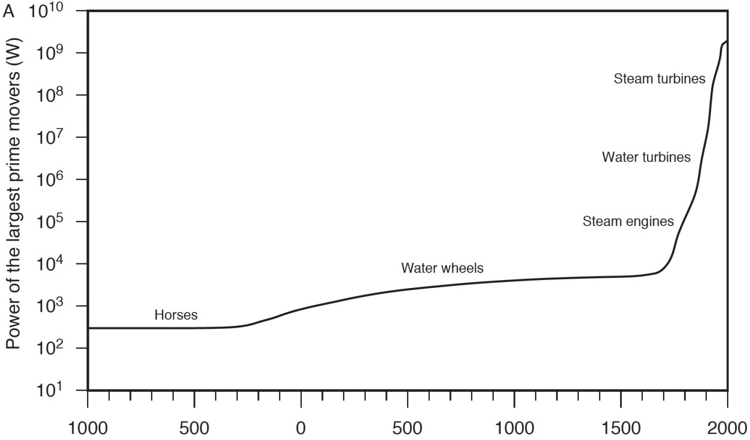
"There is no known exception to this law—it is exact so far we know. The law is called conservation of energy; it states that there is a certain *quantity*, which we call energy that does not change in manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number, and when we finish watching nature go through her tricks and calculate the number again, it is the same."

Energy and civilization

Although this conception of energy is recent, we can use it to look back at history. We can characterize the great ages of human history *in terms of the energy* extracted and used.

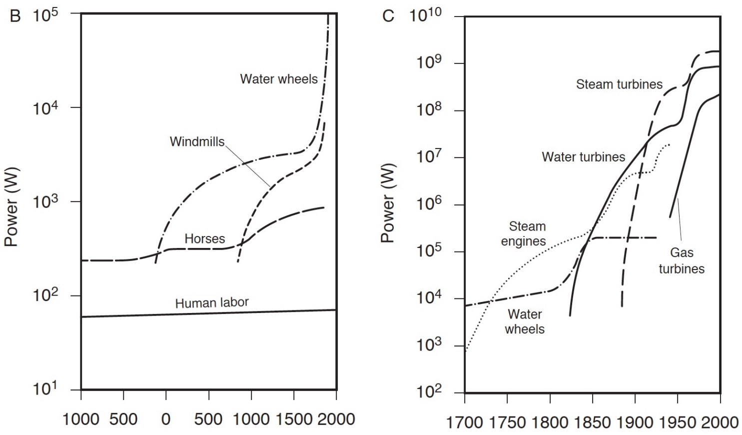
- Humans (*homo sapiens*) branched off from the other hominides roughly 200,000 years ago, and until about 12,000 years ago, all humans lived as foragers, expending energy each day to furnish that day's nourishment.
- About 5,000 years ago, humans began to build cities, to store food and use water and wind energy in the production of food and goods (Middle East, Mediterranean, Asia, etc.).
- About 1,500 years ago humans used tools to civilize less-hospitable areas (Northern Europe, etc.).
- About 300 years ago we began to build machines to do *real work*. About 200 years ago, we began to extract energy rich sources from the earth: coal, petroleum, radioactive elements, etc. ($\approx 0.1\%$ of timespan in which humans have existed.)

Power of "prime movers" throughout human history



The horizontal axis (linear) measures time from 1000 BCE to 2000 CE, and the vertical axis (logarithmic) measures maximum power in Watts (J/s).

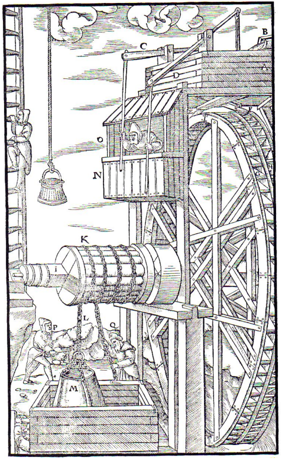
Details of the power of "prime movers"



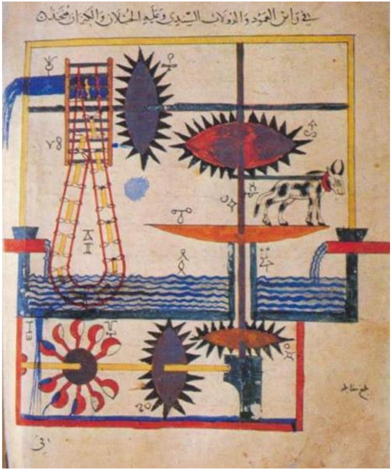
Again, notice the difference in scale between the horizontal (linear) and vertical (log) axes.

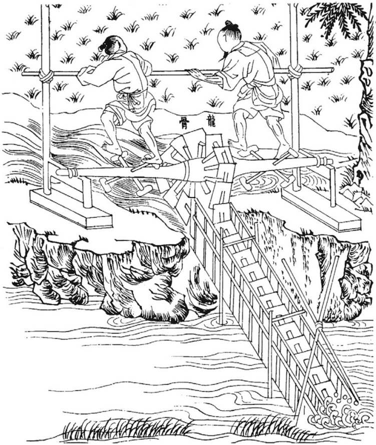
Preindustrial energy use

- Preindustrial societies used a number of *labor intensive* types of energy.
  - Animals, people, water and wind, biomass (wood, vegetable and animal oil, animal dung, peat, charcoal)
- In ancient and medieval civilizations, these were used to extensively develop human settlements, but the amount of energy was small and costly.
- Most of these technologies are fairly closely linked to agroculture.
- There was no way to store and transport *large quantities* of energy.

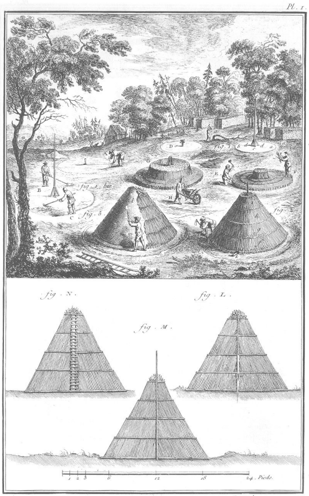


Augmented human and animal labor





Making charcoal in the 18th century



Œconomie Rustique, Charbon de Bois.

"Carbonari" in various stages of producing charcoal.

The energy density of dung is 8–14 MJ/kg, that of softwood is 21–23, and that of charcoal is 28–30.

Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers, vol. 1 (plates). Paris, 1762.

Energy density of fossil fuels

	Energy density	
Fuel	MJ/kg	MJ/m^3
Coals		
Anthracites	31–33	
Bituminous coals	20–29	
Lignites	8–20	
Peats	6–8	
Crude oils	42–44	
Natural gases		29–39

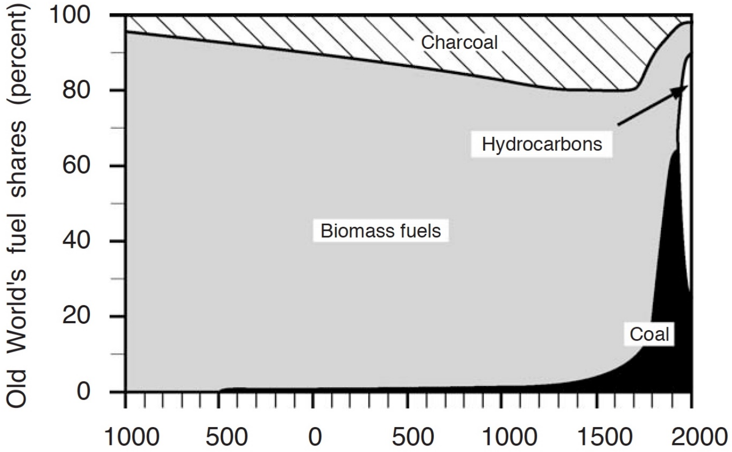
Notice that bituminous coals are sometimes in the same range of energy density as charcoal.

High energy civilization: Fossil fuels

Although the transformation has taken a few hundred years, and is still not complete, the construction of the modern world has been the result of a massive increase in the *per capita* amount of energy produced and used. This has been almost entirely due to the use of fossil fuels as our primary source of energy and to the development of new engines, or primer movers, which allow us to harness and distribute this energy in various ways.

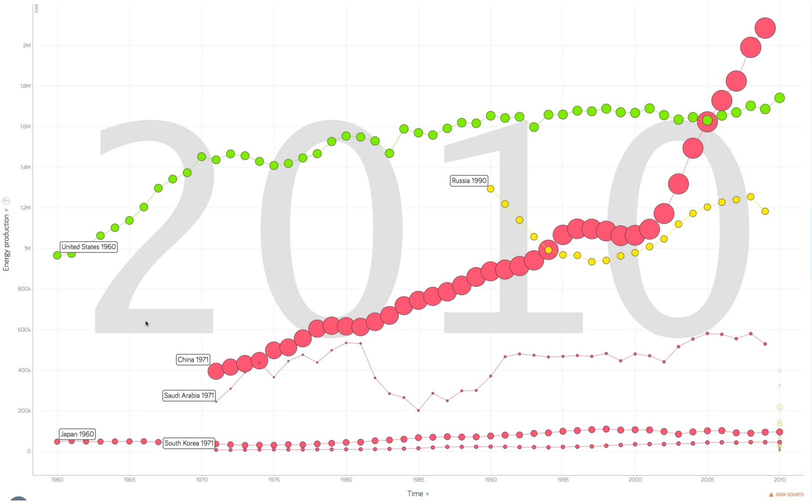
Through the direct inputs of fossil fuels and electricity, and the indirect inputs of machines and chemicals, made with and from the them, modern societies have been able to drastically increase *agricultural yields*, and hence increase human populations. This means that we have been able to produce more energy-rich food per farmer, and we have been able to increase the amount of energy in individual diets.

Transition to fossil-fueled civilization



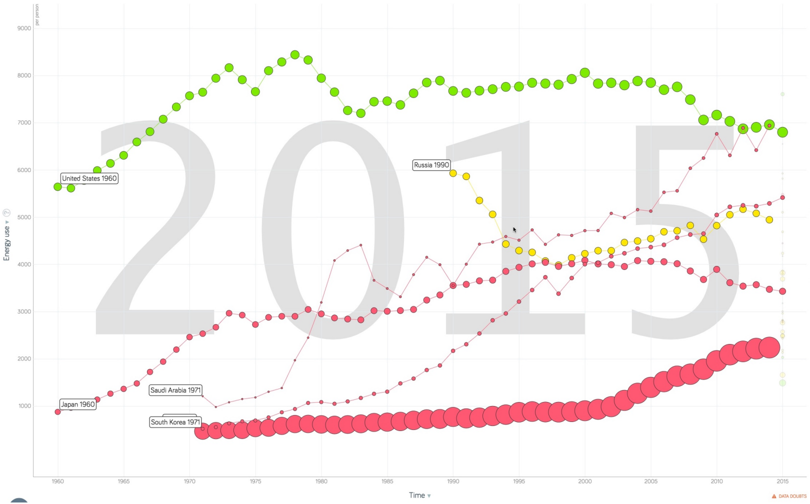
The horizontal axis (linear) measures time from 1000 BCE to 2000 CE, and the vertical axis (%) measures percentage of total use.

Recent production of energy



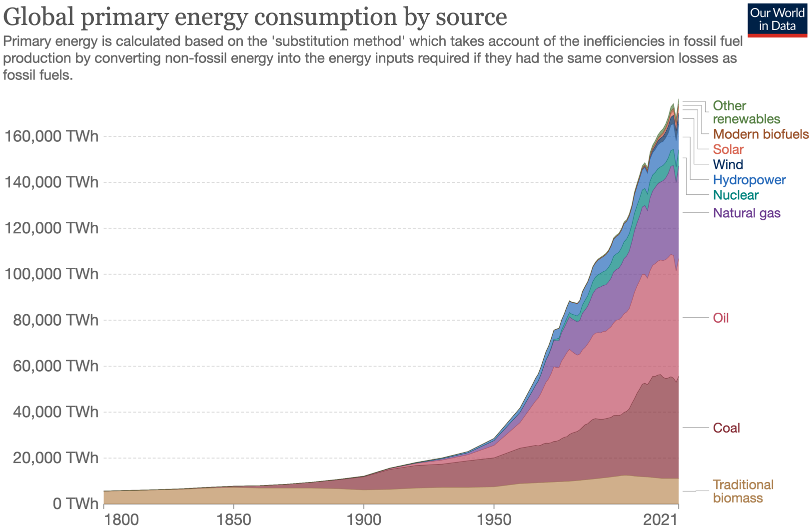
Total energy production, to 2010

Recent use of energy



Use of energy per person, to 2015

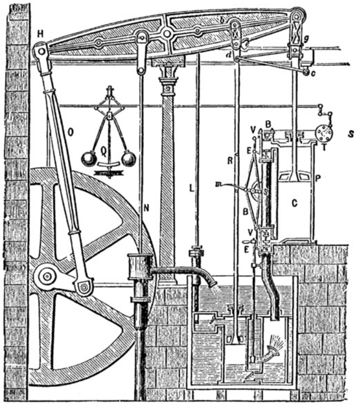
Total energy consumption, 1800–2021



Fossil-fueled civilization: peat to coal

- Peat and coal were ancient sources of energy, used by the Chinese to smelt metals and discussed by Aristotle. Use of coal, however, was always fairly modest by modern standards.
- The transition from wood and charcoal to peat was carried out by the Dutch in the 17th century. The production of coal increased 6-fold in Britain from 1750 to 1830. The American transition to coke (made from coal) was based on the availability of cheap anthracite coal in the 1830s. (Peat is 6–8 MJ/kg, coal 8–33 MJ/kg.)
- Coal was used for heating buildings, smelting iron into steel, and, most importantly, driving steam engines.
- In the 1880s, coal-powered steam engines were attached to the world's first electric generators by Thomas Edison in New York and London. These were followed by plants in Berlin, Shanghai, Tokyo, and many other cities.

The steam engine



Boulton & Watt's engine, 1784

- Boulton, 1776: "I sell here, Sir, what all the world desires to have — power."
- The steam engine, combined with coal, made possible the transformation of this cheap source of heat into work.
- Steam engines were used to power factories and locomotives.
- They were one of the driving mechanisms behind what has been called first industrial revolution.

Steam-powered production

An Adams Power Press, in use from about 1830. *The Harper Establishment* (1855).

A steam-powered loom made by Toyoda in the 1890s.

The building and drive chain have been reconstructed.

豊田式汽力織機

Fossil-fueled civilization: petroleum

- Large-scale crude oil extraction began in the late 19th century, and along with electricity, became one of the driving forces of what has been called the second industrial revolution.
- Oil is about 50% higher in energy density than coal and it is easier to transport and store (42–44 MJ/kg).
- The invention of the internal combustion engine opened up a large market for petroleum.
- The success of the internal combustion engine did not, however, mean the end of steam. Steam was used to drive the turbines in the first large electrical generators, and steam still drives the turbines in nuclear power plants.
- Petroleum is also used to produce fertilizer and feedstock for agriculture, plastics, and new chemicals used in all areas of modern life.

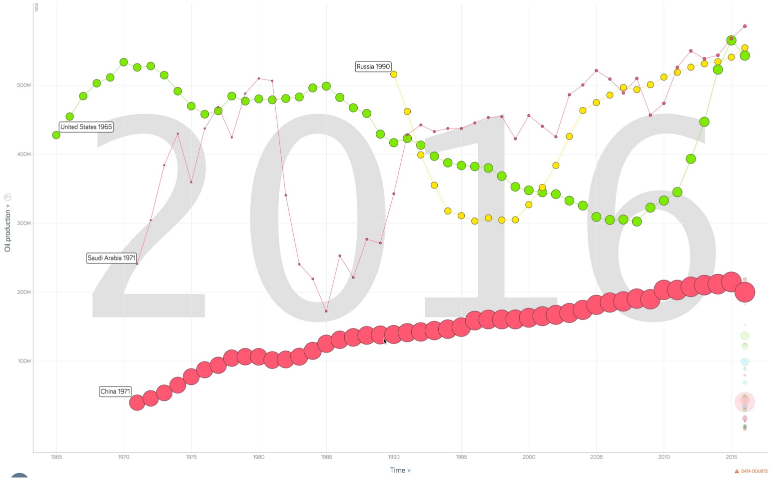
Geological formation of petroleum

Hydrocarbons and crude oil are a transformation of marine phytoplankton, zooplankton, and some algae, invertebrates, and fish. They were produced in very special conditions involving heat and pressure over up to hundreds of millions of years. This produces high carbon and low water contents, which makes them energy dense. The production of fossil fuels recovers only around 1%–.01% of the carbon in the ancient organisms.

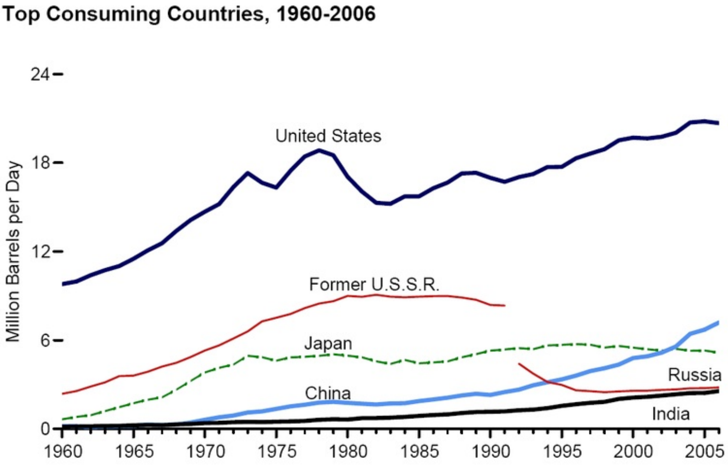
"Sweet light crude" does not exist everywhere, but only in special locations that had biologically rich histories. For example, the oil fields of Saudi Arabia were formed from dense tropical forests of the Jurassic period (-200 to -145 million ys), when there was no ice at the poles and the weather was extremely violent.

It look hundreds of millions of years for these very special natural resources to be produced, and we have burned nearly half of them in less than 150 years.

Recent production of petroleum

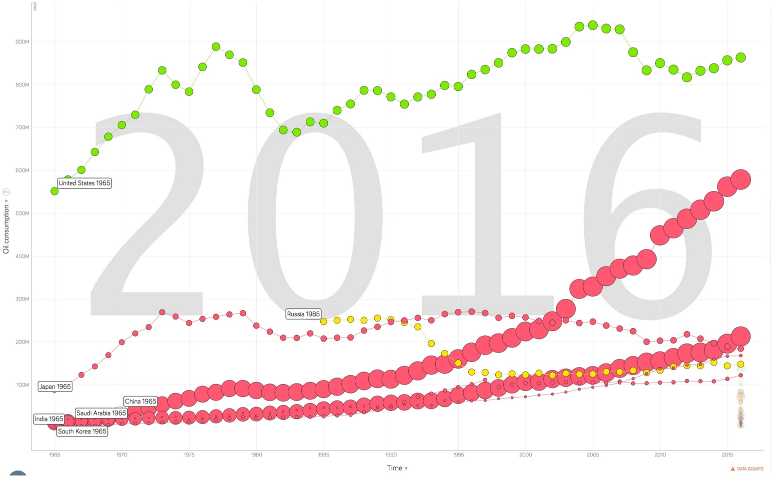


Recent consumption of petroleum



Source: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec11_20.pdf

Consumption of petroleum to 2016

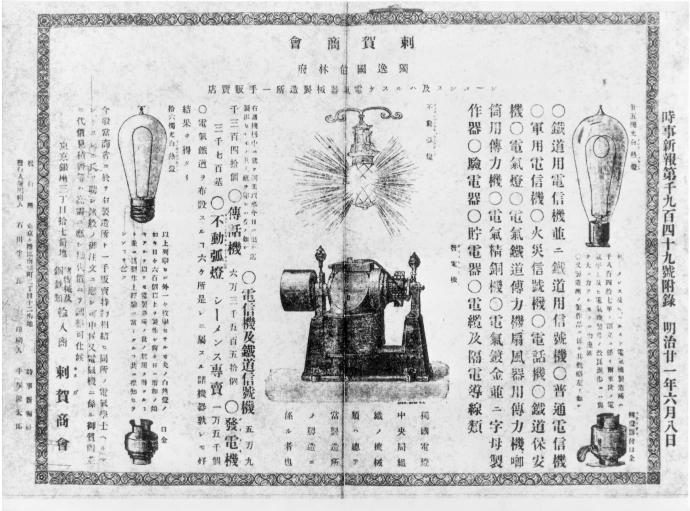


Total consumption of oil, to 2016

Electricity

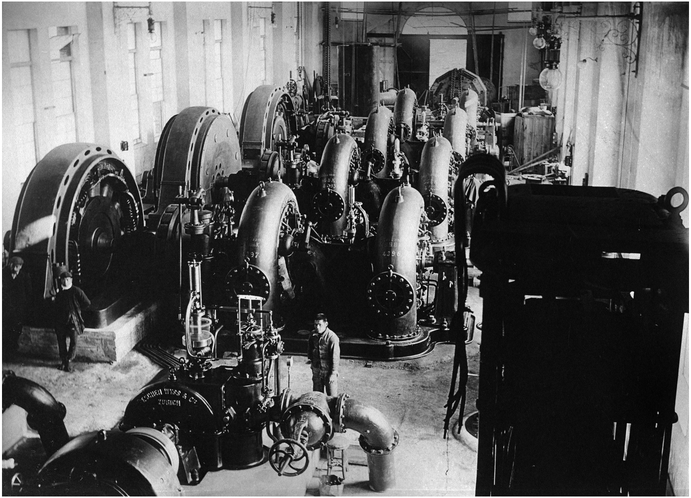
- The generation, transmission and use of electricity were unparalleled achievements in energy innovation.
- The practical use of electrical current required the invention and instillation of new *technological systems*.
- Thomas Edison and many other system builders used their vision, determination and organizational talent to make electricity a practical reality.
- The ready availability of cheap electricity has transformed the modern world, and along with petroleum, forms the energy backbone of modern life.

Electrical illumination



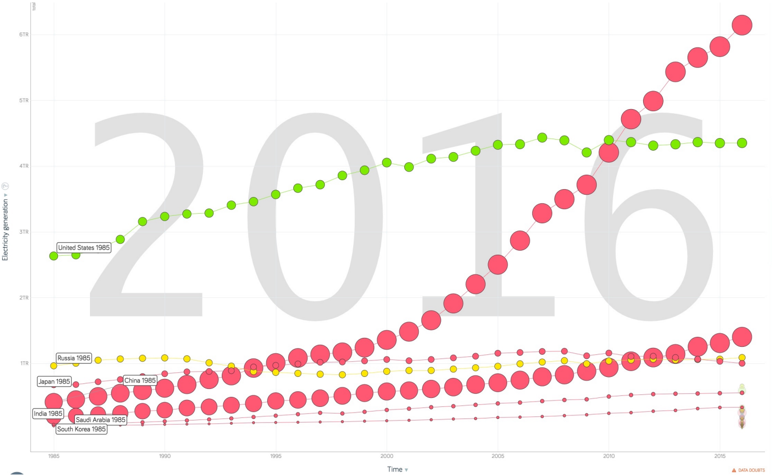
An advertisement for Siemans' electrical products, 1888

Early generation of electricity



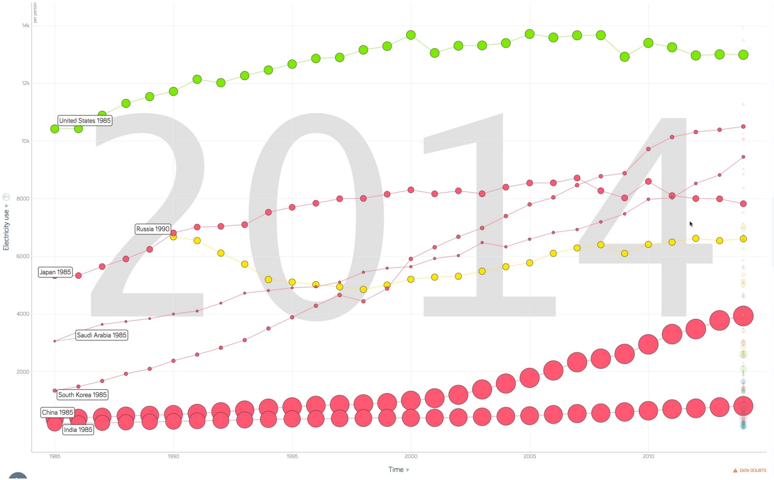
Siemans machines in the Kobu Railway hydroelectric plant, 1905

Production of Electricity



Total production of electricity, to 2016

Consumption of Electricity



Electricity use per person, to 2014

Early production of petroleum

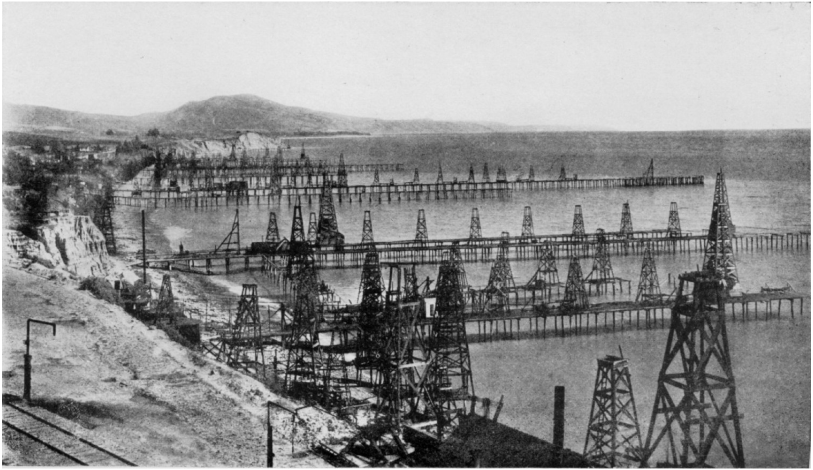
- Petroleum was used in ancient civilizations and we have records of its use in Roman, Persian and Chinese sources. The earliest crude oil wells were in ancient China, which had a crude oil industry. All of these civilizations burned the oil directly, or used it for weather-proofing, but there is no connection to the modern industry.
- The modern history begins with the refining of kerosene (1852, Lukasiewicz, Austro-Hungarian Poland) and general processes of fractionation by distillation (1854, Silliman, US).
- Around this time the first commercial wells were drilled.
- Early on, the industry was driven by a demand for kerosene and oil lamps. The development of the electrical grid, however, began to destroy the market for kerosene.

Titusville, Pennsylvania, Edwin L. Drake's well, 1859

Petroleum in the World Wars

- In the early part of the 20th century, however, the increasing availability of automobiles made the oil industry a national concern in most developed countries.
- With the construction of networks of filling stations, the infrastructure was put in place to ensure a constant supply of fuel.
- WWI irrevocably changed the role of petroleum in the world.
  - At the beginning, planning was still done in terms of *horses*. Ex. Britain entered the war with only 800 motor vehicles, but had 56,000 trucks and 36,000 cars by the end. The US shipped over 50,000 vehicles and built 15,000 planes.
- It became clear that modern wars would be fought with oil and steel, and oil began to provide a critical advantage that changed how nations regarded this resource. It is still a central part of international relations.
  - This influenced the division of the Middle East after WWI.
- Until 1940, the US was the leading producer of oil (65%).

Offshore oil wells, California, 1915



Petroleum in the postwar period

A BP oil well in Iran

- In the 1930s–40s, massive oil fields were discovered in Kuwait and Saudi Arabia.
- This shift to Middle Eastern sources, meant that the price of crude was often linked to politics in the region.
- In the 1970s there were massive "oil shocks" as a result of politics in the Middle East:
  - In 1973, after the Arab–Israeli War (Egypt and Syria against Israel), and again in 1979, after the Iranian revolution.

Great Britain, 1973

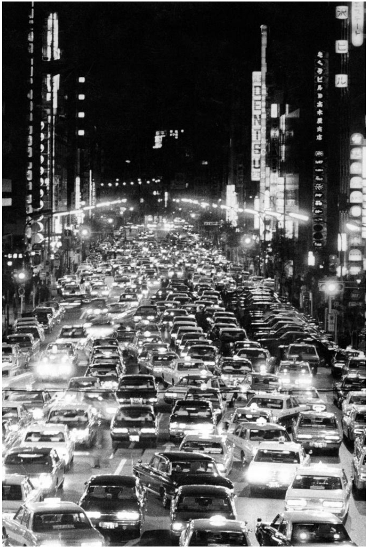
Germany, 1973

Milano, Italy, 1973

Japan, 1973

Tokyo, Japan, 1973 (節電)

Ginza, Tokyo, Japan, 1973



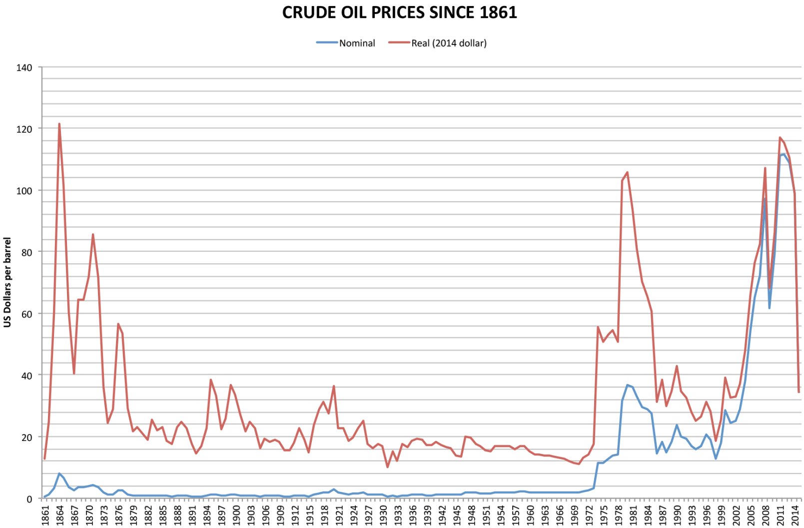
Taxi drivers in Ginza protesting gasoline rationing.

- In the 1980s, however, the Middle Eastern petroleum industry went into high production and the prices dropped again.

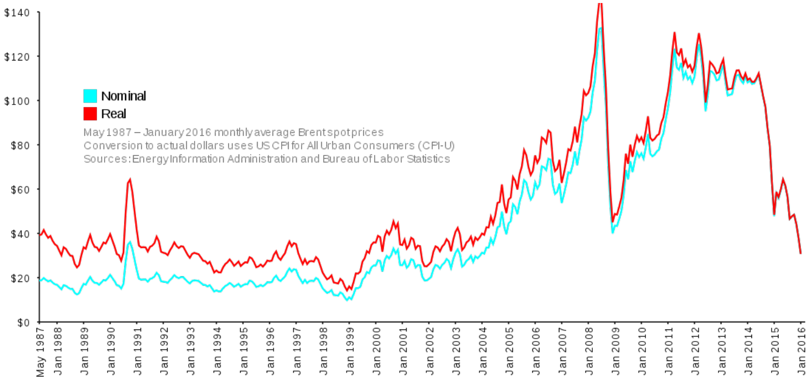
Petroleum and international relations

- Oil continues to be one of the core components of modern life, providing the majority of the energy for our contemporary societies.
  - Oil has come to mean economic prosperity and quality of life.
  - There is often a large energy gap between wealthy and poor nations.
- The role of oil, has sometimes lead to concentration of wealth and power in just a few individuals or institutions.
  - USSR under Stalin, the Saudi family, the Shah of Iran during the 70s, the Russian oligarchs in the 90s, etc.
  - State ownership of utilities, subsidization of production, manipulation of prices, high taxation of use, etc.
- The desire of oil consuming nations to secure their supplies in the Middle East has lead to much interference in the region.
  - Soviet invasion of Iran (1945-46); US troops to Lebanon (1958, 1982); Western and Soviet arms sales; Western support for Iraq; The Iraq Wars (1990-1991, 2003-2010); Libya (2011).

Oil prices, 1860s–2014



Oil prices, 1987–2016

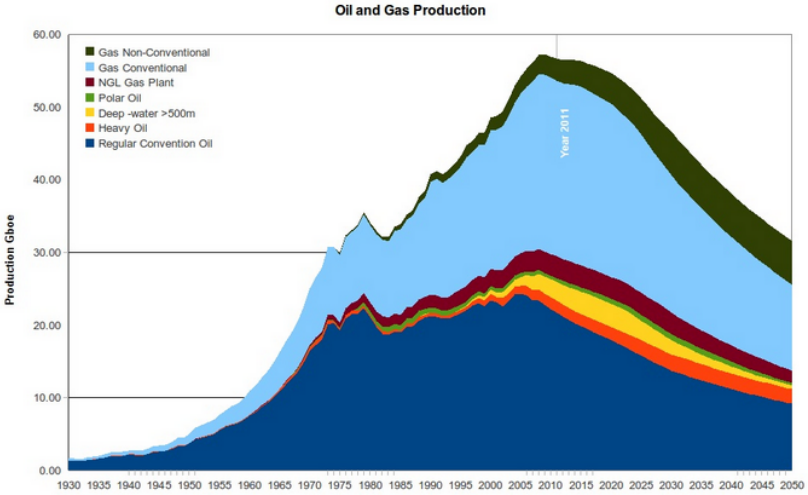


Oil prices, 2014–2023

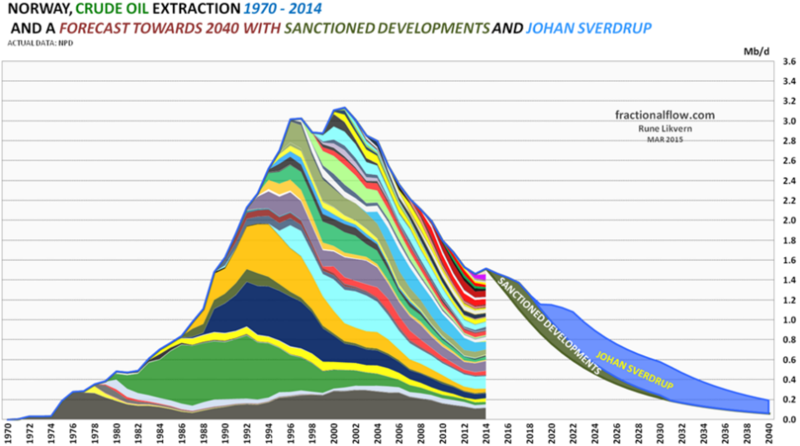
Peak Oil

- Peak oil is a concept that was developed by M. King Hubbert, in 1956, to describe the point in time when the maximum rate of oil production is reached, after which production goes into decline.
  - This is both a local and a global concept.
- Hubbert noted that after discovery, production in an oil region begins to climb at an accelerated rate and then plateau, and he modeled this to predict when production would peak and the region would go into decline.
- He was successfully able to predict that US oil production would peak in the late 60s (actual peak, 1970). (This was prior to 21st century extraction methods.) He predicted world oil production would peak in 2005. Current estimates place the year around 2010–2012.
- That is, many people believe we have now past *global peak oil*.

Oil and gas production, worldwide



Norway's Oil Production to 2014

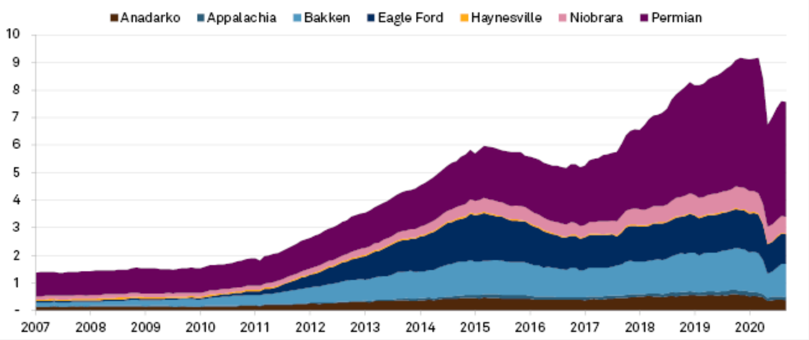


Shale Oil, and Natural Gas

- Recently, new techniques for extracting oil and gas — known as hydraulic fracking — have lead to new reserves of crude oil and natural gas being declared.
  - For example, North Dakota, which started producing in 2006, was producing almost as much crude as Texas until 2014.
- These changes will push the date of peak oil back — but not by much, both locally and globally — and they will alter the global economic picture and balance of power.
- There are, however, environmental costs to developing these types of energy sources.
  - Production itself produces contaminants that might harm the local land and water — water containing toxins is pumped back into the ground as part of the process.
  - In natural gas fracking, natural gas is often released into the ground and directly into the atmosphere.
  - Moreover, with more cheap oil to burn, we will continue to pollute the atmosphere, causing further global warming.

US Shale Oil Production

US shale oil production (million bbl/d)



As of Aug. 17, 2020.
Source: U.S. Energy Information Administration

Oil Consumption

- The demand for oil is very high and still climbing.
- At the end of 2019, the world used about 95 million barrels of oil a day, of which
  - India consumed 5.2 million barrels a day,
  - China consumed 14 million barrels a day, and
  - US consumed 19.4 million barrels a day.
- At the peak of the COVID19 lockdowns in 2020, the global demand for oil only dipped 7%.

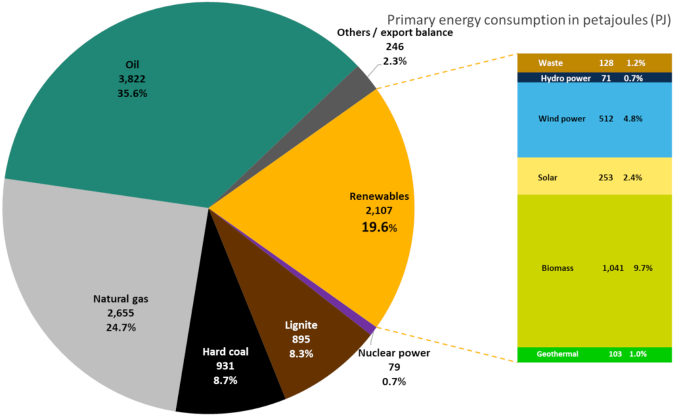
Economist, October 2003

Renewables

Since the 1970s, there has been a lot of faith placed on renewable sources of energy to replace fossil fuels, but these have so-far not lived up to their promises.

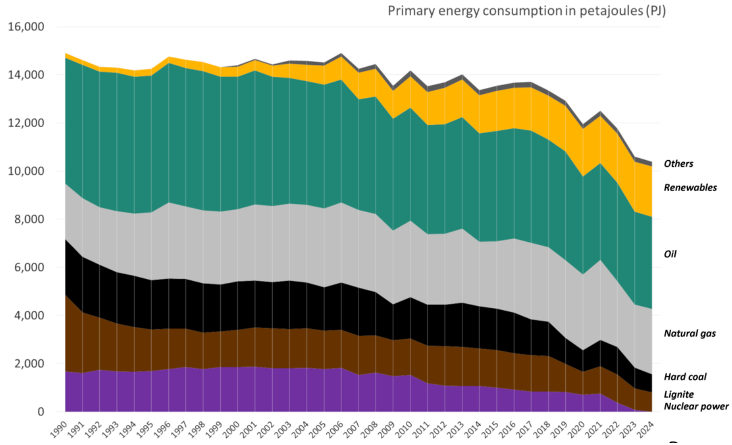
- Renewables are less efficient than fossil fuels, so after 30–40 years, they still only make up a small percentage of our energy budget. (We must distinguish between power and energy.)
- The infrastructure for renewable sources requires a huge amount of natural resources, including fossil fuels.
- A considerable part of renewable energy is *biomass*, which is simply *burnt*. This is inefficient and polluting.
- The infrastructure of renewables is fairly short-term and disposing of its waste is polluting and requires fossil fuels.

A small part of the solution



Germany's energy mix in 2023. We see that renewables account for only 19.6%, and "clean" sources account for $< 10\%$. Germany is regarded as one of the leaders in "clean" energy sources. (+3% in 5 years.)

A gradually changing situation



Germany has reduced consumption in total, and increased the use of renewables. But they have also lost a lot of heavy industry in this time.

A strain on resources

Many of the minerals, such as lithium, needed by the “clean” energy industry are highly polluting to local environments, and in insufficient supply to replace current methods.

Biomass energy

A large portion of "renewable" energy comes from biomass, which often involves cutting down forests, chipping the trees and burning the results. It is not clear that this is really renewable; it is certainly not clean.

“Clean” energy pollution

Solar panels are highly polluting to produce, they do not last very long, and when they break down they are highly polluting to the local ground water.

“Clean” energy waste

Wind turbines require a lot of fossil fuel energy to make and install, they do not last long, and they produce mountains of unreusable waste.

Final Remarks

- We have looked at the idea that energy is a fundamental *concept* and also as a kind of *entity*.
- We have considered the idea that civilizations can be characterized by their usage of energy.
- We developed a picture of the modern fossil-fuel based civilization.
- We have looked, briefly, at the recent history of petroleum.
- We have looked, briefly, at the so-far empty promises of renewables.