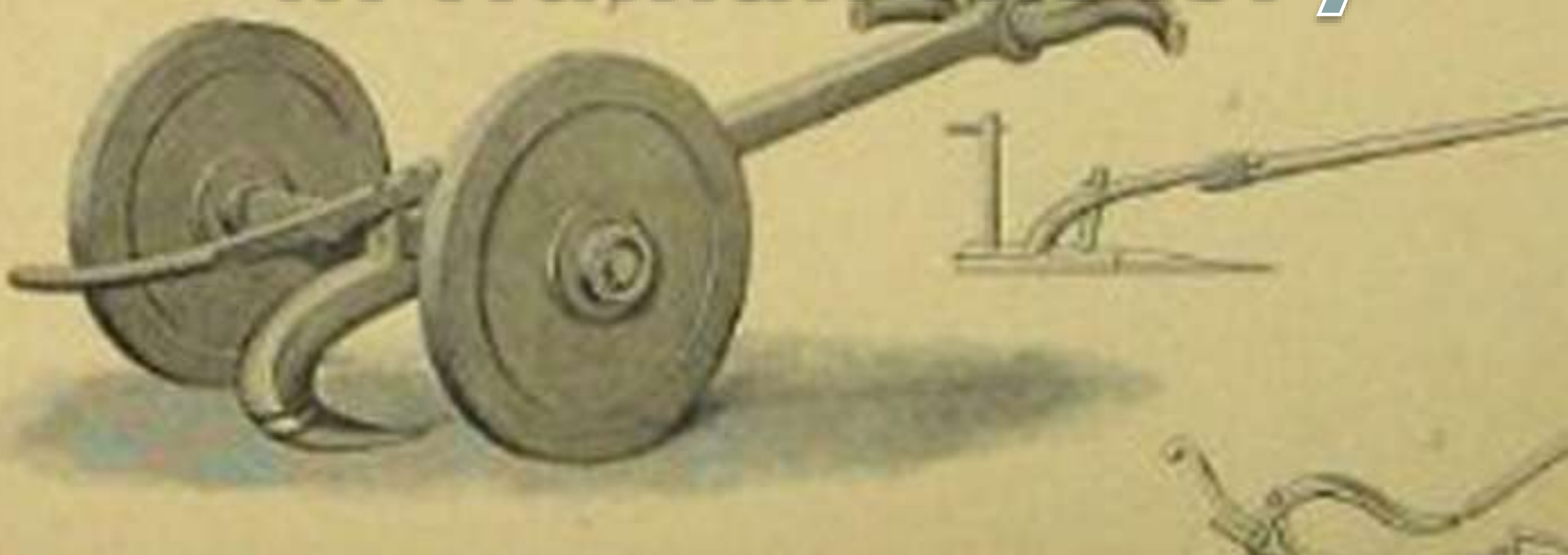
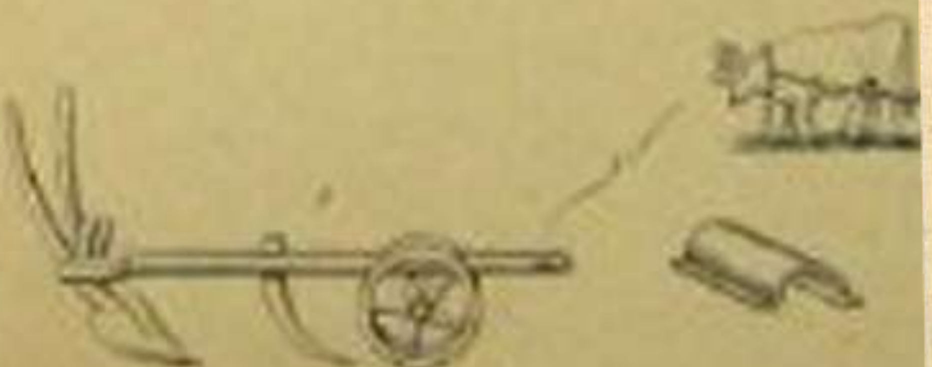
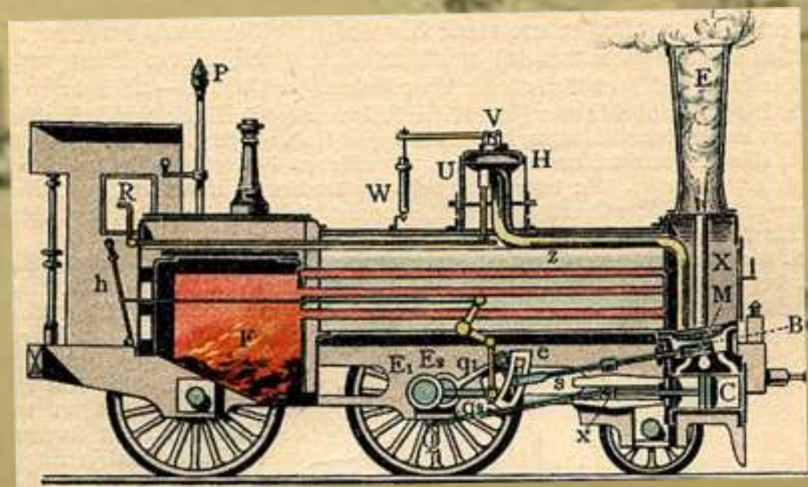
Tools and Fuels in Human History







Agenda for Section (Sustainability @ "Anthropocene")

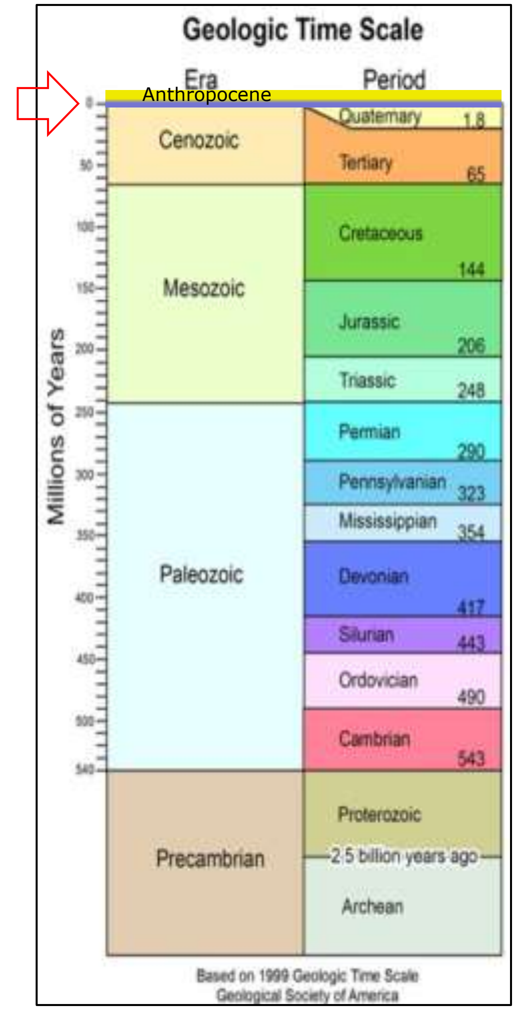
Grand picture Habitat and resource utilization

- Energy concept, human utilization of Energy
- Tools and fuels in human history

- Sustainability of Human Activity & Life on Earth,
  Limit to growth, Club of Rome,
  Socio-economic/ecological network.

- Finite resources: arable land and water for food production, materials for fabrication & construction, fuels for machinery & transportation,
  Human eco-footprint, choices, and dilemmas,

- Energy utilization and environment,
  Energy consumption and human development
  External costs of energy use,
  Planetary climate, greenhouse effect.

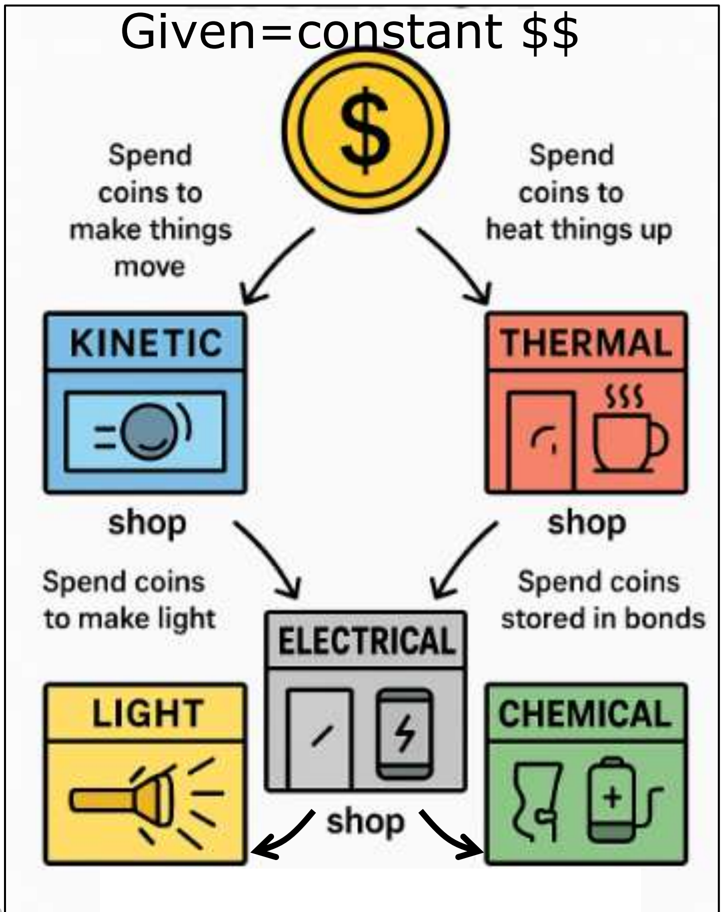


The Energy Concept

General meaning of "Energy": a measurable capacity to affect changes in material properties (movement, internal constitution), to do physical/chemical work. Different convertible types of energy: potential, kinetic, bonding, …

Conservation Law

Total energy existing at any point in space-time remains constant



Simple illustrative model:
Energy ≙ constant amount of funds, can be spent different ways (purchases of goods/services). Each "shop" has various items for sale.

Total value of purchases remains constant.

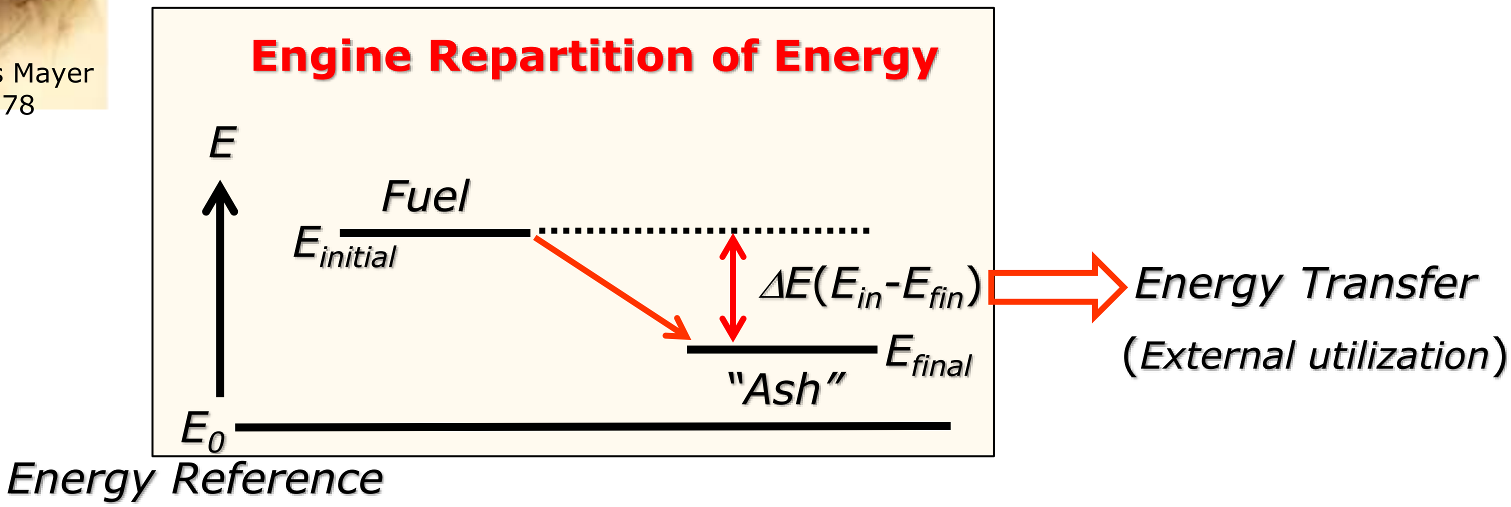
Not included: VAT tax in each exchange purchase = useless "waste"

Tools/Engines

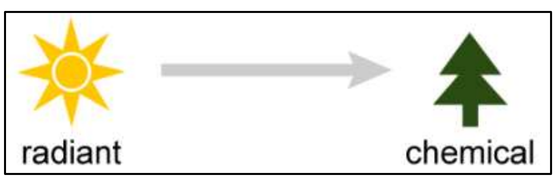
Schematic of Human Energy Utilization

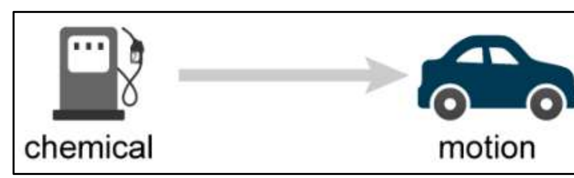

Robert Julius Mayer
1814-1878

Conservation of Energy =1st Law of Thermodynamics (TD)
Energy in an isolated system can never be created or destroyed. It can only be transformed. Only energy differences count.



Examples For Energy Conversion





Main Human Energy Utilization: Tools & Fuels

- Production and processing of food (hunting, gathering, farming, agriculture,…, cooking)
- Shelter, sanitation and healthcare
- Transportation of goods and personnel
- Warfare
- Communication, intellectual & cultural development

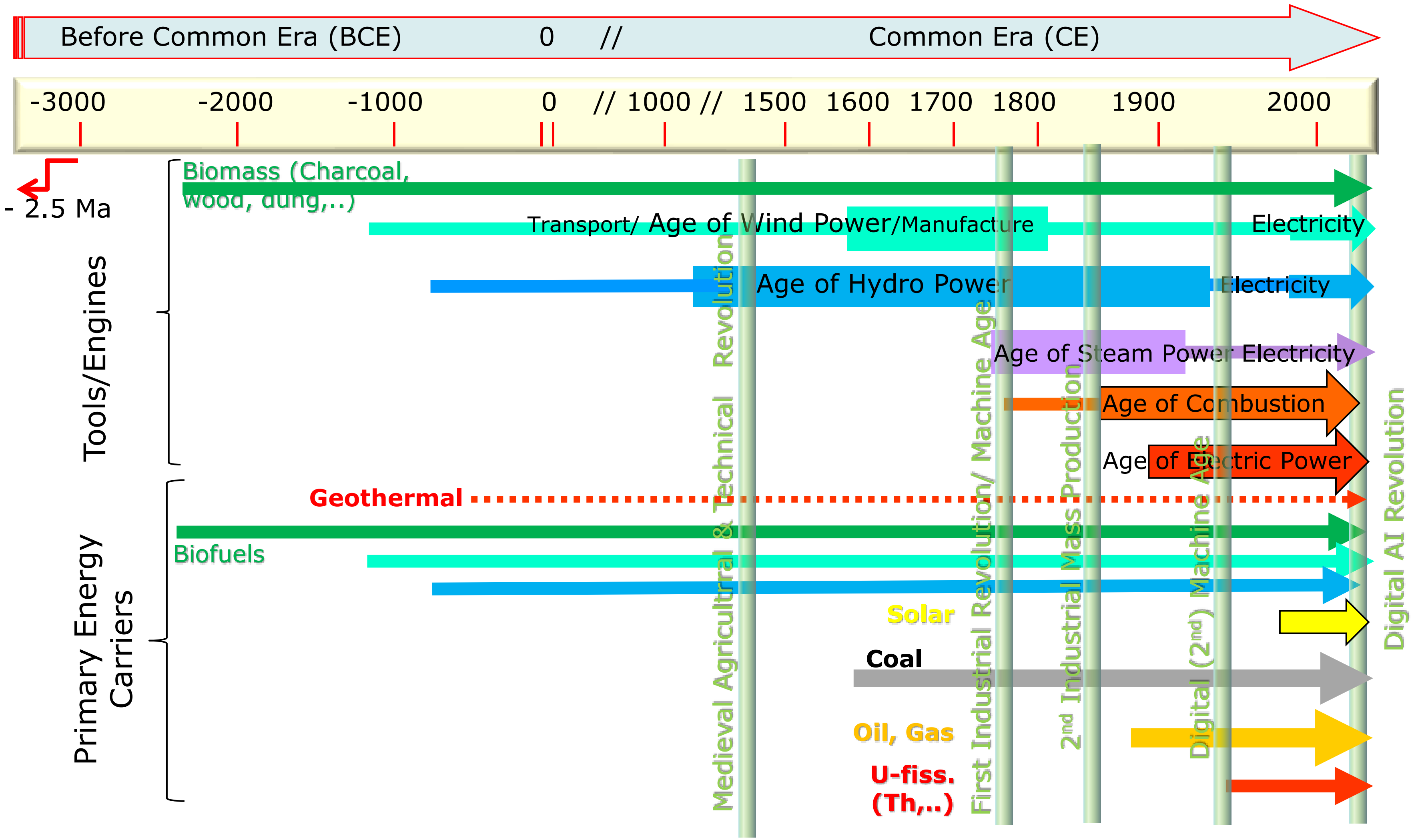
Historical evolution of technologies for harnessing of energy resources→ Development of methods and tools (engines, fuels) for performing work, energy prospecting and "production."

Parallel, overlapping evolution pathways → complex network.

Major Technical Revolutions (Western/Global)

Period	Name	Core Innovations, Tools	Energy Source/ Driving Force	Social & Economic Impact
∽30ka BCE-400 CE	**Prehistoric to Classical Eras**	Fire, surface soil plowing, Basic tools: Inclined plane, lever, pulley, screw, wedge, wheel and axle, bronze and iron metal tools & weapons	Human & animal (oxen, horses,..) muscular work, Combustion of biomass (wood, dung,..), geothermal springs, solar insolation, wind (sails)	Feudalistic class organization, agricultural subsistence
10^{th}–13^{th} c.	**Medieval Technical Revolution**	Heavy plow, horse collar, watermills, windmills, mechanical clocks, Gothic architecture	Human & animal muscular work, water wheels, windmills Biomass (wood, dung,..),	Agricultural surplus, population growth, urban revival, rise of trade and crafts
Age of Enlightenment (1680-1790), Laboratory Science				
1760–1840	**First Industrial Revolution**	Laboratory physics & chemistry, Steam engine, mechanized textiles, carbon-iron mills, canals & railways	Coal combustion, steam, natural gas (coal gas, town gas), animal fat	Urbanization, factory system, rise of working class, capitalism & industrial middle class
1850–1914	**Second Industrial Revolution (19^{th} c. Technical Revolution)**	Steel (Bessemer), electricity, petroleum, chemical industry, tele-communications, railroads, military (cannons, tanks), early automobiles, airships, airplanes.	Coal and oil combustion, electricity, internal combustion engines, steam-, gas-, water-turbines	Global trade integration, rapid urban growth, science–industry link, labor movements, imperial expansion (globalization 1.0)
WWI (1914-1918), WWII (1939-1945)				
1950s–today	**Digital Revolution / Second Machine Age**	Material chemistry, plastics, computers, microchips, nuclear fission, air & space technology, , hydraulic fracking, mobile, internet, robotics, 3D printing, bio-med techn. IoT,	Coal, oil and natural-gas combustion, electricity, hydroelectricity, digital information, emerging renewables, nuclear fission power	Post-war blocks, national order, Knowledge economy, automation of work, globalization 2.0, digital platforms, "social media," growing inequality
2010s–today	**AI Revolution**	Smart phones, machine learning, deep learning, generative AI, autonomous systems, AI + biotech/nanotech/quantum	Gas and oil combustion, hydro-electric, Data + algorithms, advanced computing power, data centers	Intelligent automation, new industries. productivity gains, job disruption, ethical/ regulatory challenges, geopolitical competition

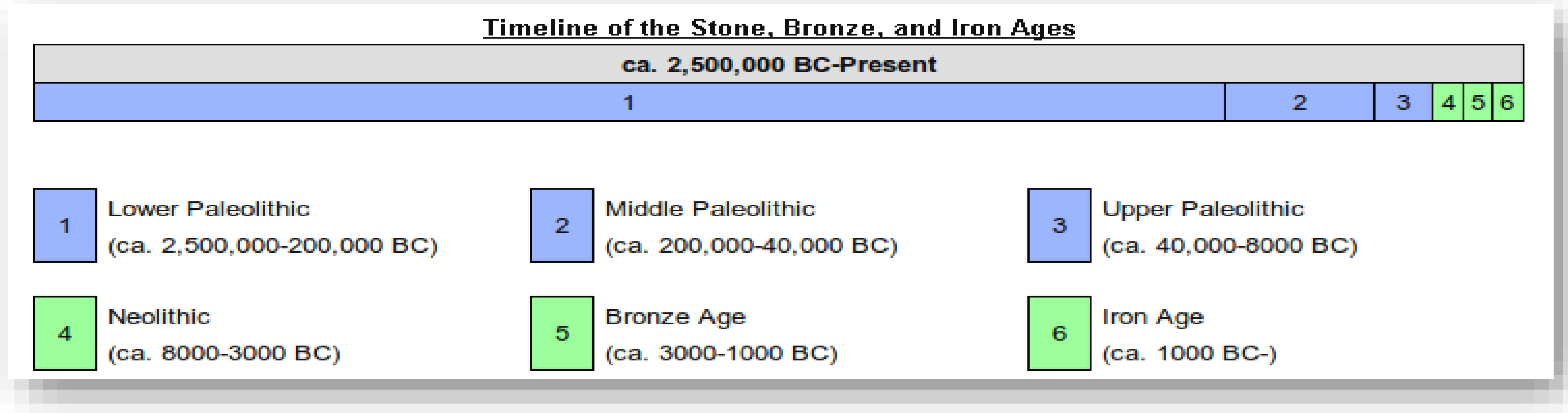
Timeline Energy Tools & Fuels (Western/Global)

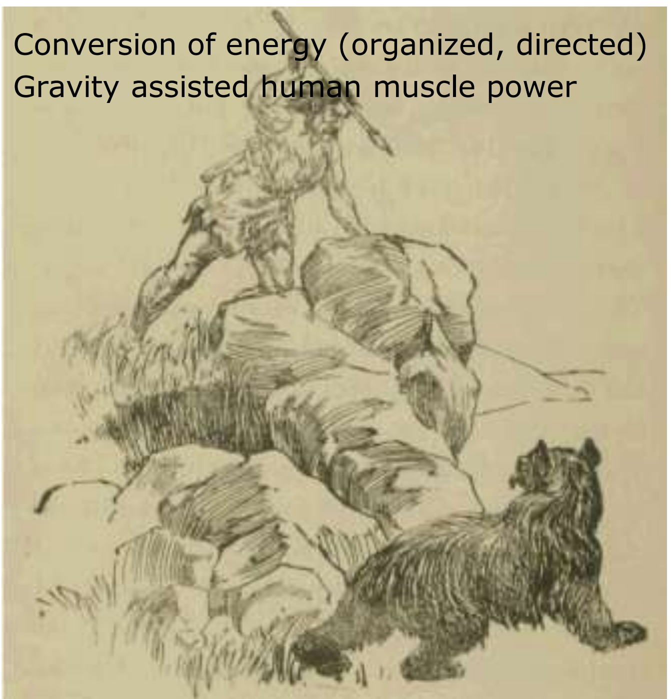


Future: Proven technologies using ample resources efficiently (sustainably) will likely remain vital. Others need exploration/improvement.

History in illustrative examples →

Prehistoric Energy Conversion Methods





Objects set in motion→ directed energy = momentum

Fire-A Most Versatile Tool

Discovery News (2012): Scientists analyzed material from *Wonderwerk Cave* in South Africa. Evidence for controlled use of fire by humans < - 1 Ma BCE (lower paleolithic age).

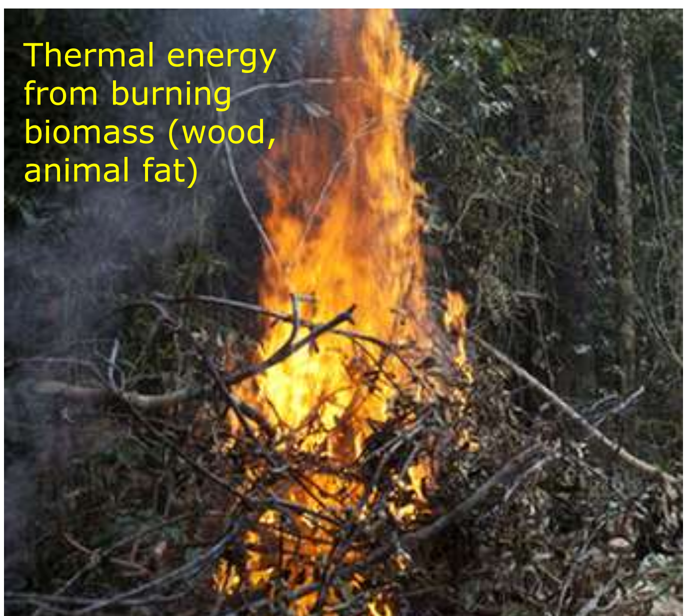
Chemical energy conversion→diffuse heat energy

Opened new avenues for evolution, as well as for new tools and technology. → bronze and iron ages

Controlled fires and cooked meat → human brain evolution.

Fire needs fuel !

Wood burning during millennia decimated forests everywhere
Examples: Deforestation of Lebanon (BCE), England (>1650), Africa, South America, SE Asia, Haiti,…. (rainforest now)



New technologies

Charcoal - Potent Biofuel (From Wood/Plants)

Charcoal production invented a Bronze Age.

Still used in the 19th century, rural European areas also much later.

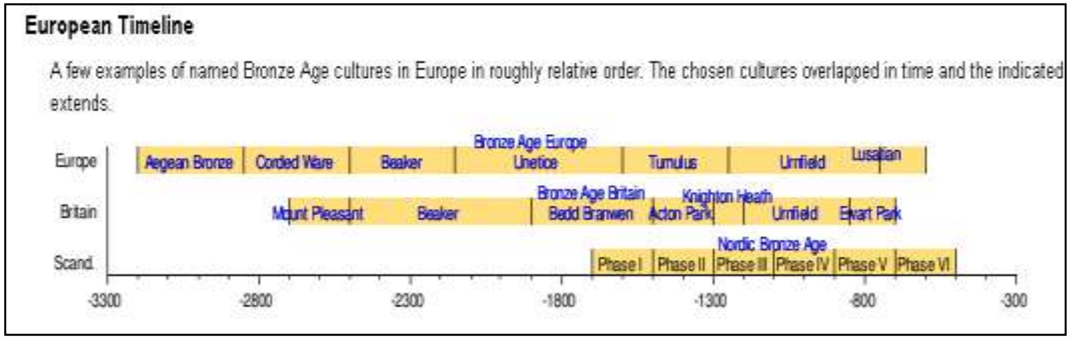
Mostly now in Africa

Similar process produces "town gas" = synthetic gas (pyrolysis)

Charcoal: Dark grey residue (carbon + ash) of slow pyrolysis = heating of wood or other organic substances in the absence of oxygen. This removes water and volatiles.→ impure form of carbon since it contains ash. → soft, brittle, lightweight, black, porous material resembles coal. Higher heating value than wood.

Bronze Age (3000-1000 BCE)

Bronze Age: Humans start using metals, first pure copper, along with stone tools, then bronze (alloy: typically 88% copper and 12% tin). Bronze melts at lower temperature (930-950 ^{0}C) than Cu (1084 ^{0}C) or Fe (1536 ^{0}C). Bronze is poured into molds.

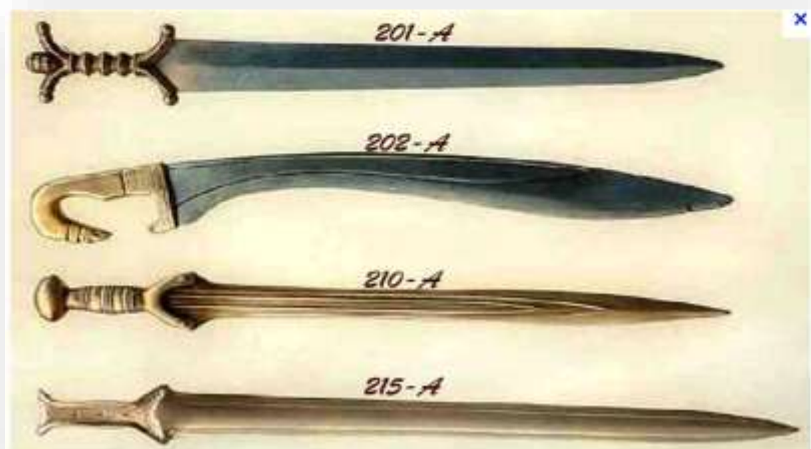


Artifact (Bronze)

http://www.a-work-of-art.net/page02.htm

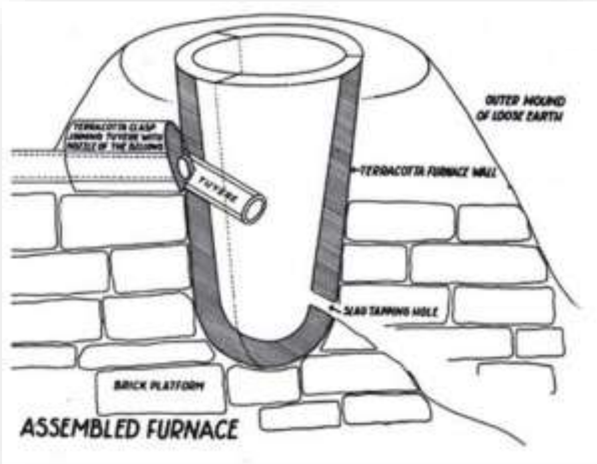
Reenactment/Wikipedia

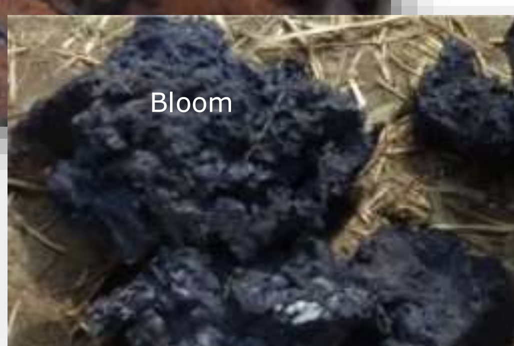
Sharp edged and long tools/weapons become common. More efficient than stone tools.



The Iron Age (1000 BCE - …)

Bloomer Smelt Oven





1000 BCE: End of Bronze Age, beginning of iron age. Earlier, iron was rarely used, mostly for decorative purposes.

$$FeCO_3 \text{ (Siderite)} \rightarrow FeO + CO_2$$

Burning wood/charcoal produce carbon monoxide (CO), metallic iron is produced:

$$FeO + CO \rightarrow Fe \text{ (solid)} + CO_2$$

Produced iron not molten, but "Bloom" → remelt/reheat + forge into shape of tools and weapons.

→ Early in Iron Age discovered steel (crucible steel, ingots).

Steel: alloy of iron and carbon, stronger than pure iron, can be forged into lighter tools, sharper edges. →

The masters

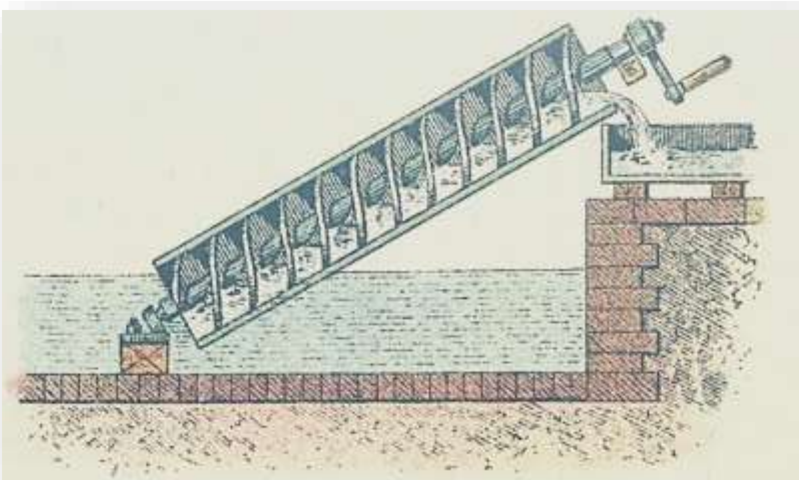
A Great Inventor and Scientist

Archimedes (287-212 BCE)
Bronze sculpture by G. Thieme, Berlin-Treptow/Germany)

Archimedes (287 - 212 BCE)

Combined math with physics,

- discovered the principles of density and buoyancy
- mathematical principles of the lever
- created elaborate pulley systems
- defined the concept of the center of gravity
- created the field of statics, using Greek geometry to find equilibrium states for objects
- other inventions, e.g., "water wheel" for irrigation, war machines for Syracuse against Rome (First Punic War).



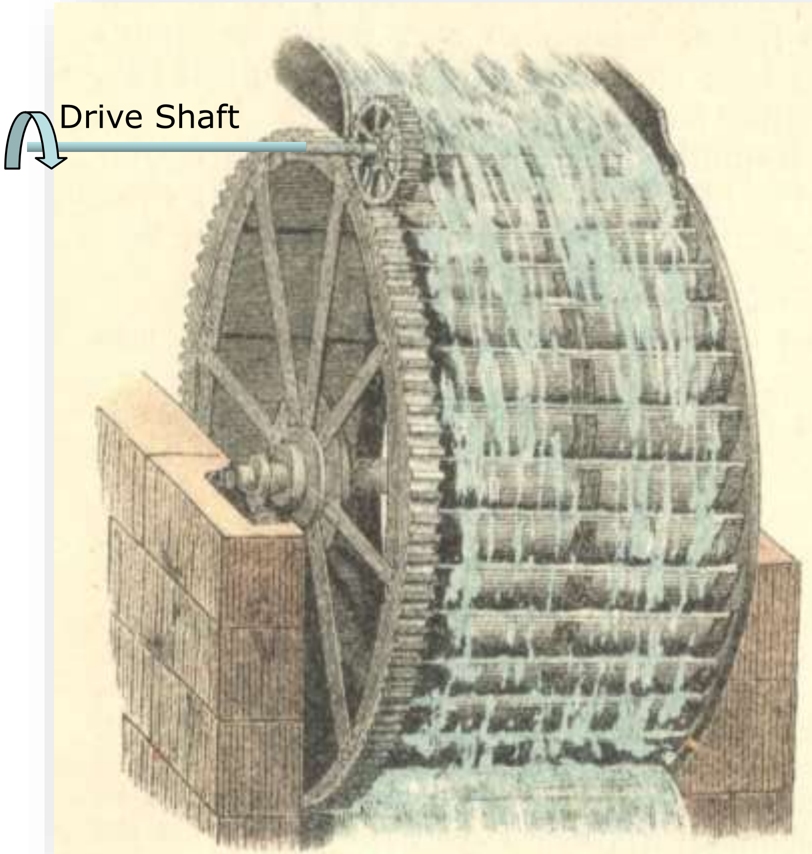
Archimedes' water wheel. Still used for agricultural irrigation, coal transfer, etc.

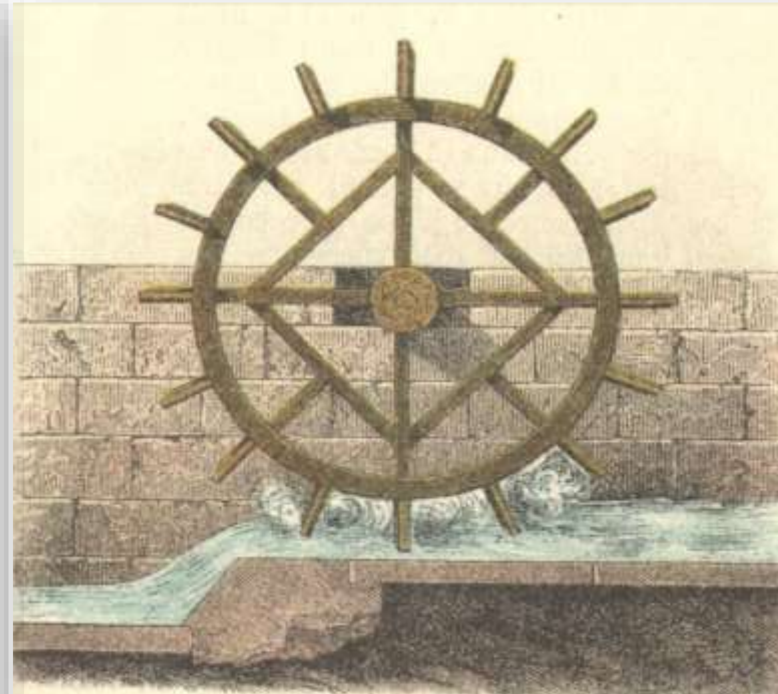
Six Simple Machines:

- ○ Inclined Plane
- ○ Lever
- ○ Pulley
- ○ Screw
- ○ Wedge
- ○ Wheel and Axle

Physics principles of simple machines →Website.

Hydro Power: Run-of-the-River Water Wheels





↑ Undershot waterwheel

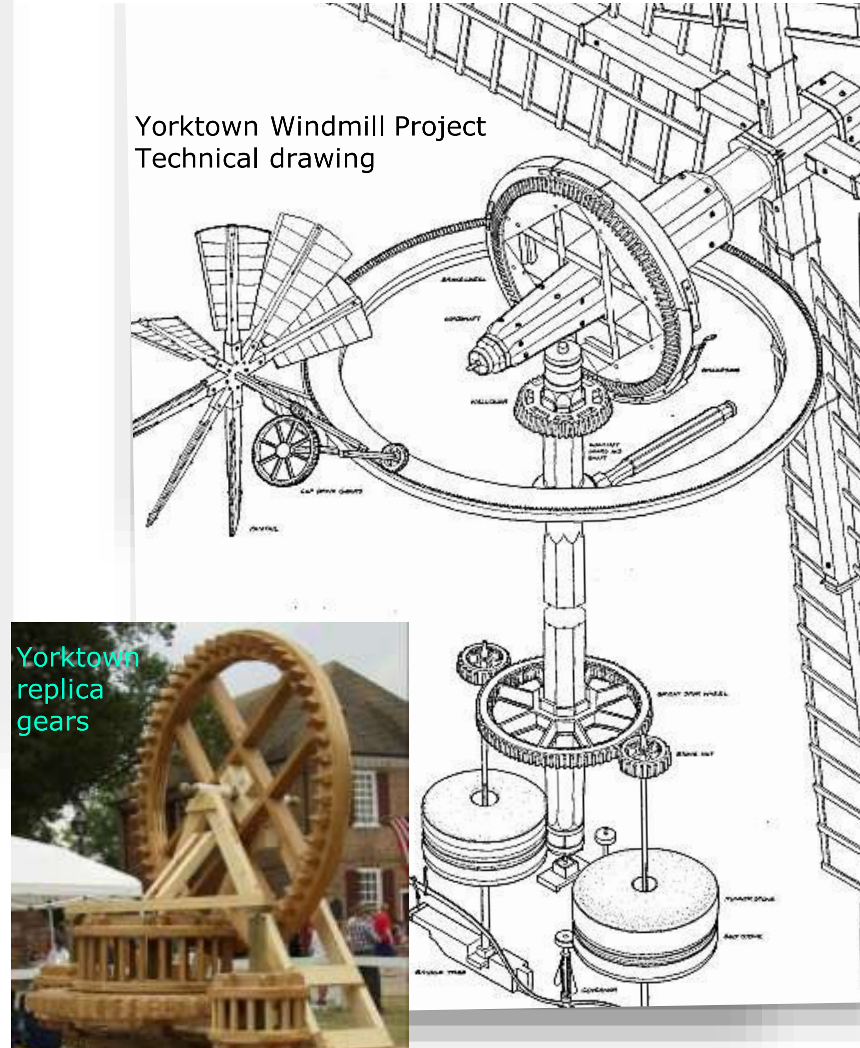
← Overshot waterwheel

Used until 19th century, displaced by steam engines, later by electric motors.

Pre-Industrial Wind Power

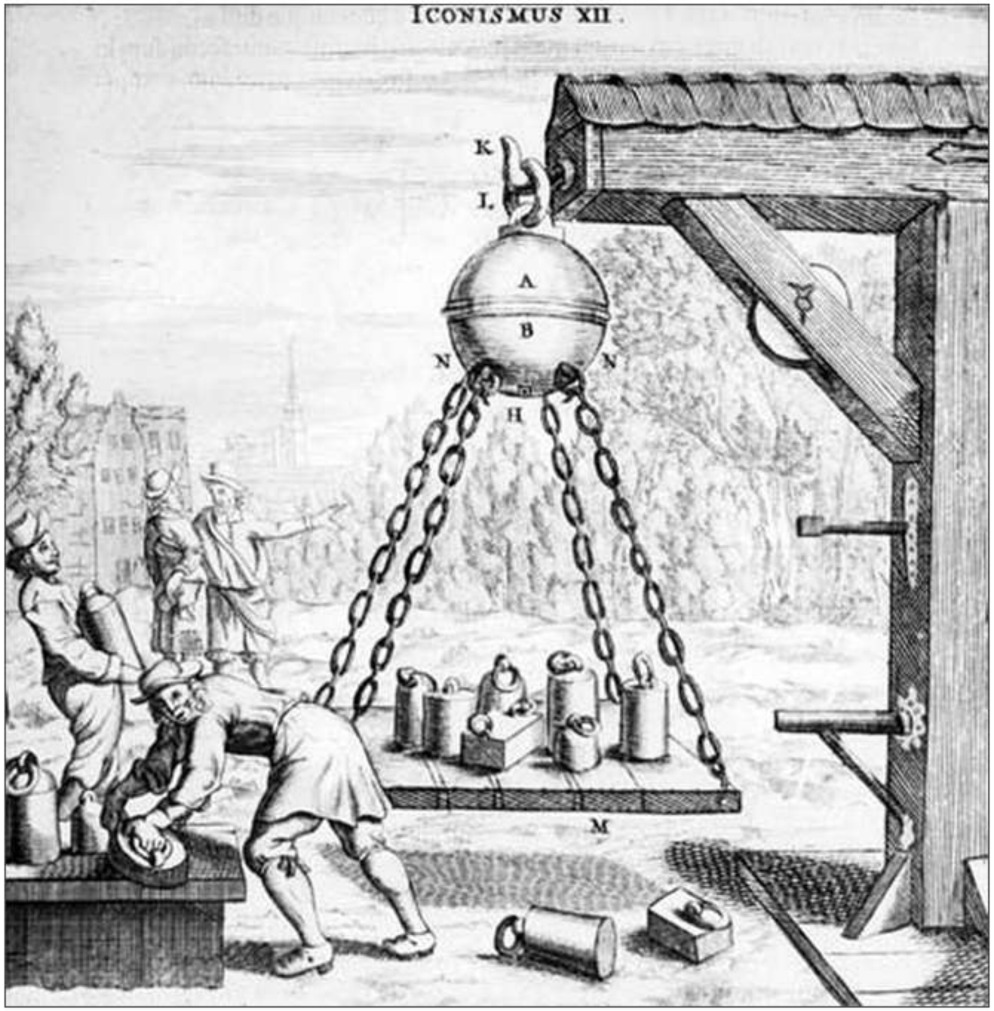
Dutch windmill with manually turned tower, 17th century. All-wooden gears. Flower grinding. Replaced manual mills.
Allowed industrial manufacture of wooden ships → Dutch Navy
Foundation of Dutch Empire 1650-

http://www.yorktown-windmill.org/html/public/final-design.html
Accessed Oct. 2012



Modern ways to harness → electricity

The Power of Static Air Pressure/Vacuum



Mid-17th century: Interest in pumping air, vacuum effects .

Mayor Otto v. Guericke (1654) Magdeburg/Germany:

Invented air pump → Pumping demonstrations.

Two well-fitted hemispheres pumped out → held together by atmospheric pressure.

→ study of vacuum vs. pressure, heat (Lavoisier, 1770s)

Measure pressure

P = force(α weight) /area.

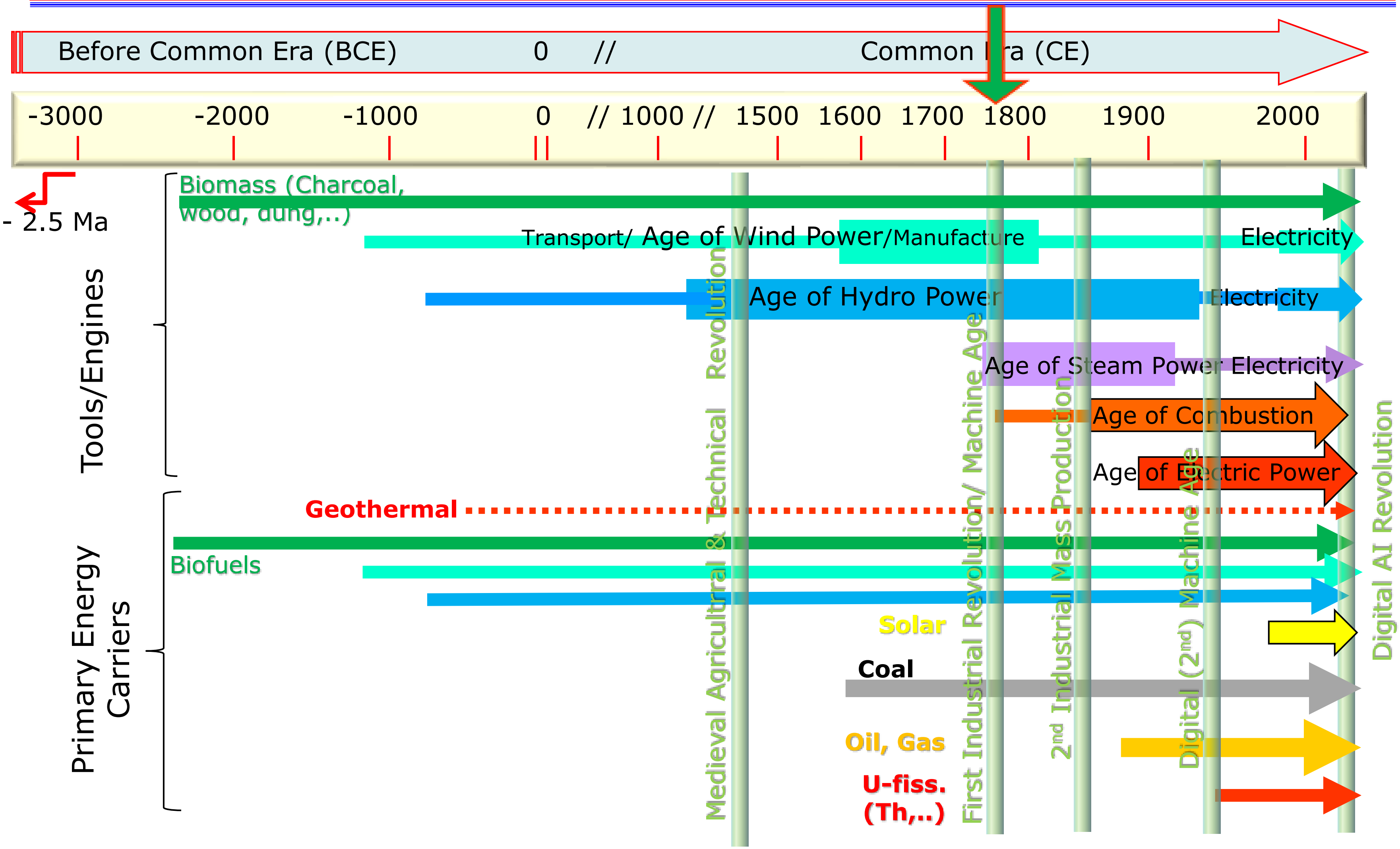
29.92″ Hg = 1013.25 mb = 1.013 kPa.

760 mm Hg =29.92″ Hg

Force on 1,000 cm^2 = weight of 1 ton

W. Udo Schröder, 2025

Timeline Energy Tools & Fuels (Western/Global)



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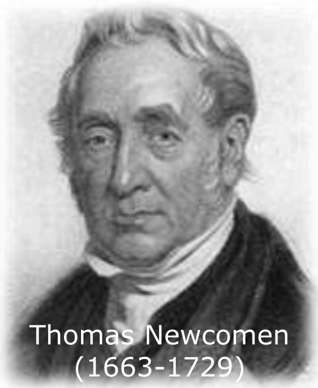
History in illustrative examples →

1st Industrial Revolution: 18th Coal Power


Thomas Newcomen
(1663-1729)

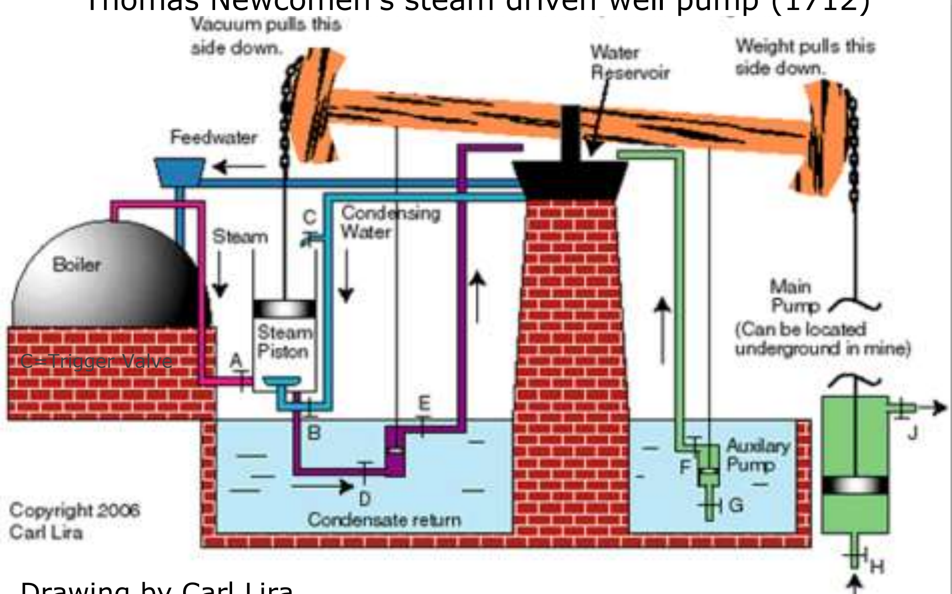
Folklore: Thomas Newcomen (or James Watt) noticed power of steam on lifting lid of teakettle.

(However, steam power was known since longer than 100 BCE. Practical applications through middle ages.)

Thomas Newcomen built the first practical steam engine. Not very efficient: cylinder had to be heated and cooled repeatedly, stressing cylinder, wasting a lot of energy. 50 years later improved by James Watt.

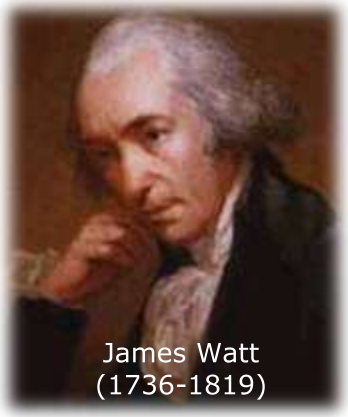

Coal miner @ underground mine (in old times)
Photograph, The iPinion Journal (Apr. 2010)
http://www.theipinionsjournal.com/

Thomas Newcomen's steam driven well pump (1712)



Drawing by Carl Lira

James Watt's Modern Steam Engine



Technical holdup: Cylinder undergoes multiple warm/cool cycles, wasted energy, large piston/cylinder need tight tolerances to hold vacuum.

James Watt's breakthrough development: separate condenser (1765).

1755 Trained in London
1763 Discovers Newcomen's engine problem
1765 Invents external condenser
1769 Roebuck and Watt patent engine
1774 Boulton acquires Roebuck's patent rights. Watt moves to Birmingham
1776 First Boulton and Watt commercial engine

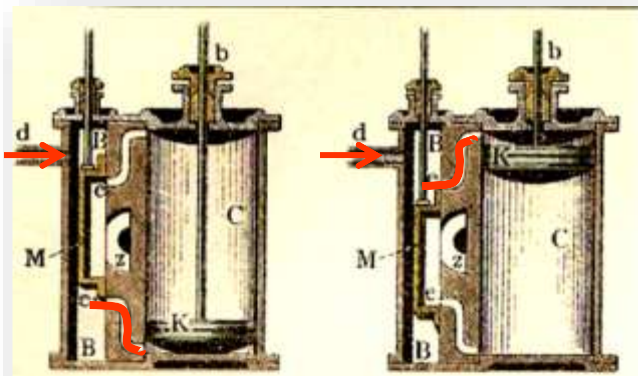


Fig. 36. Tiefste Stellung des Kolbens K. Fig. 37. Höchste Stellung des Kolbens K.
Längsdurchschnitt des Zylinders C und der Dampfkammer B.
d Dampfrohr. M Muschelschieber. ee₁ Dampfzuleitungskanäle.
z Öffnung für den verbrauchten Dampf.

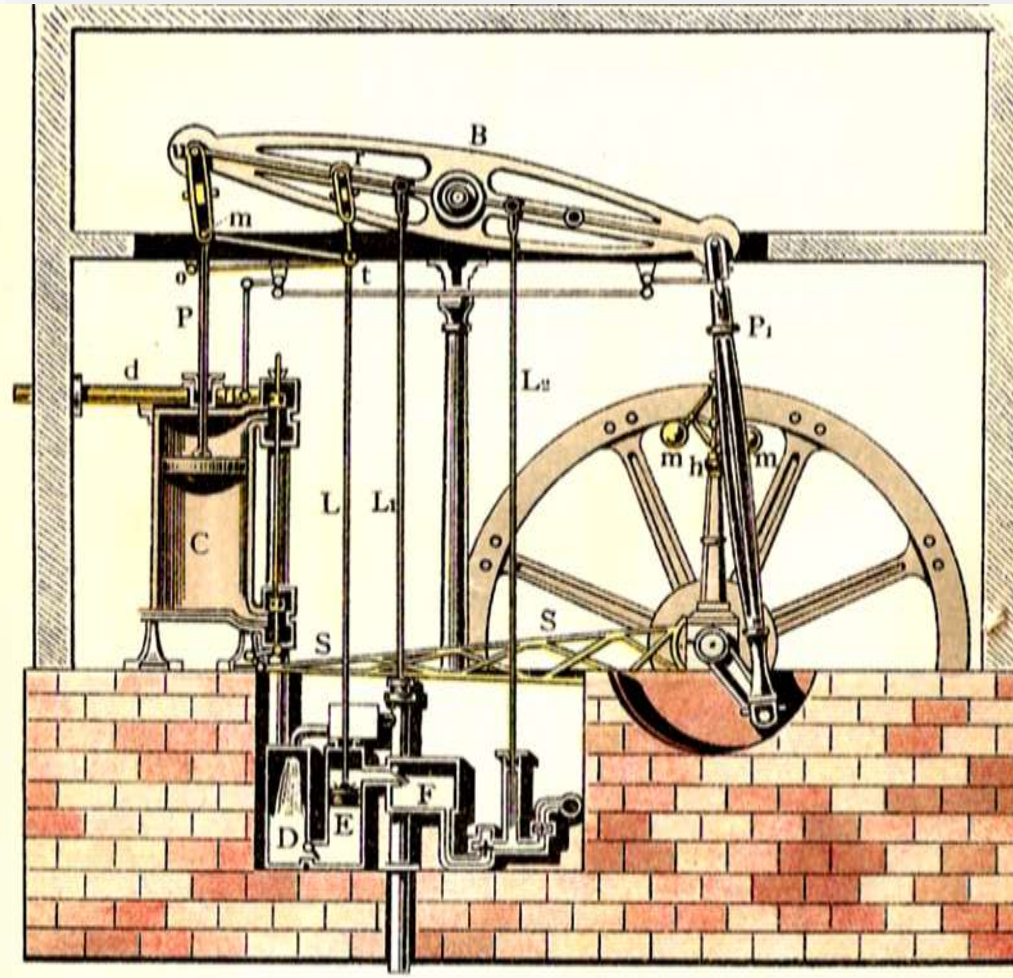


Fig. 34. Wattsche Dampfmaschine.
C Dampfzylinder. d Dampfzuflußrohr. B Balancier. R Schwungrad. D Kondensator. LE Luftpumpe. L₁F Kaltwasserluftpumpe des Kondensators L₂ Warmwasserluftpumpe des Dampfkessels. S Exzenterstange der Steuerung. P₁ Pleuelstange mit Kurbel.

Industrial Revolution Mass Manufacturing

The Great Allis-Corliss Engine at the 1893 World's Columbian Exposit...

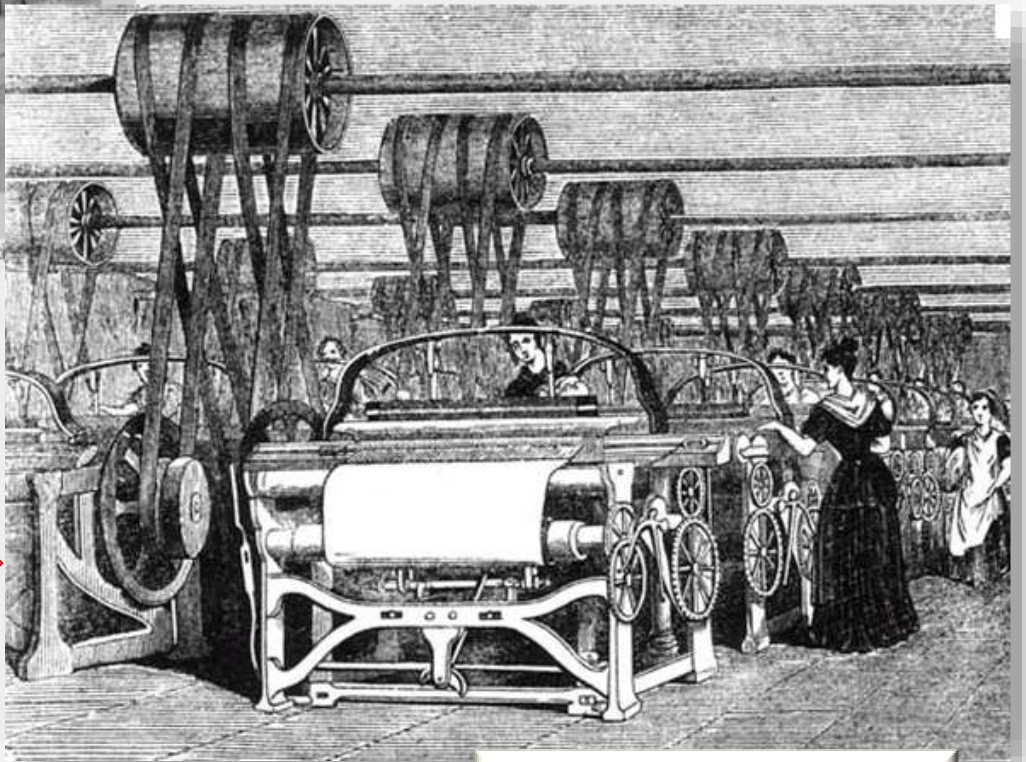
From: Dr. G.F. Corliss, Marquette University, (George.Corliss @ Marquette.edu) Accessed: Sept. 2012

Steam engines delivering ~ 100 hp were used to drive a factory machine park.

British textile industry, weaving factories.

Transmission via belts and shafts, same rpm, little control.

A Roberts loom in an English weaving factory in 1835. Note drive shafts (cast iron) and leather belts.



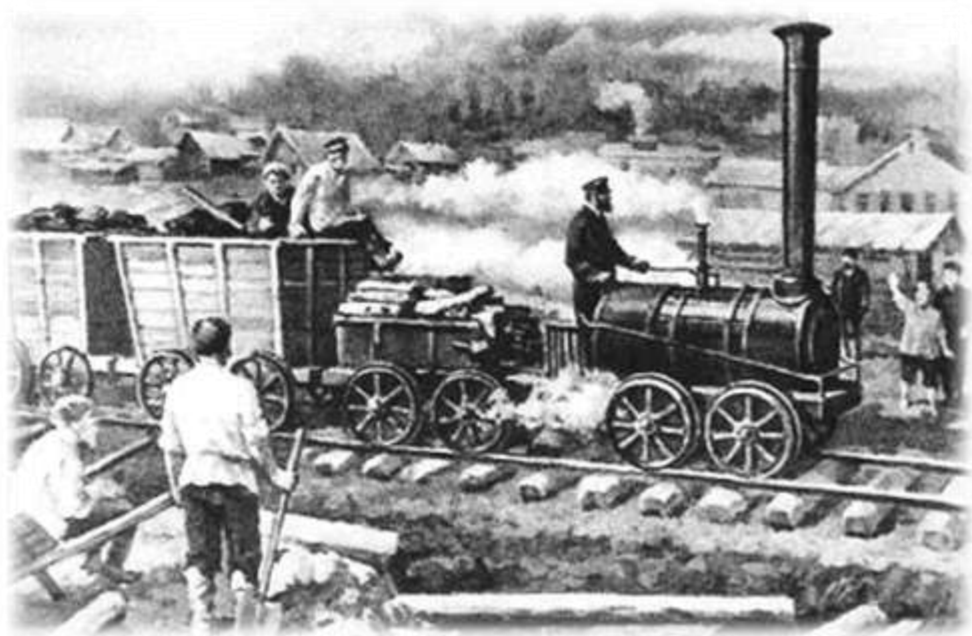
Abundant fuel: Coal

First Steam Powered Railroads

George Stephenson & Richard Trevichik build the world's first public railways, the Stockton and Darlington railway in 1825 and the Liverpool-Manchester railway in 1830. Stephenson was the chief engineer for several railways.

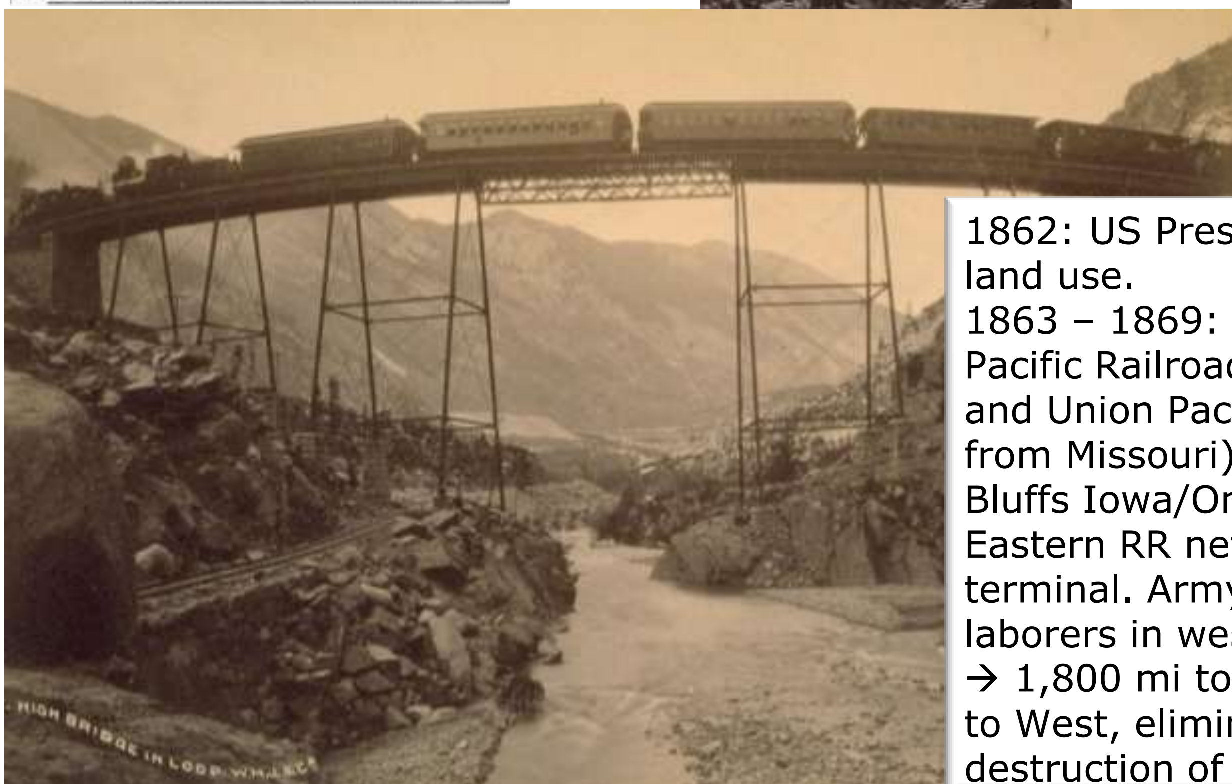
Existing railroads were suited to the hilly terrain of English Tyne and Wear countryside, where canals would not have been practicable.

Wooden or iron English "Newcastle Roads" = first 17th century railways, horse drawn Chaldrons replaced by steam driven locomotives.



1830: The first American railroad, on wooden ties, "Baltimore and Ohio Railroad" (18 mph).

Transcontinental Railroads



1862: US President Lincoln authorized land use.
1863 – 1869: 200 mi RR laid by Central Pacific Railroad of California (eastward) and Union Pacific Railroad (westward from Missouri). Connected Council Bluffs Iowa/Omaha (and existing Eastern RR network) with Oakland/CA terminal. Army veterans + Chinese laborers in western construction parts.
→ 1,800 mi total. Immigration settlers to West, elimination of buffaloes, destruction of native culture.

Ocean Steamers


SS Savannah, 1819

First Atlantic crossing by steamship.
Painting by Hunter Wood.

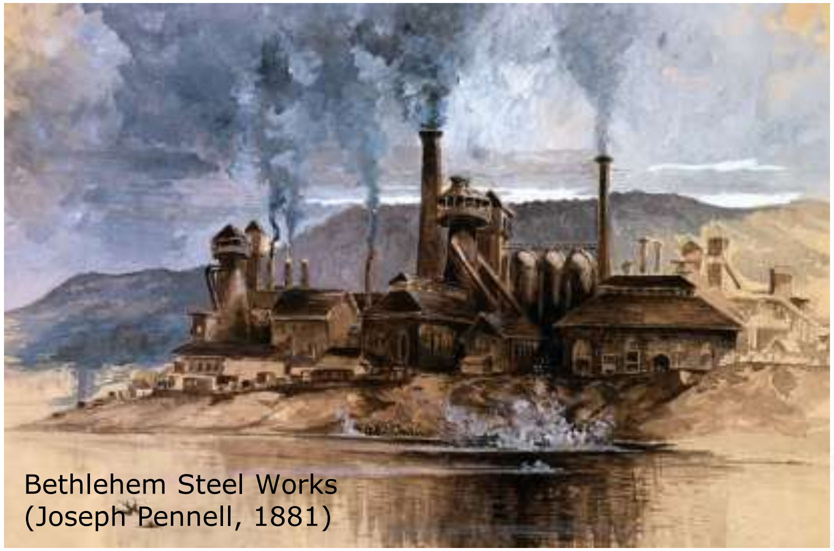

The HMS Great Britain, 1845, propeller.


The SS Great Western1838, Bristol/England, Oak hull, paddle wheel.

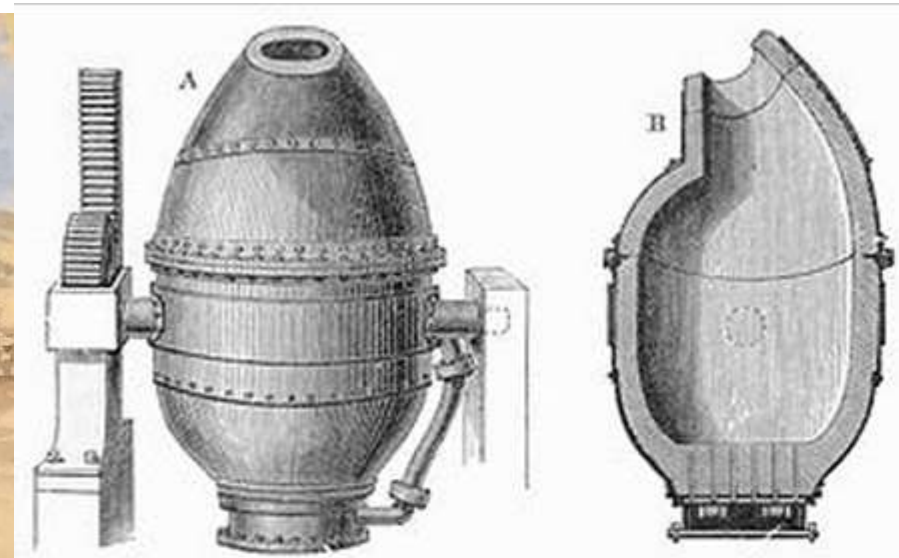
Ocean going steam ships (since app. 1819)

The Great Britain: Iron hull, 3,600 tons, 4 engines @ 1,000 hp.
Engines +boilers (200 tons water) weigh 540 tons.
28" dia, 16 ton main shaft drives single 15'6" dia submerged propeller.
Boilers heated by 24 coal fires.

Rise of American Steel Industry



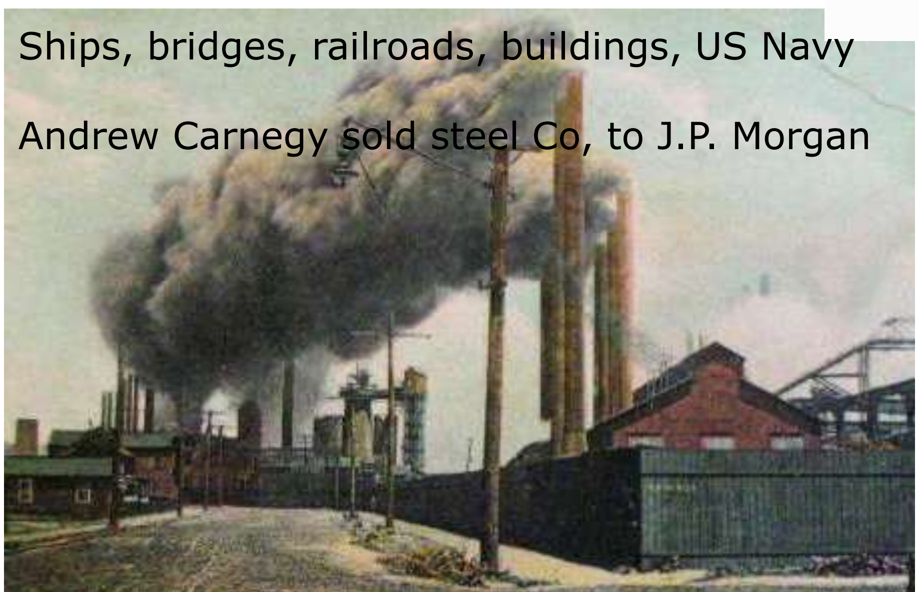
Bethlehem Steel Works
(Joseph Pennell, 1881)

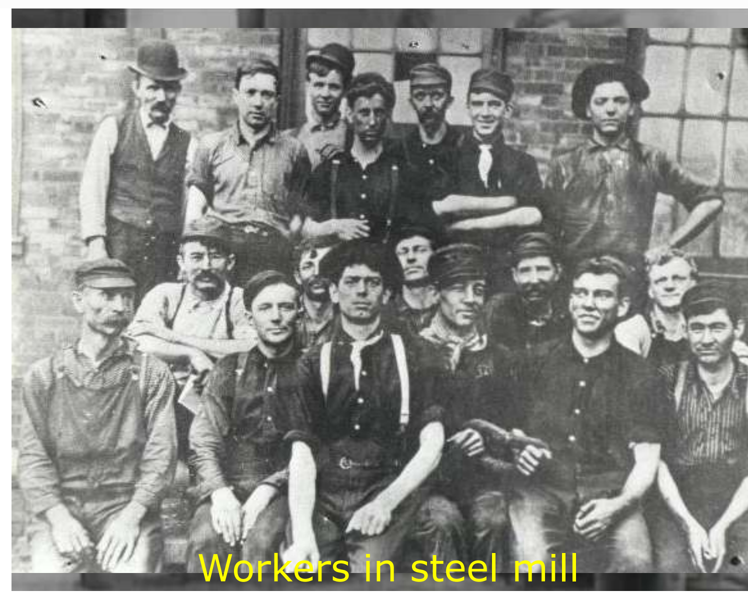


Bessemer steel process 1851

Ships, bridges, railroads, buildings, US Navy

Andrew Carnegy sold steel Co, to J.P. Morgan





Workers in steel mill

End Part I