# Tools and Fuels in Human History

# Human Energy Utilization: Tools & Fuels

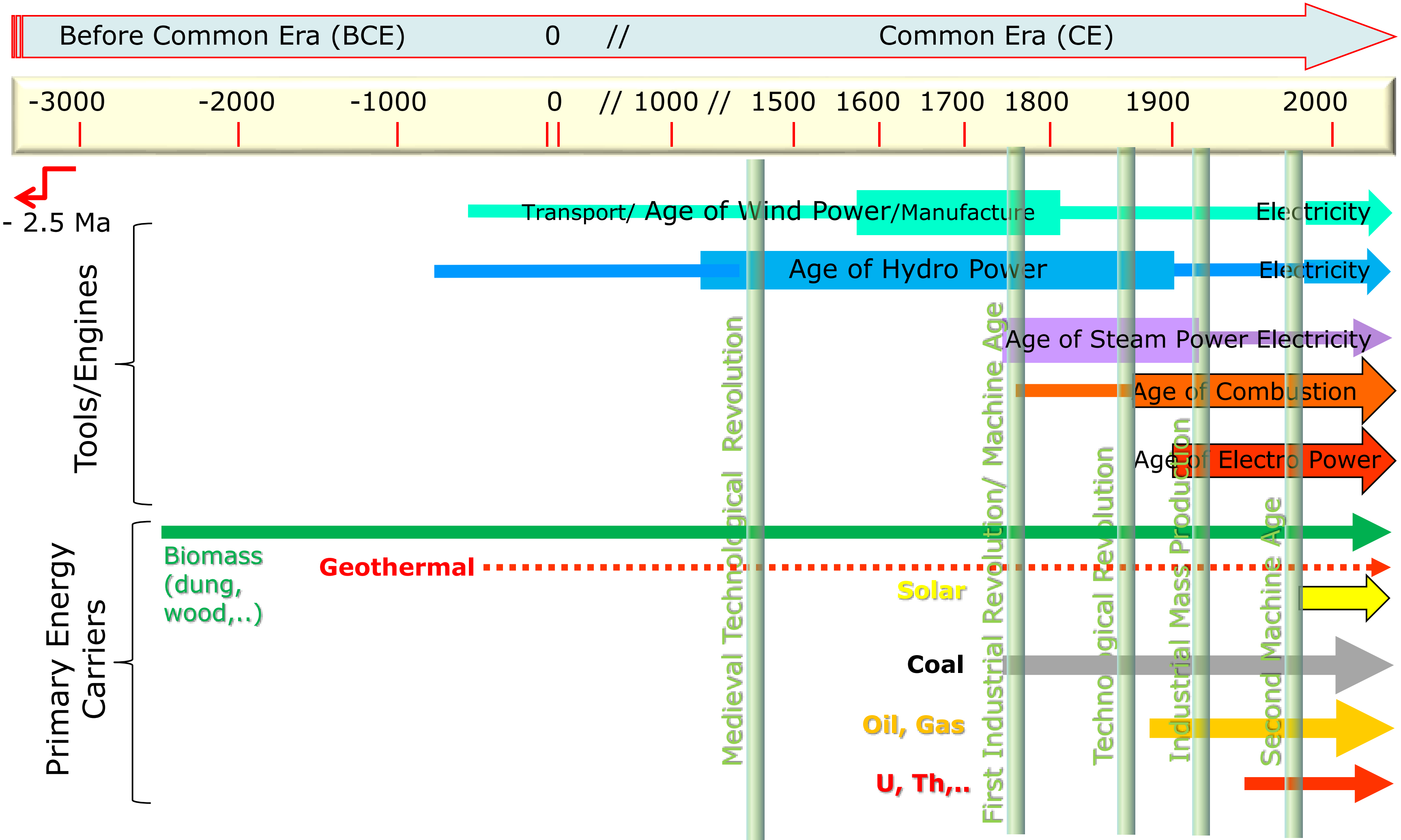
**Main energy uses:**

- Production and processing of food (hunting, gathering, farming, agriculture,…)
- Shelter, sanitation and healthcare
- Transportation of goods and personnel
- 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.

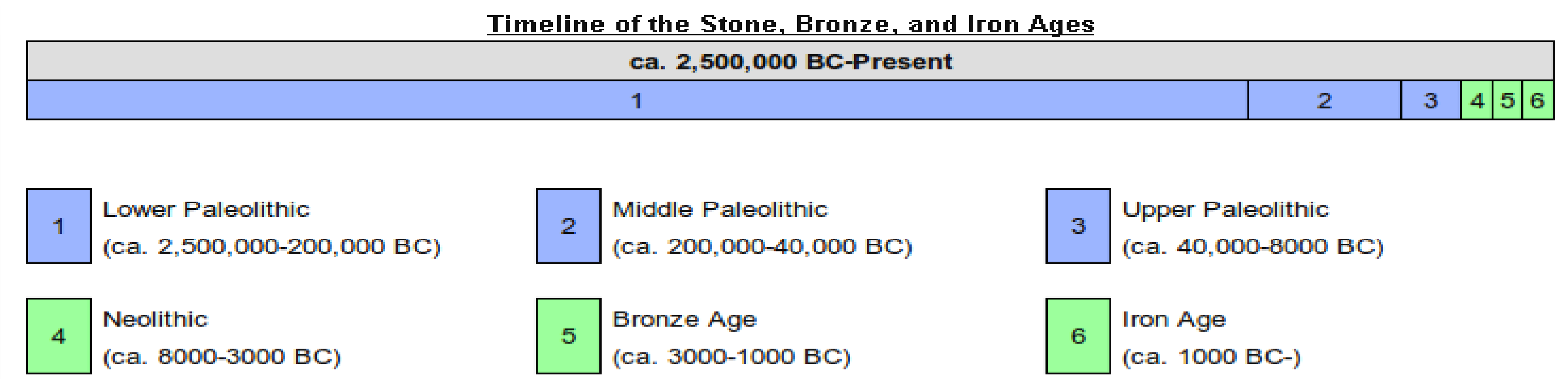
# Time Line Tools & Fuels (Western Cultures)

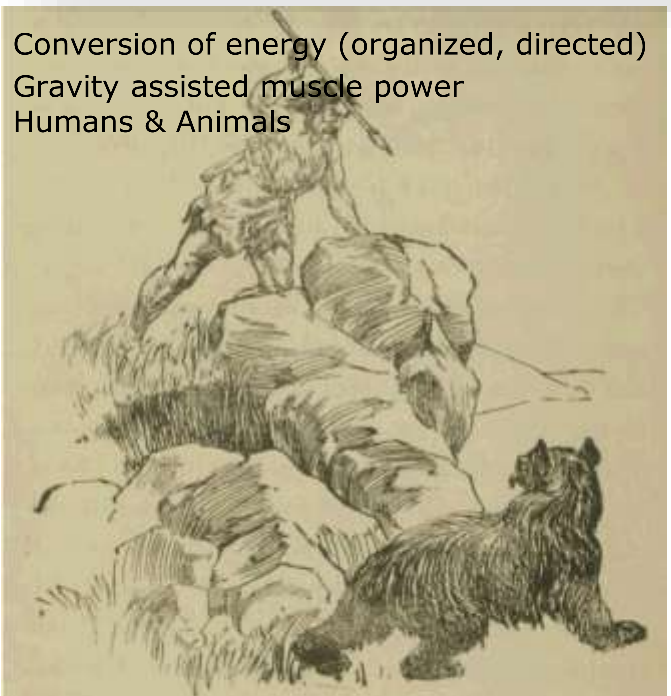



Future: Proven technologies using ample resources efficiently (sustainably) will likely remain vital. Others need exploration/improvement.

History in illustrative examples →

# Prehistoric Energy Conversion Methods



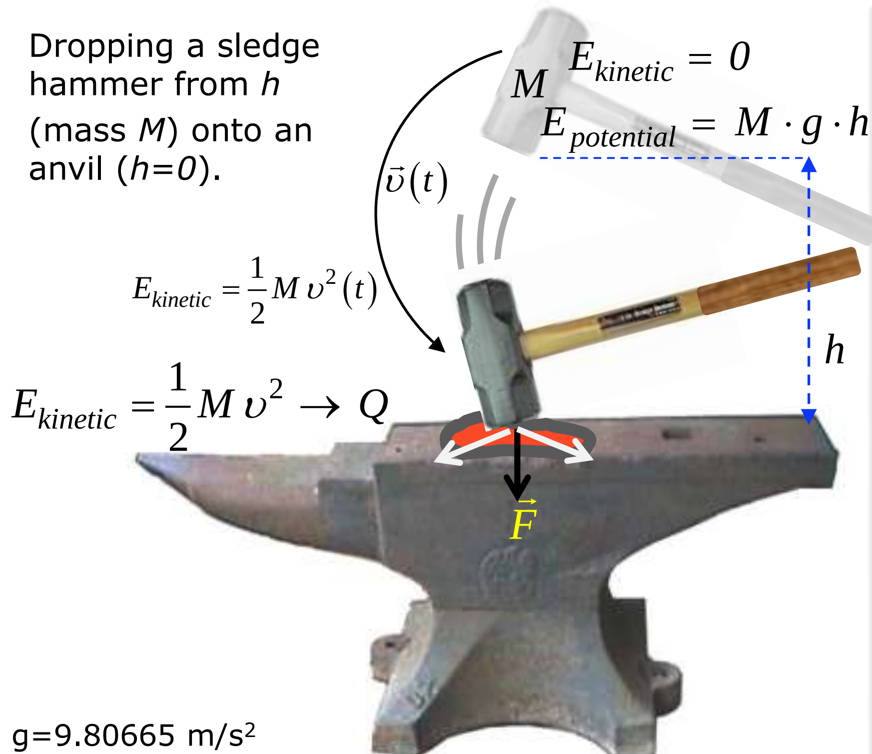

# Simple Tools for Energy Conversion


Stone axes and hammers/weapons. Grooves are for attachment to wooden handles, tied with rawhide strips. Note evidence for wear on the lower part of the leading edge.
http://www.matrixbookstore.biz/stone_age_tools.htm

Hammers are for crushing or flattening (forging) objects. Downward force *F* diverted sideways.

Convert kinetic energy (of swinging hammer) into deformation and thermal energy.

Dropping a sledge hammer from *h* (mass *M*) onto an anvil (*h*=*0*).




$g = 9.80665\ m/s^2$
gravitational acceleration

Thermal energy Q ←→ Heat
Disorganized, non directional energy

# 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).

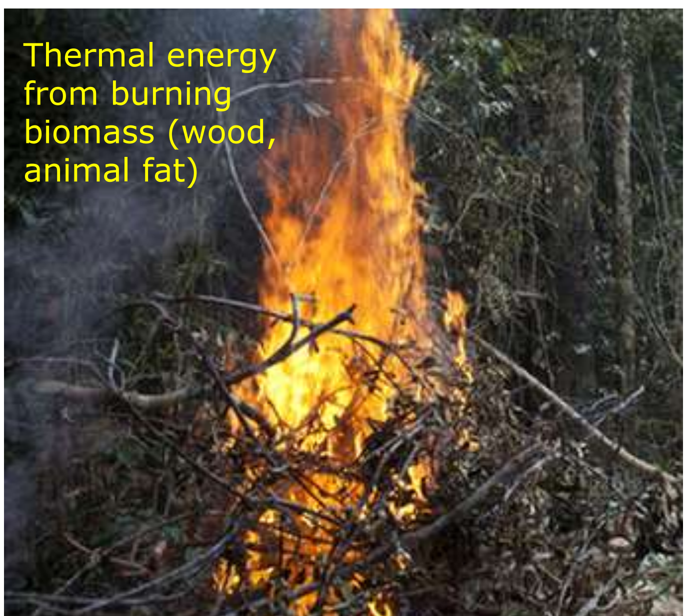
**Conversion chemical energy → heat energy:**

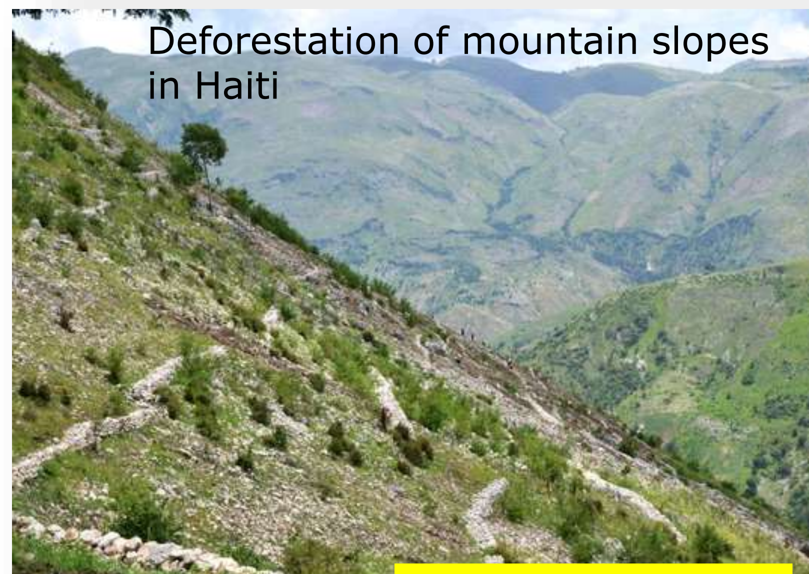
Opened new avenues for evolution, as well as for new tools and technology. → bronze and iron ages

Controlled fires and cooked meat may have influenced human brain evolution.

**Fire needs fuel !**

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

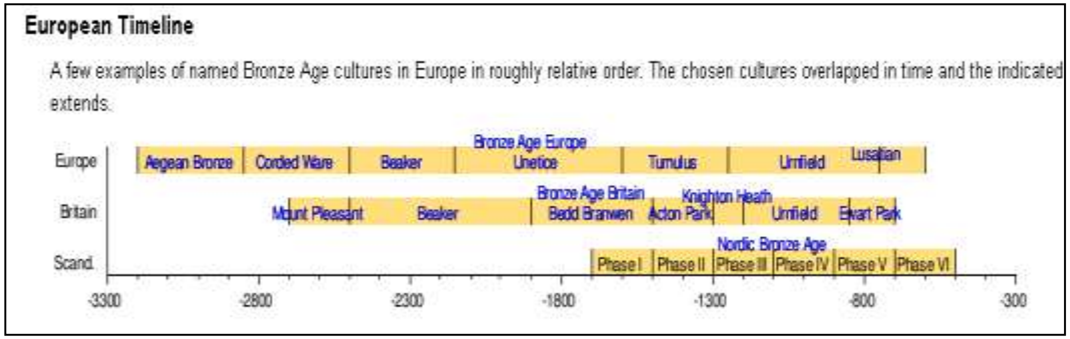



New technologies

# 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.

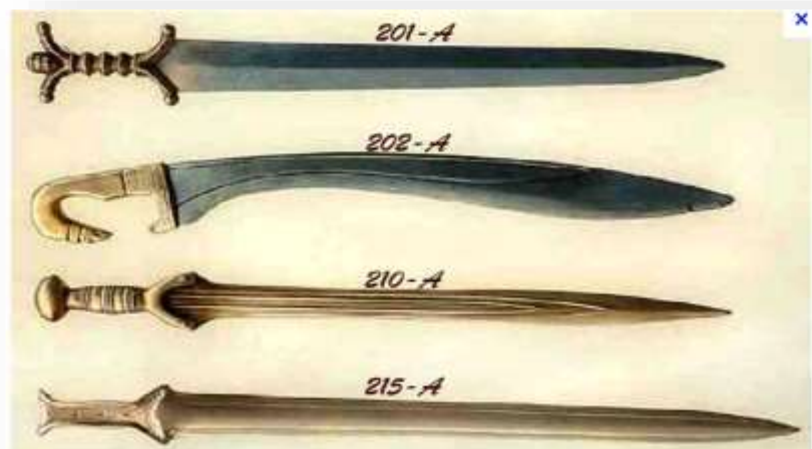



Artifact (Bronze)

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

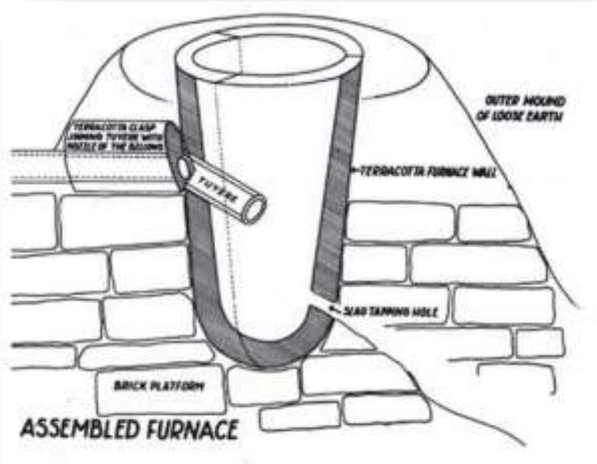
Reenactment/Wikipedia

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.

$FeCO_3$ (Siderite)→ $FeO + CO_2$

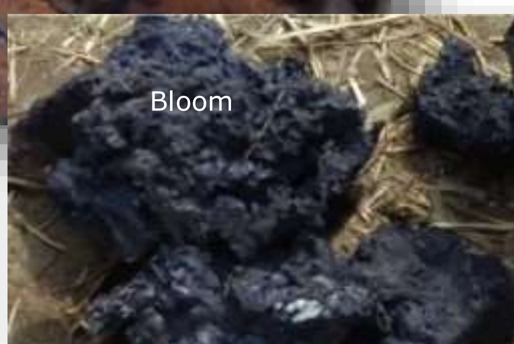
Burning wood/charcoal produce carbon monoxide (CO), metallic iron is produced:

$FeO + CO$ → Fe (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. →

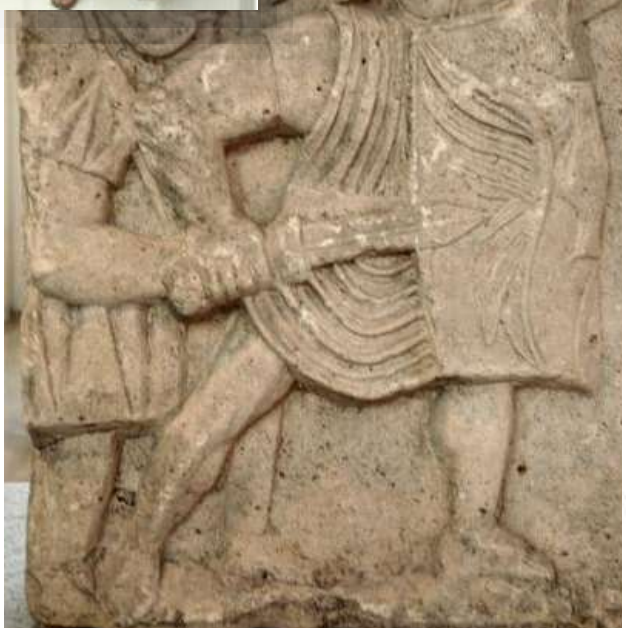

The masters

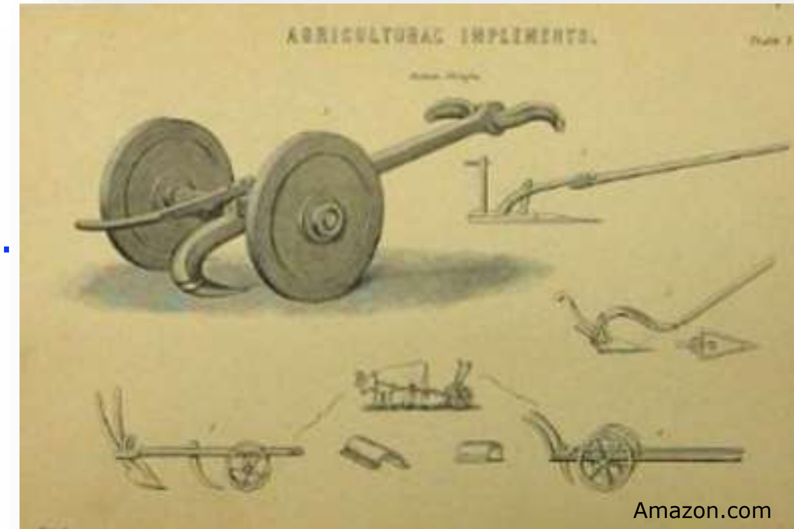
# Roman Ingenuity (30 BCE - 400 CE)

Lorica hamata Rheinisches Landes-museum, Bonn)

Roman metal implements for efficient application of human/animal force → Energy Conversion.

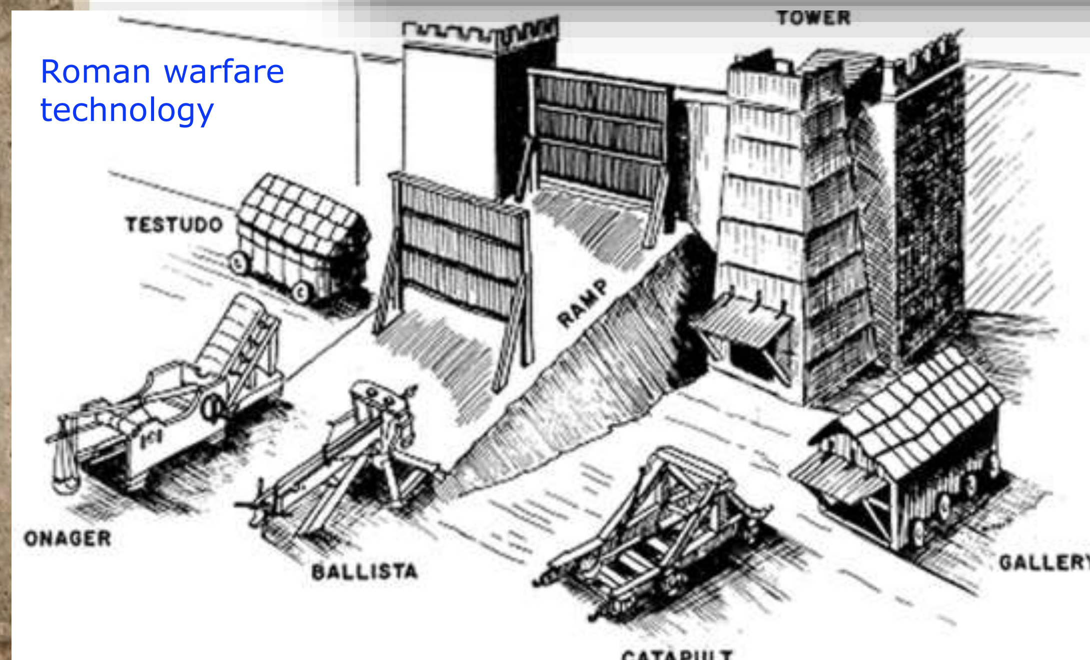
Intellect. Source: Ancient Greece.






Amazon.com

Roman warfare technology



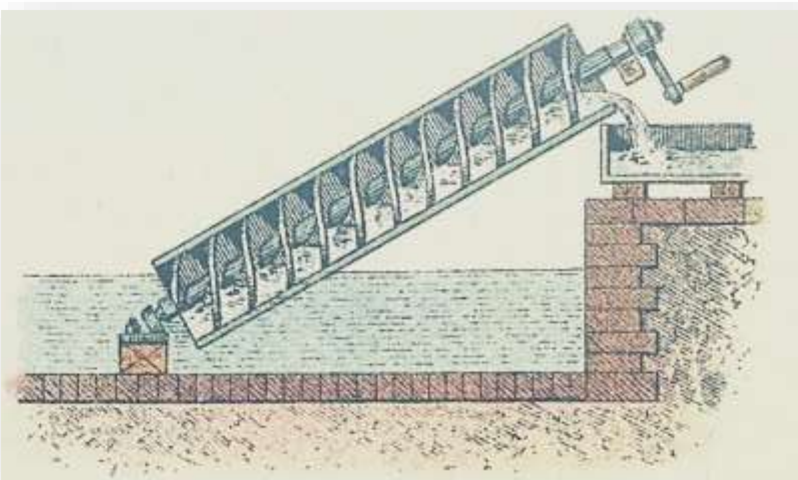
# A Great Inventor and Scientist

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.

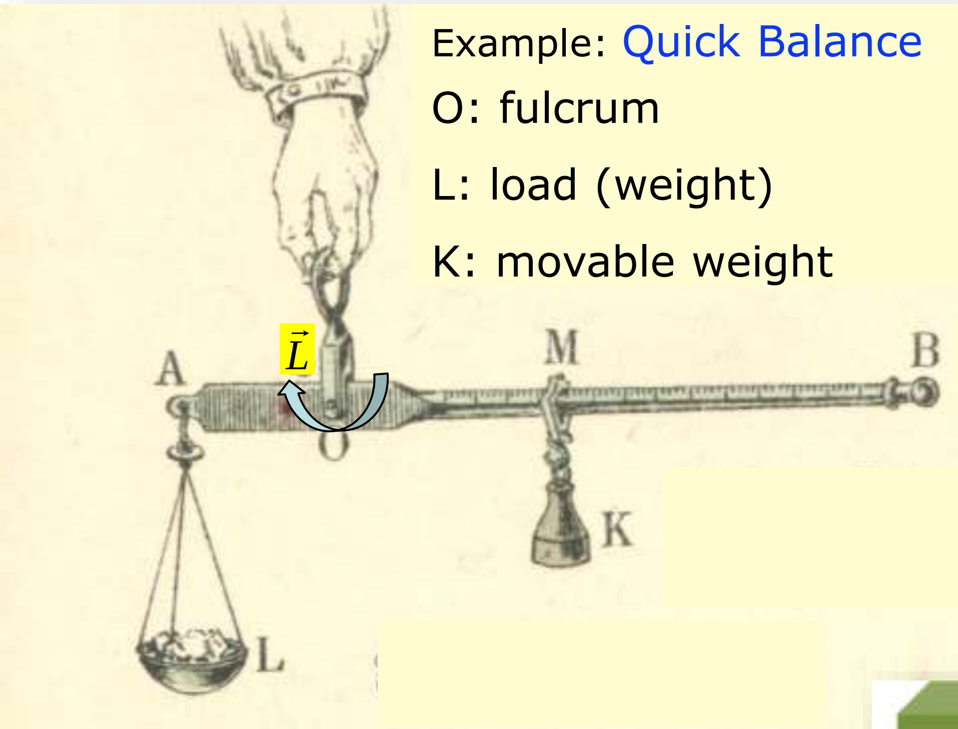
## Six Simple Machines:

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


Next: Discussion of physics principles of some simple machines.

# Basic Machines: The Lever

Archimedes (~200 BCE) Law of the Levers




$$F_1 \times a = F_2 \times b \;\rightarrow M_1 \times g \times a = M_2 \times g \times b$$

$$\rightarrow F_2/F_1 = M_2/M_1 = a/b < 1$$

*But angular momentum $\vec{L}$ and (work) energy are conserved*

$$F_1 \times h_1 = F_2 \times (b/a) h_1 = F_2 \times h_2$$

**Lever, Torque, Force**

(*Lever* = movable beam connected to ground by a *fulcrum*, *arm* = length left or right of fulcrum)

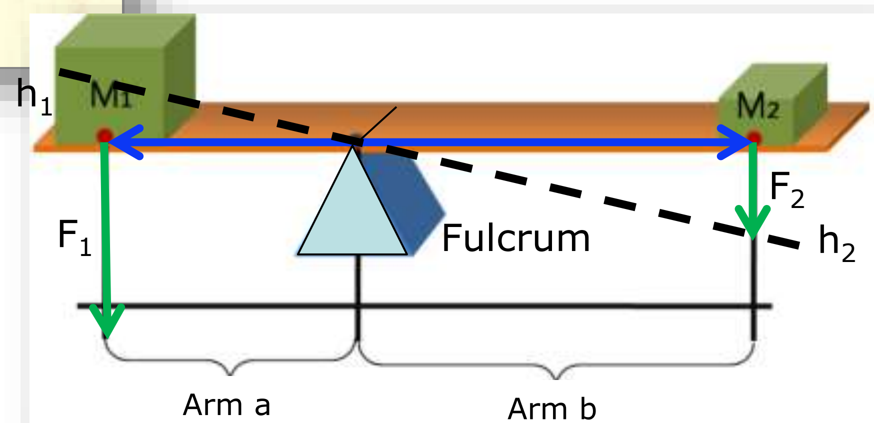
**Torque = Force x Arm**

→ Changes angular momentum $\vec{L}$

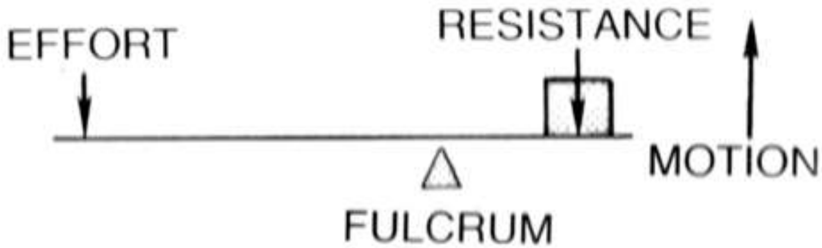
Force = Mass x g

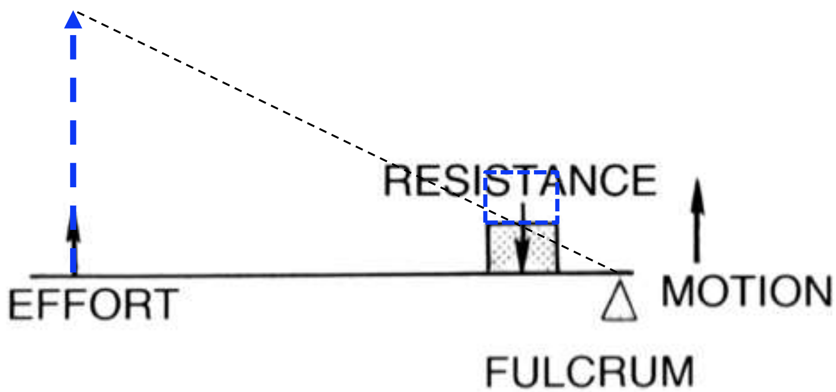
g=9.80665 m/s²

gravitational acceleration



# Lever Applications



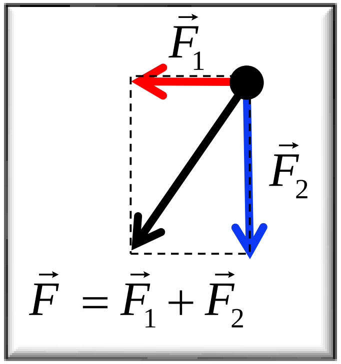





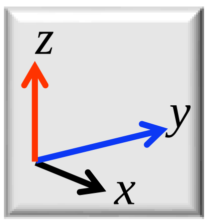
# Application Lever

Replica of Roman flower mill (Xanten/Germany),
Wikipedia Aug. 2012

# Simple Tools: The Inclined Plane



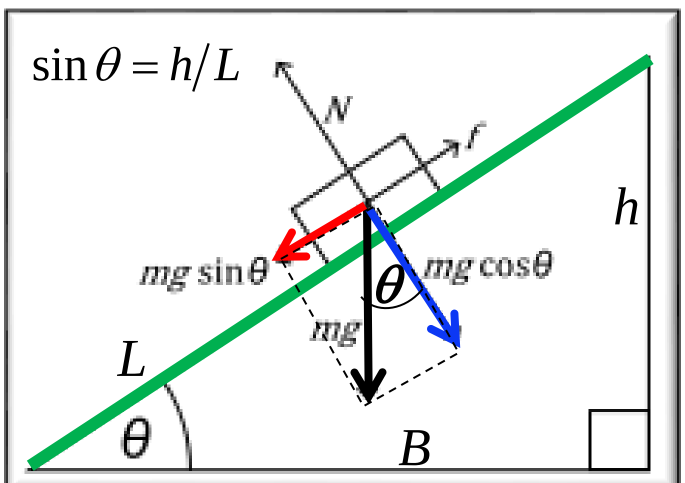

Forces are vectors (have magnitude and direction) Relative to an arbitrary coordinate system {x,y,z}. Several forces attaching to the same point add, component by component, to a resultant force.




Arbitrary coordinate system: decompose force *F* into components {$F_x$, $F_y$, $F_z$}

*Vector, component representation*

$$\vec{F} = \begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} \quad \rightarrow \quad \vec{F}_1 + \vec{F}_2 = \begin{pmatrix} F_{1,x} + F_{2,x} \\ F_{1,y} + F_{2,y} \\ F_{1,z} + F_{2,z} \end{pmatrix}$$




An inclined plane facilitates lifting of heavy objects (mass ***m***), but does not save work.

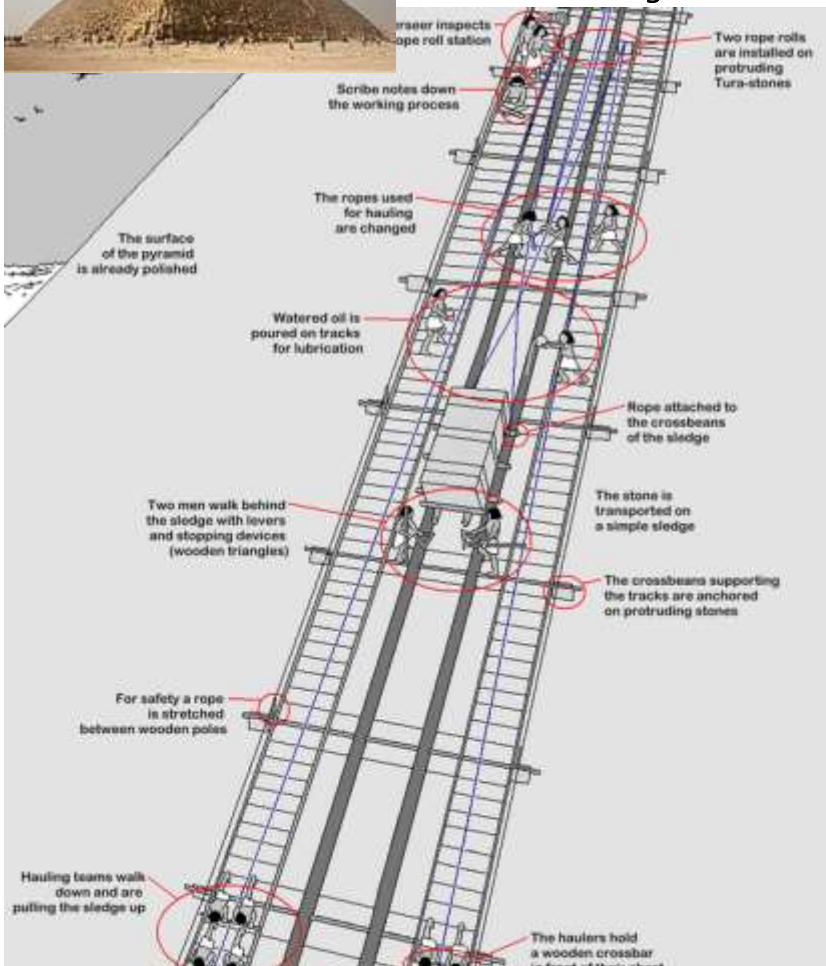
$$Work = force \cdot path\,length = (mg\sin\theta)\cdot L = mg \cdot h$$

If no friction (*f* = 0), expended work is the same= gain in potential energy $\Delta E = mg \cdot h$

# Inclined Plane Applications

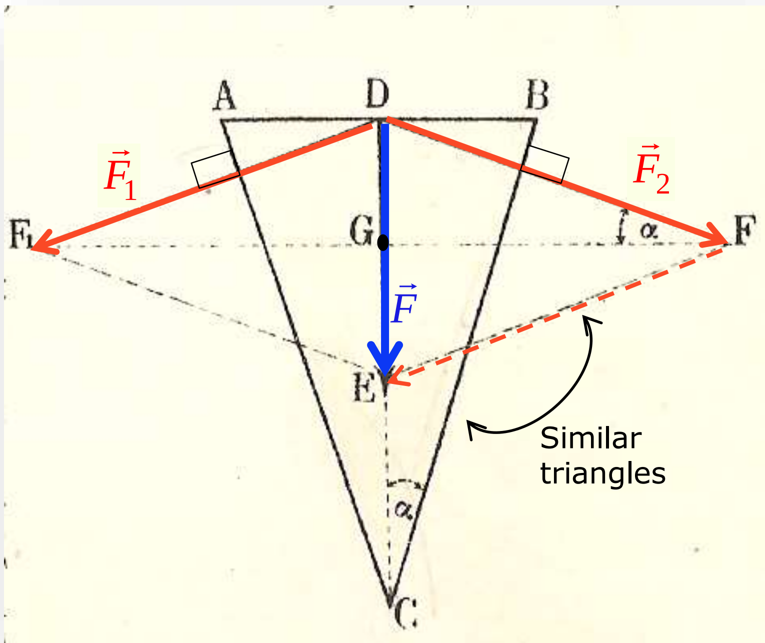
Hypothetical pyramide construction method (Franz Löhner).

Track systems (tracks plus ladders left and right) installed on the inclined plane of a pyramid. Rope rolls (wooden blocks with a rolling bar). Rolls and tracks and ladder-like rigs anchored on outer protruding stones.




Franz Löhner [www.cheops-pyramide.ch](http://www.cheops-pyramide.ch), August 2012

# Simple Tools: The Wedge




Functionality of axes, wedges, arrow/spear tips

→ application of wedge principle, decomposition of forces working against resistance.

$$\vec{F} = \begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} \quad \rightarrow \quad \vec{F}_1 + \vec{F}_2 = \begin{pmatrix} F_{1,x} + F_{2,x} \\ F_{1,y} + F_{2,y} \\ F_{1,z} + F_{2,z} \end{pmatrix}$$

$$\overline{DG} = \overline{DF} \cdot \sin\alpha = \left|\vec{F}_2\right| \cdot \sin\alpha$$

$$= \overline{DF_/} \cdot \sin\alpha = \left|\vec{F}_1\right| \cdot \sin\alpha$$

$$\overline{DE} = 2\,\overline{DG} \rightarrow \left|\vec{F}_1\right| = \left|\vec{F}_2\right| = \vec{F}/(2\sin\alpha)$$

Even a relatively weak driving force $\vec{F}$ can overcome a large resistive lateral force $-\left(\vec{F}_1 + \vec{F}_2\right)$ by using a thin enough wedge, with an opening angle α with $\sin\alpha < \left|\vec{F}\right| / 2\left|\vec{F}_1\right|$.

→ Sharper edges cut better, longer arrow heads penetrate deeper.

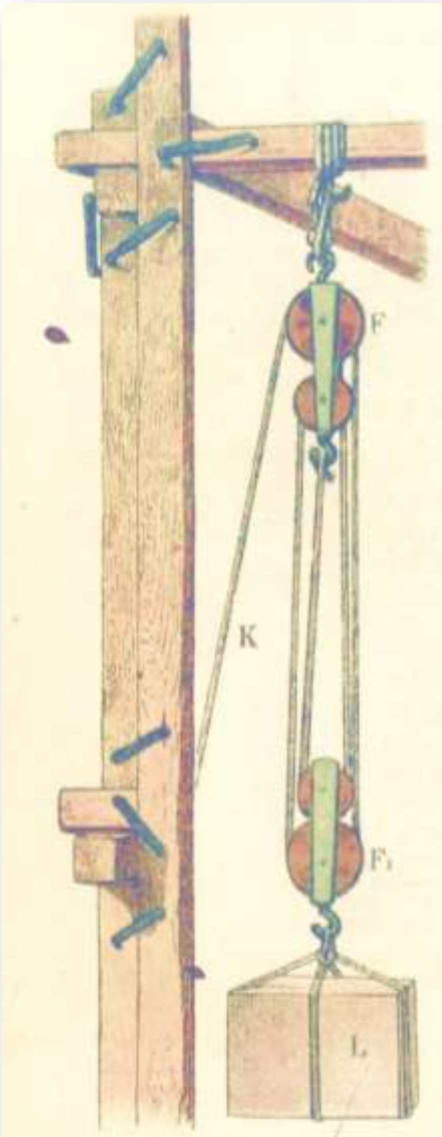
However, no energy (work) is saved! It is just easier (force), but takes longer (path).

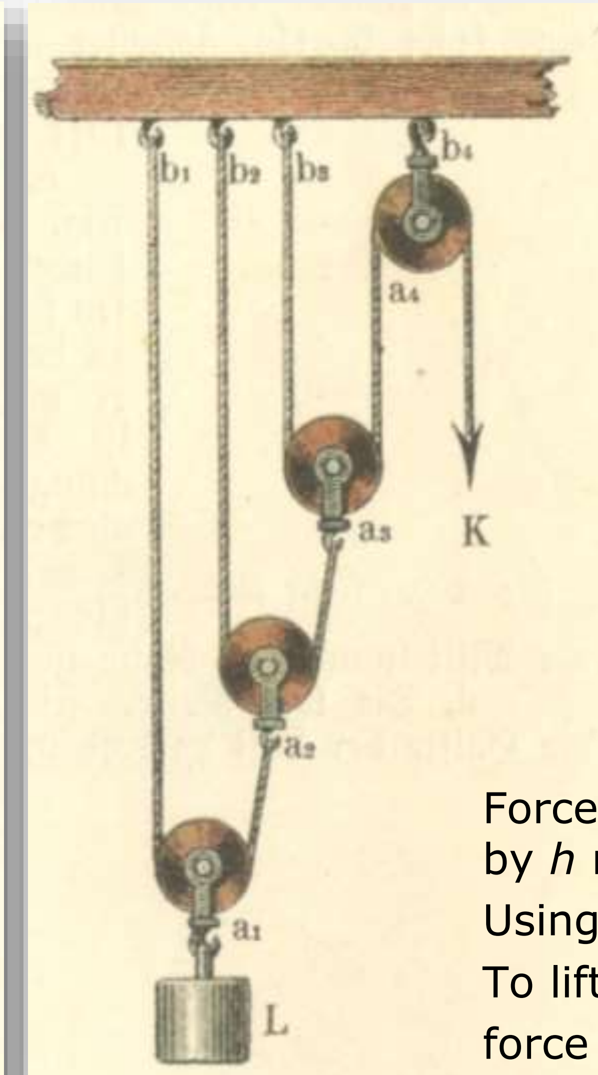
If the wedge is to open a gap of width ±***w*** in the direction of the resistance, the wedge must be driven the larger distance $w_\perp$=***w***/(sin α) into the material. →

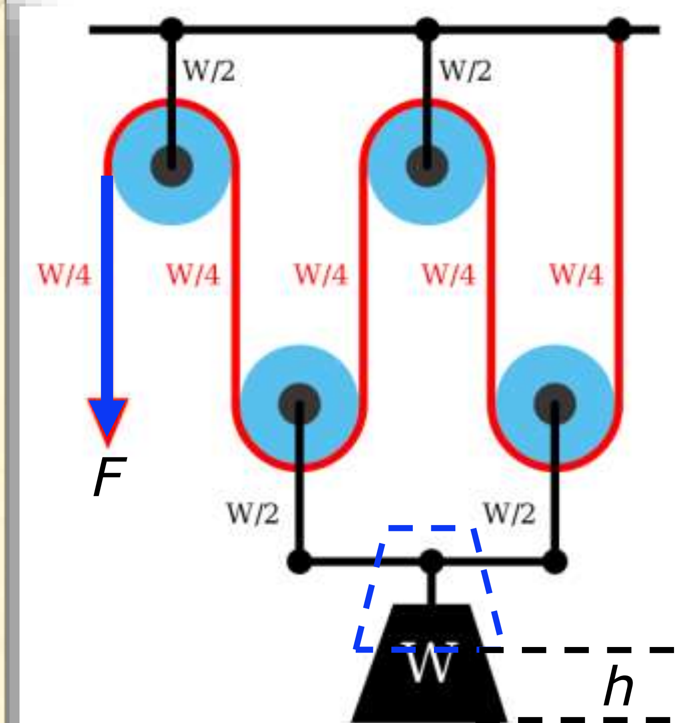
$$\left|\vec{F}_1\right| \cdot w + \left|\vec{F}_2\right| \cdot w = \vec{F} \cdot w/(\sin\alpha) = \vec{F} \cdot w_\perp \rightarrow \textit{Energy is conserved}!$$

→ Limitations of stone-age cutting/shaping tools and weapons made of flint stone: short and stubby.

# Simple Tools: Rope and Pulley



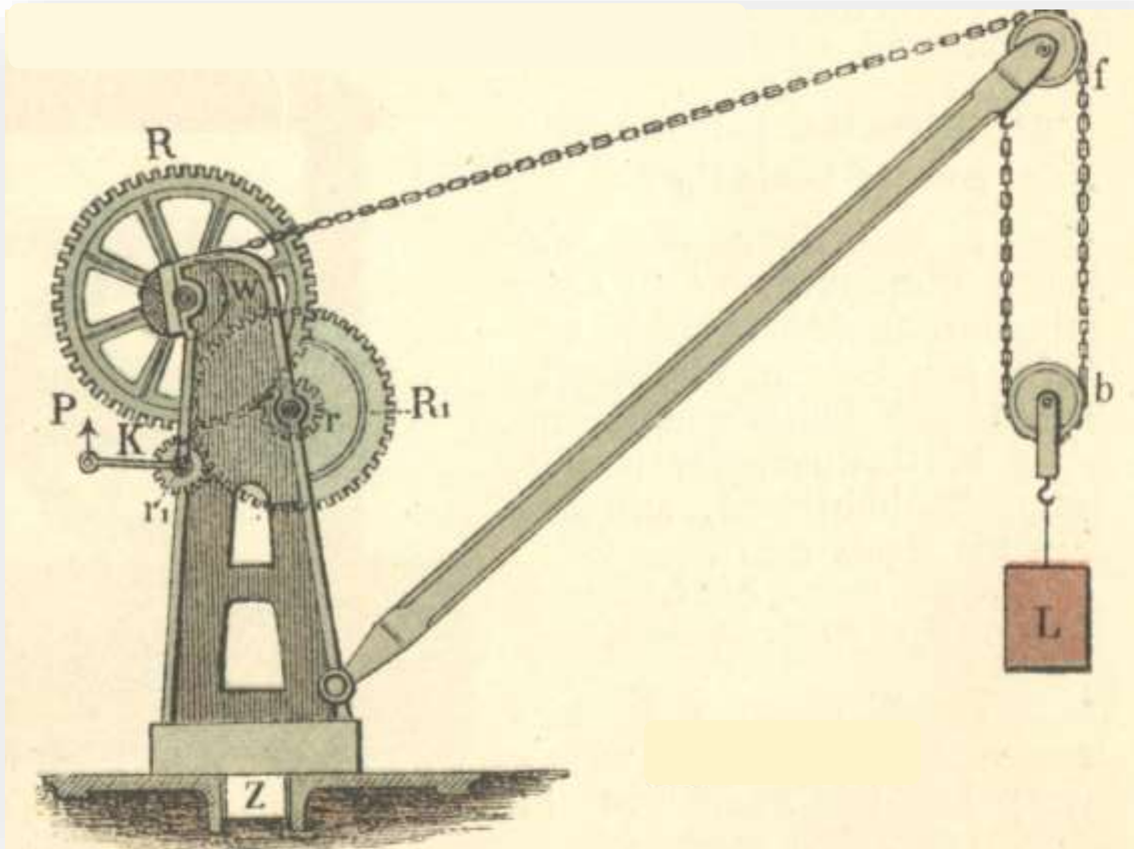

Force required to lift weight W=m·g by *h* requires $\Delta E = W \cdot h$

Using 4-wheel pulley → F = W/4

To lift weight *W* by distance *h*, force has to pull rope of length 4·h

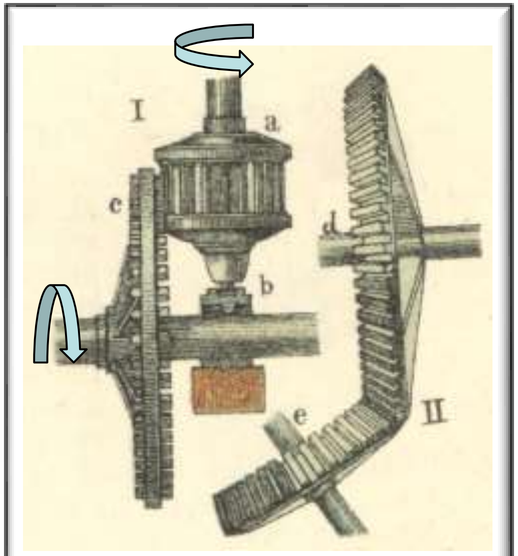
→ *Work* $\Delta E = F \cdot (4 \cdot h) = W \cdot h$

# Hand Crane with Gearbox



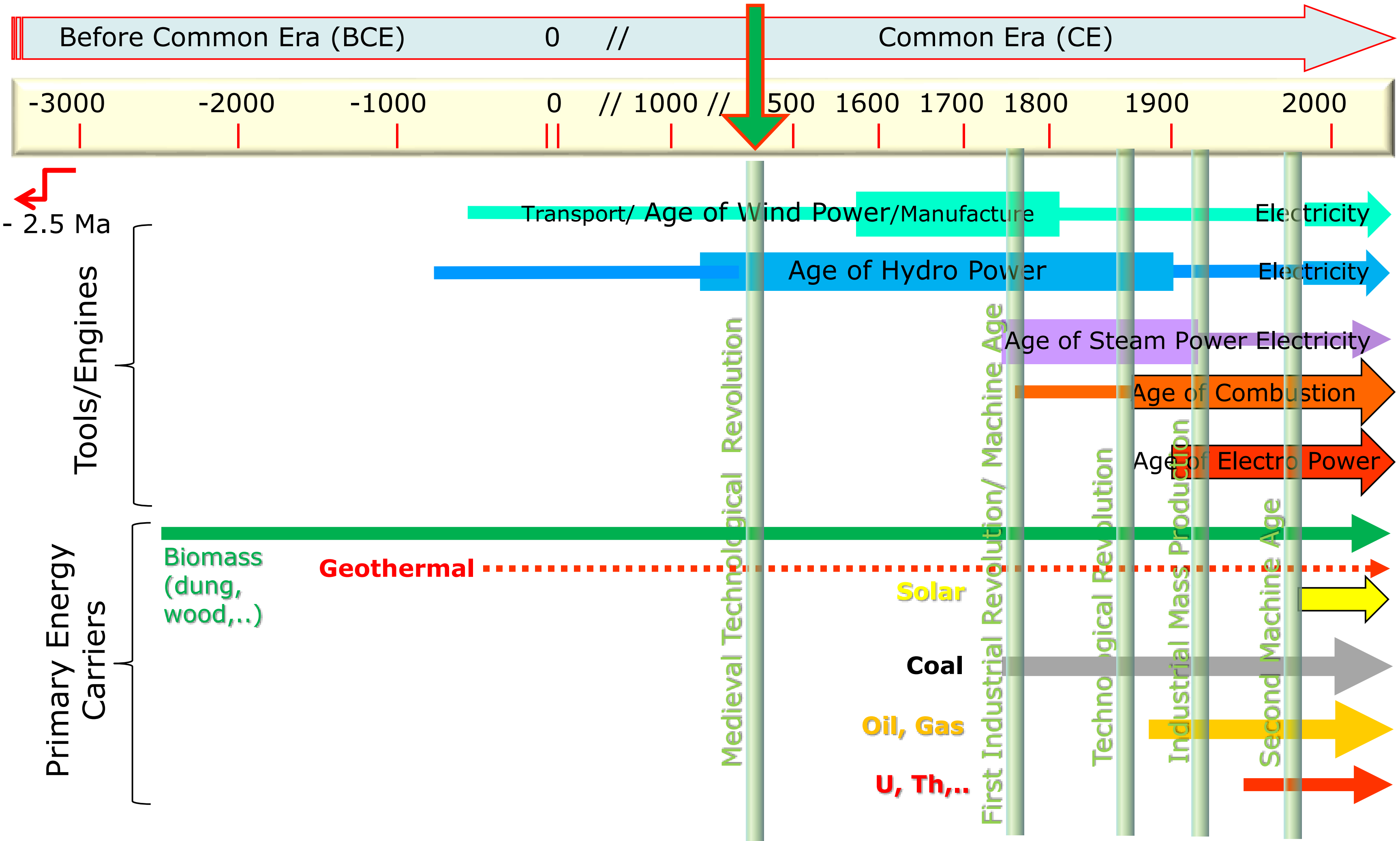

Multiple leverages via gear ratios.

Gears allow changes in rotation axis




Advance: Replace muscle power by kinetics of natural flows

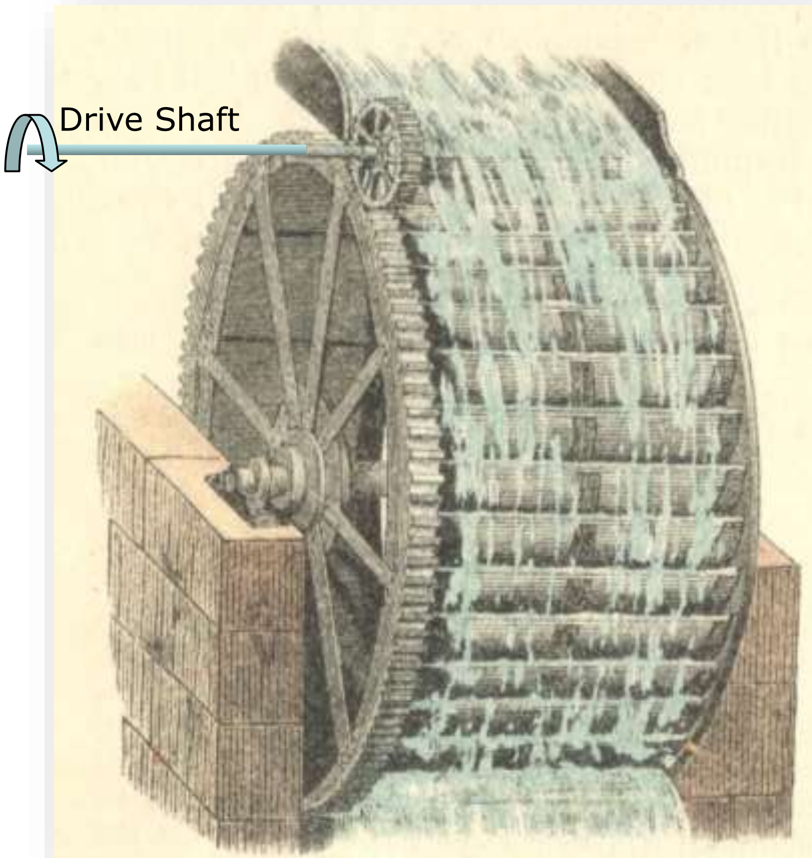
# Time Line Tools & Fuels (Western Cultures)

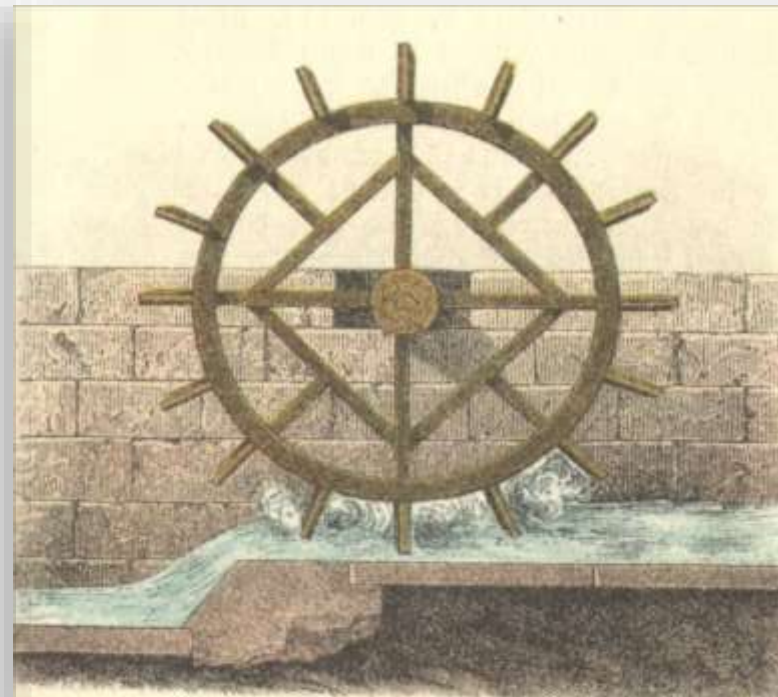



Future: Proven technologies using ample resources efficiently (sustainably) will likely remain vital. Others need exploration/improvement.

History in illustrative examples →

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



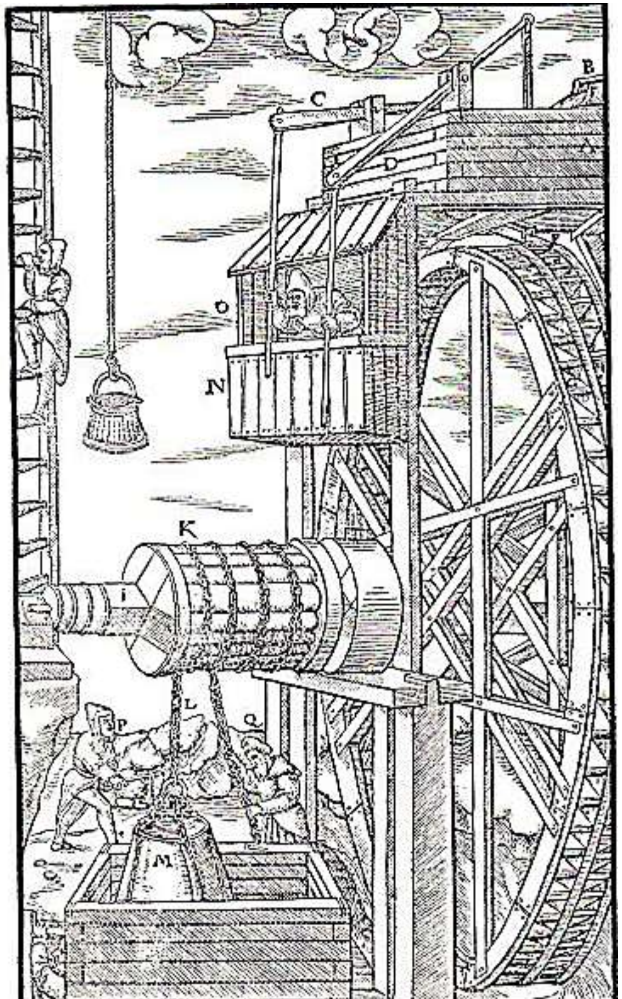



↑ Undershot waterwheel

← Overshot waterwheel

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

# Water Mills



Water mill used in medieval mining.

Historic water mill
Renchtal, Schwarzwald/Germany

# Wind Power for Transportation



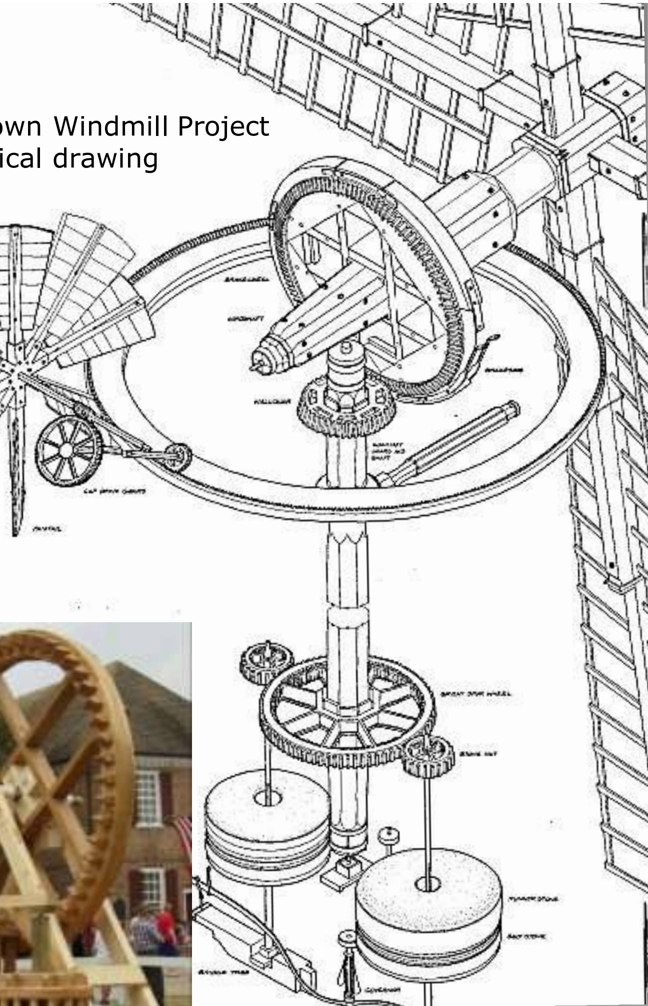

Largest full-rigg *Preussen* leaving the port of New York (1908)

← Auxiliary cruiser SMS *Seeadler* (1916). Function of hull, keel

# 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-

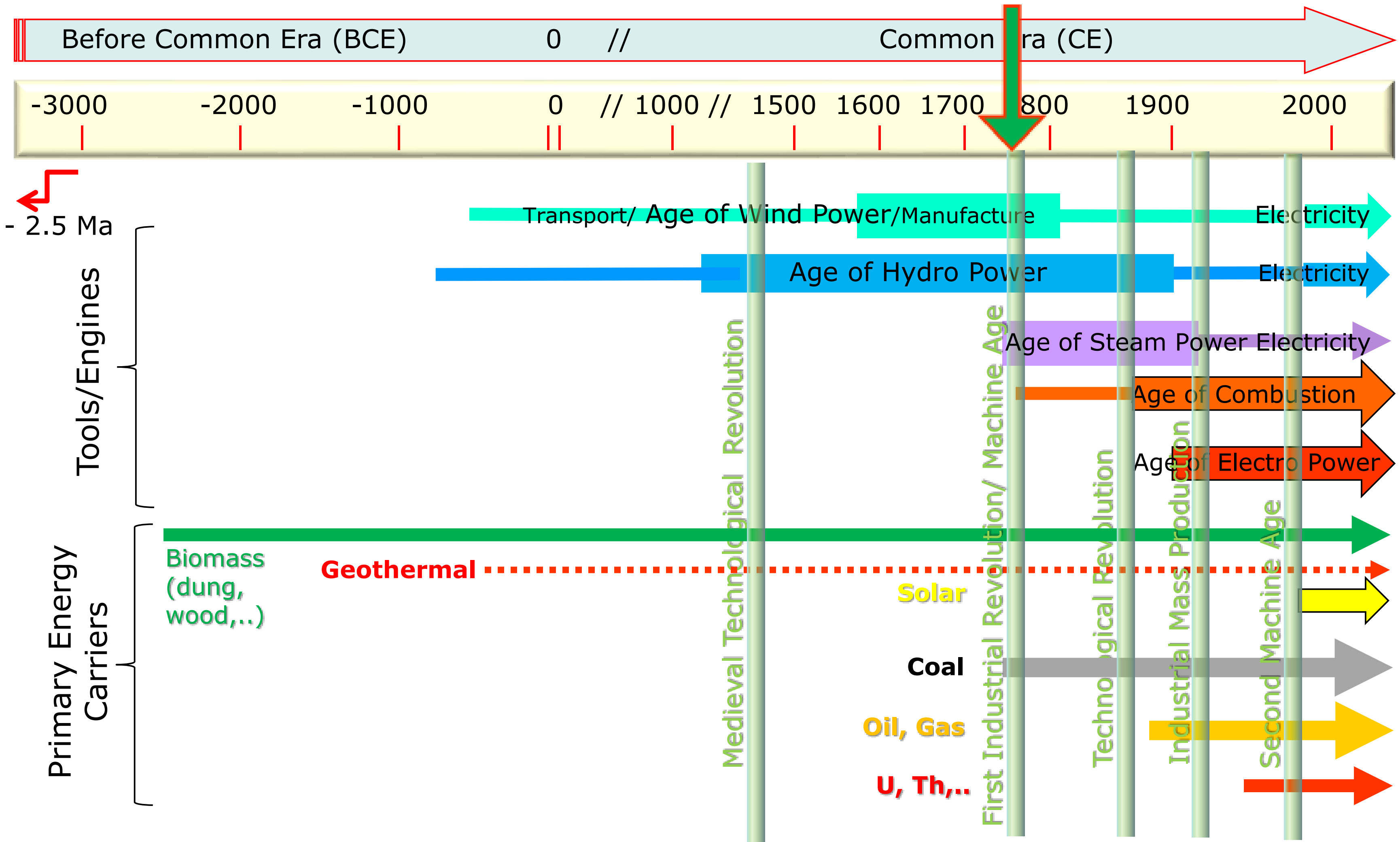
http://www.yorktown-windmill.org/html/public/final-design.html
Accessed Oct. 2012





Modern ways to harness

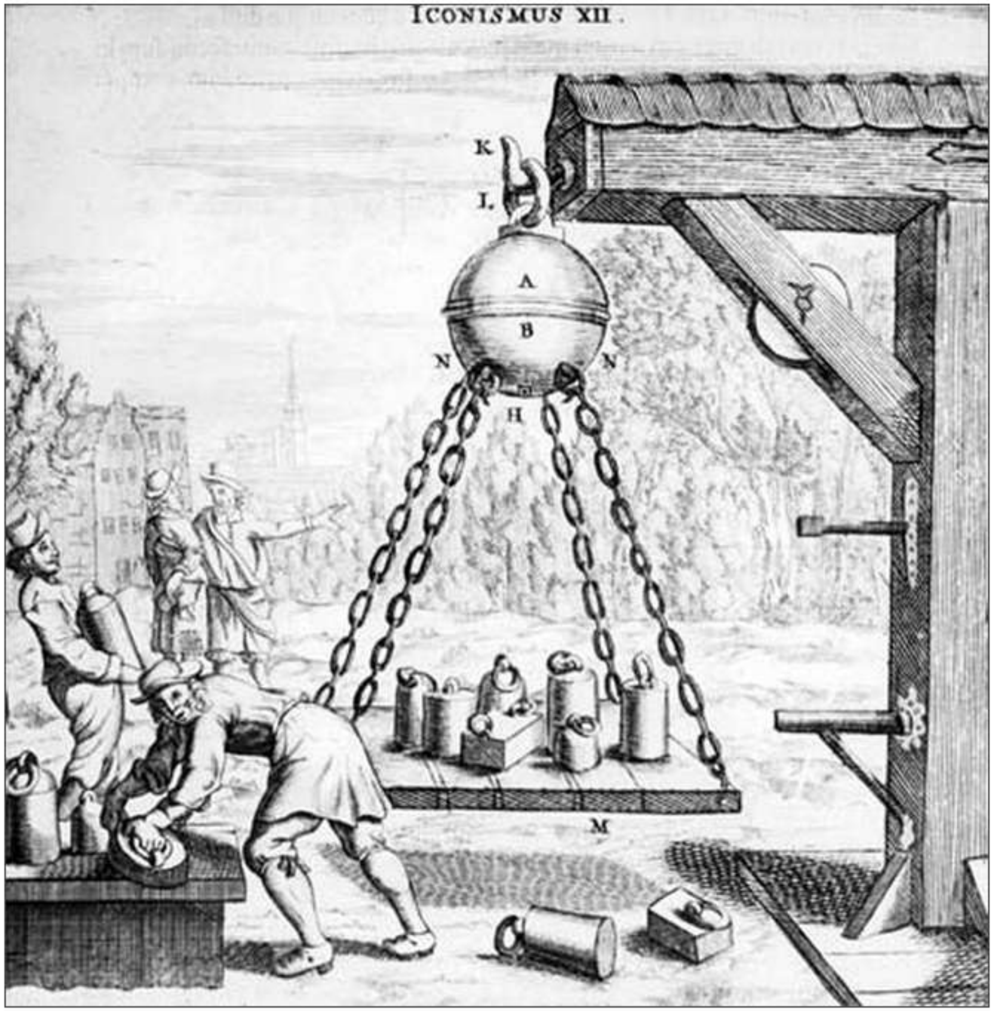
# Time Line Tools & Fuels (Western Cultures)




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

History in illustrative examples →

# 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.

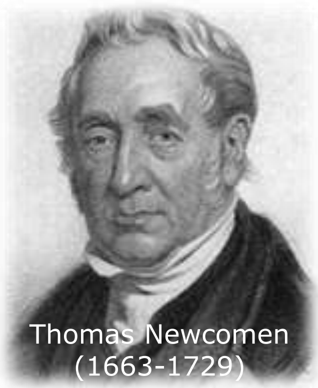
Measure pressure

P = force($\alpha$ 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

# 18th Century Steam Power

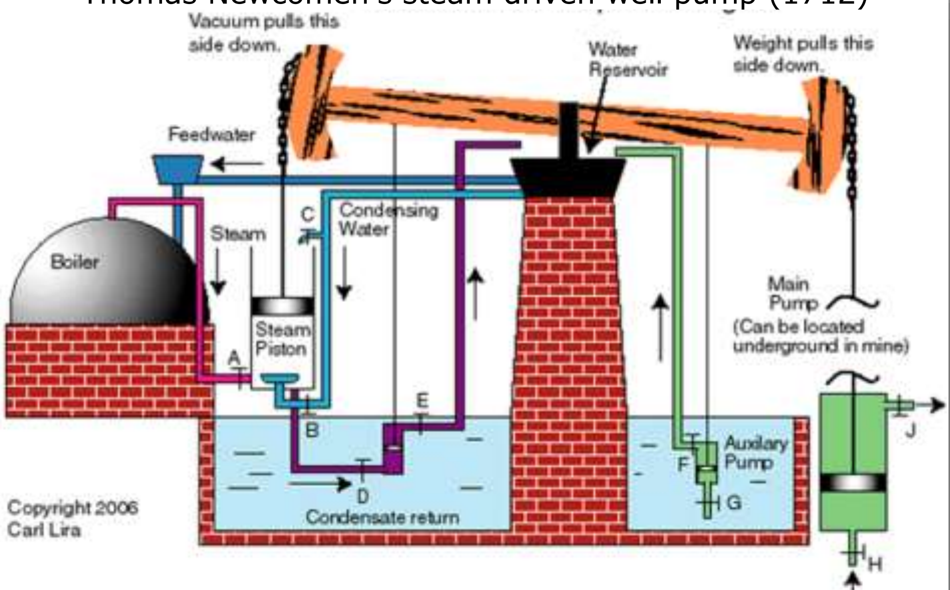

Thomas Newcomen (1663-1729)

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.)

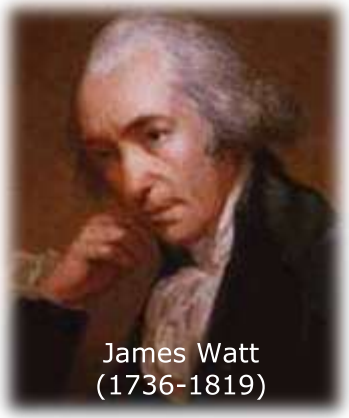
Thomas Newcomen built the first practical steam engine. Not very efficient: cylinder had to be heated and cooled repeatedly, stressing cylinder, wasting a lot of energy. 50 years later improved by James Watt.

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

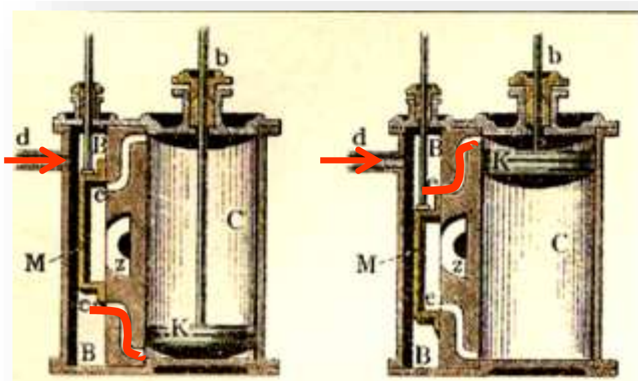



Fig. 36. Tiefste Stellung des Kolbens K. Fig. 37. Höchste Stellung des Kolbens K.
Längsdurchschnitt des Zylinders C und der Dampfkammer B.
d Dampfrohr. M Muschelschieber. ee₁ Dampfzuleitungskanäle.
z Öffnung für den verbrauchten Dampf.

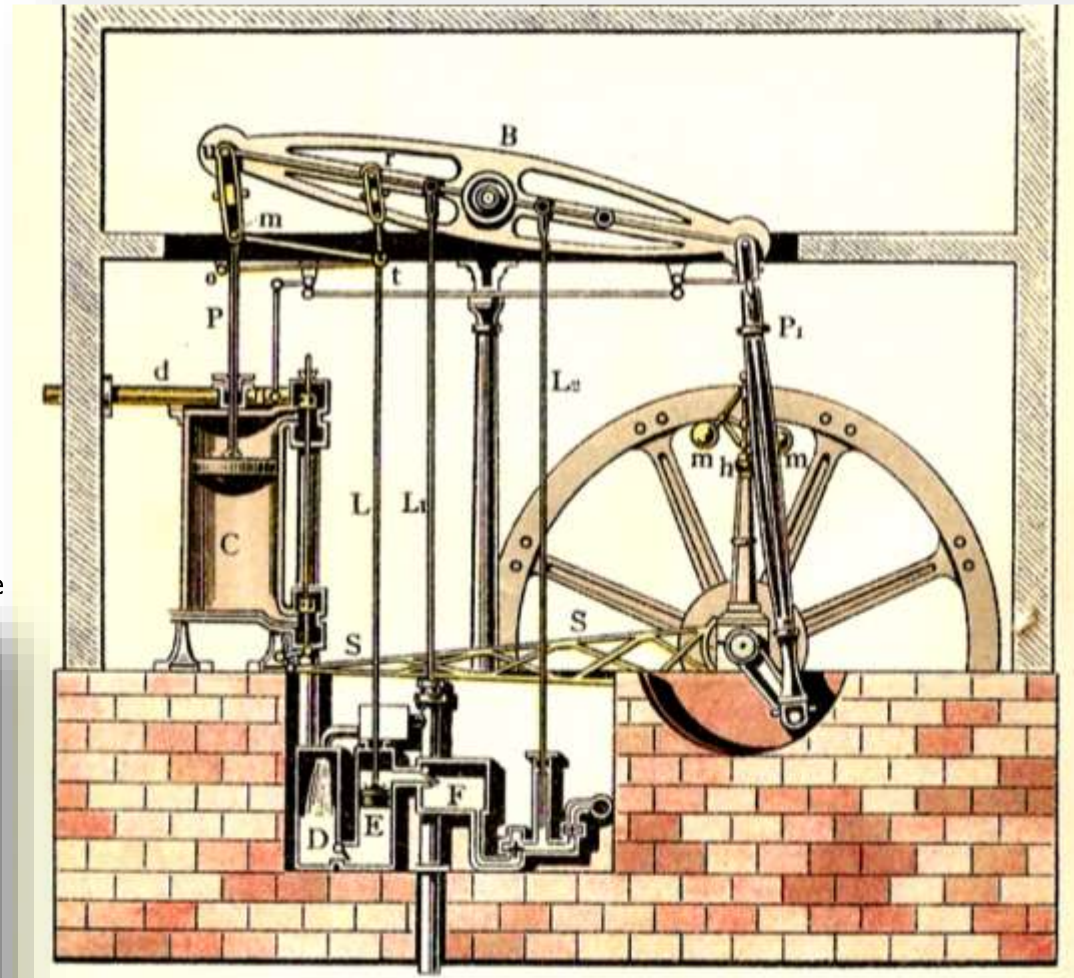



Fig. 34. Wattsche Dampfmaschine.
C Dampfzylinder. d Dampfzuflußrohr. B Balancier. R Schwungrad. D Kondensator. LE Luftpumpe. L₁F Kaltwasserluftpumpe des Kondensators L₂ Warmwasserluftpumpe des Dampfkessels. S Exzenterstange der Steuerung. P₁ Pleuelstange mit Kurbel.

# America's Centennial Exposition

George H. Corliss.
Inventor, Providence, RI

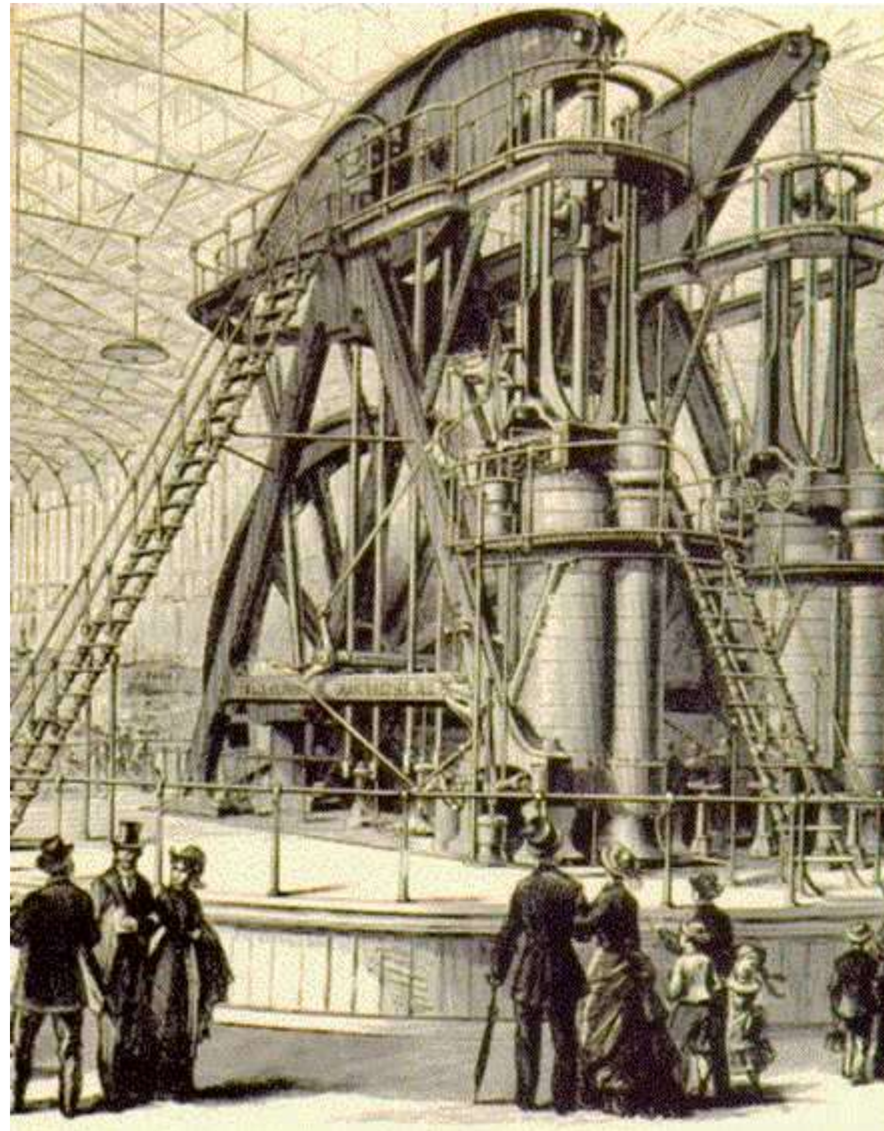
American made Corliss engine at the Philadelphia exhibition:

Eye witness account:
"It stood in excess of forty-five feet above the floor and has cylinders of forty-four inches in diameter with a ten foot stroke. Another characteristic is the huge fifty-six ton, thirty feet in diameter, and twenty-four inch face, flywheel which made up to thirty-six revolutions per minute." (McCabe)

**Much of the original research and development had been done in Europe. American businessmen imported machinery and ideas and soon improved on design, further invented and developed their own technology.**

**America's Centennial Exposition, held in Philadelphia in 1876** →→→

The pictured steam engine powered all machines and devices in the exhibition. It was operated by a single engineer. W=1,400 hp



# Industrial Strength

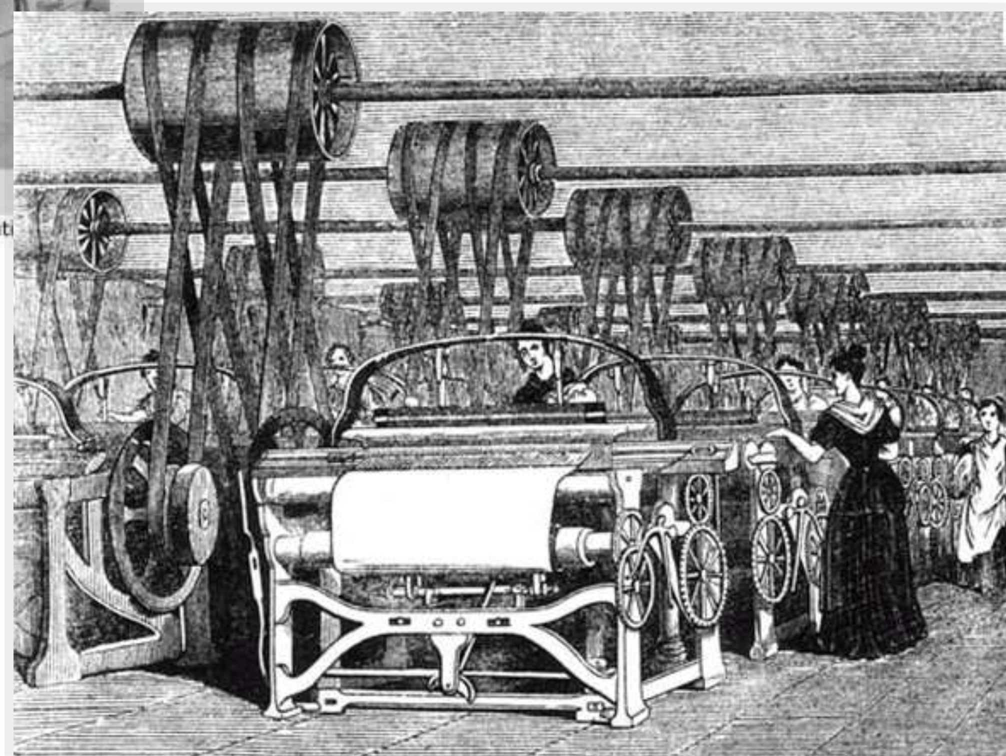
The Great Allis-Corliss Engine at the 1893 World's Columbian Expositi

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.

# Fossil Fuel: Coal

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

Coal: known since centuries for heating and iron melting.

New steam engines needed fuel of high caloric value → encouraged new coal mining activities in England.

**Increased mining enabled English industrial revolution.** Powered steam engines.

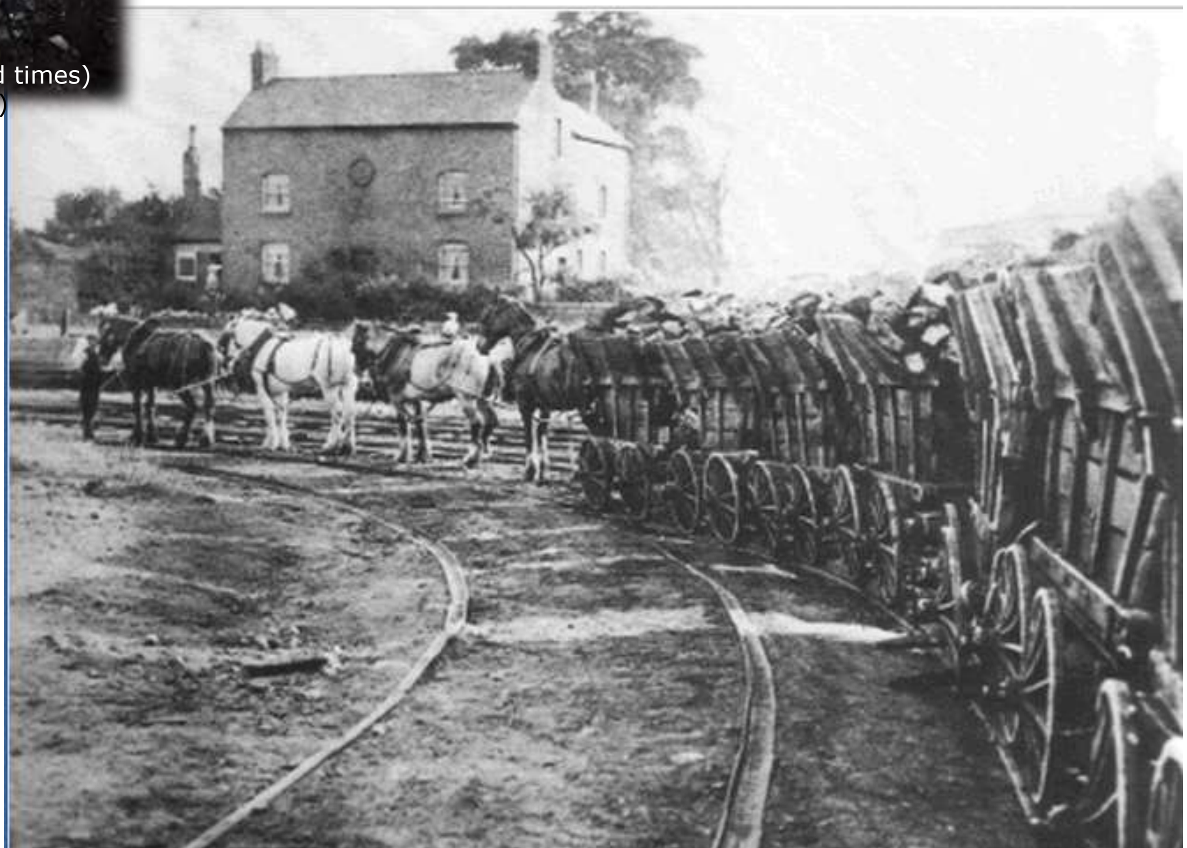
**US**: Coal replaced wood and charcoal beginning middle 19th century, produced in the East (Appalachians) or imported.

Early (17th century) underground coal mines established at Tyne and Wear rivers: easy coal transport using river barges drawn by horses.

Railroads replaced canals in hilly terrain.

First rail roads had wooden rail tracks, later iron rails.

Already in 17th century: Colliery railways ("Newcastle Roads") provide long-distance coal transport → more distant mines.



# Ocean Steamers


The HMS Great Britain, 1845, propeller.


SS Savannah, 1819

First Atlantic crossing by steamship.
Painting by Hunter Wood.

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.


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

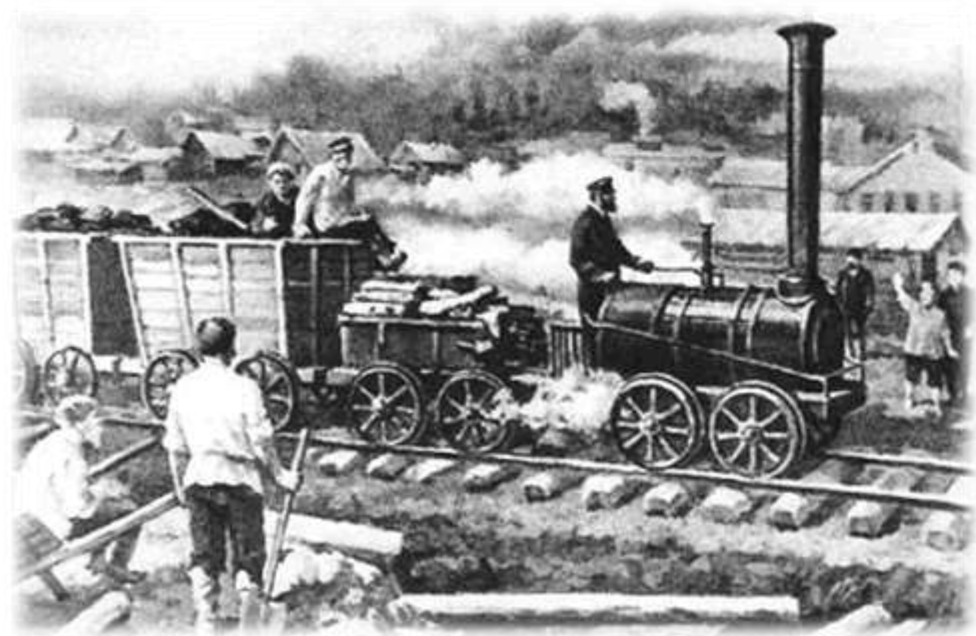
# First Steam Powered Railroads

George Stephenson (1781-1848)

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 17$^{th}$ century railways, horse drawn Chaldrons replaced by steam driven locomotives.



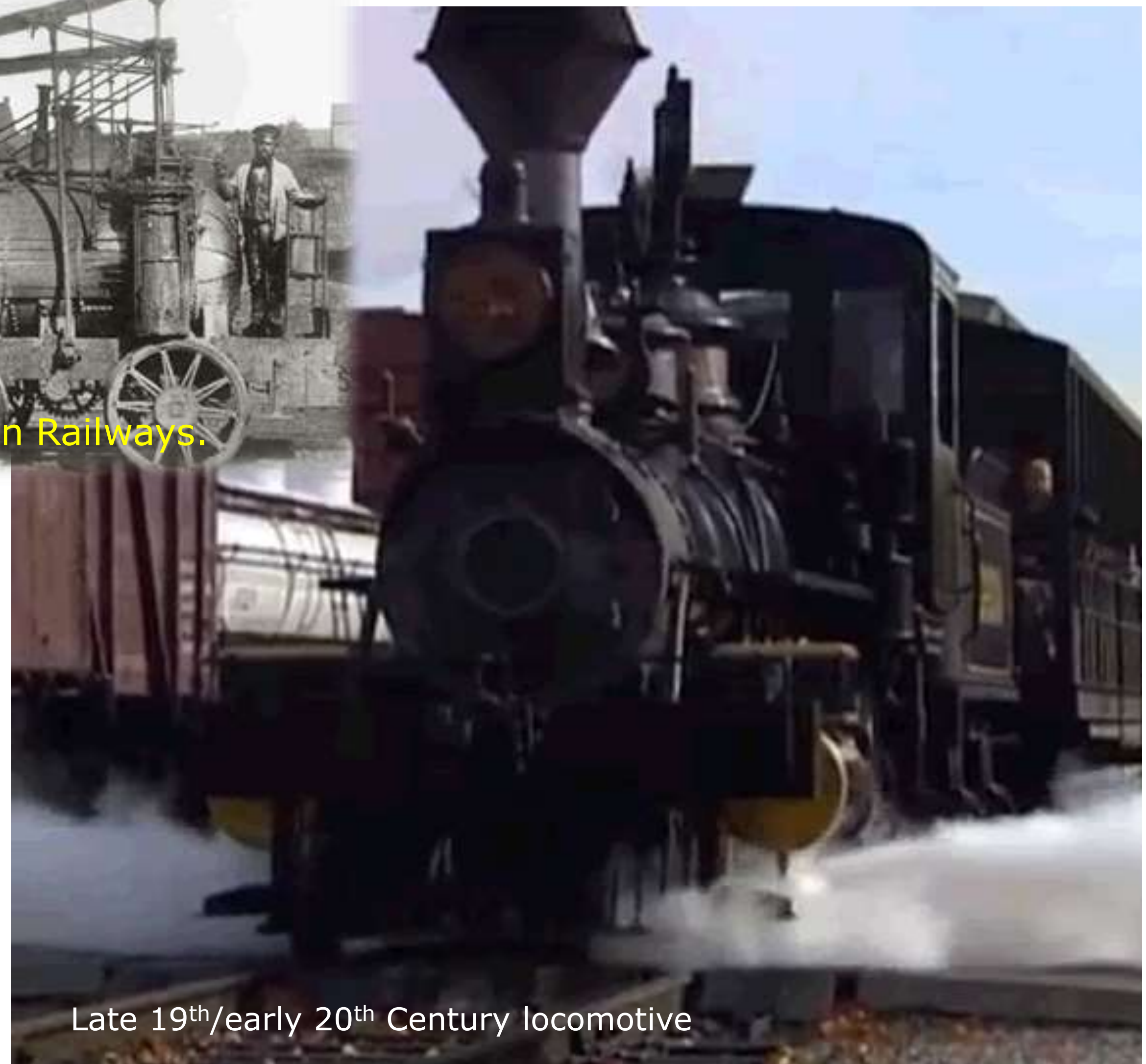
1830: The first American railroad, "Baltimore and Ohio Railroad" (18 mph).

# “Iron Horses”

1800/1900s industrial revolution → link fossil fuel to transportation

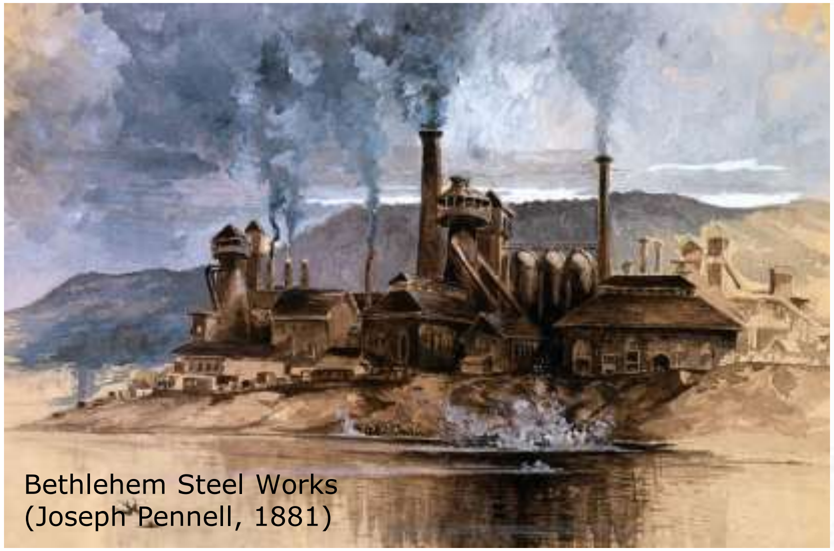
Puffing Billy (1862) Victorian Railways.

Puffing Billy in Australian museum exhibition

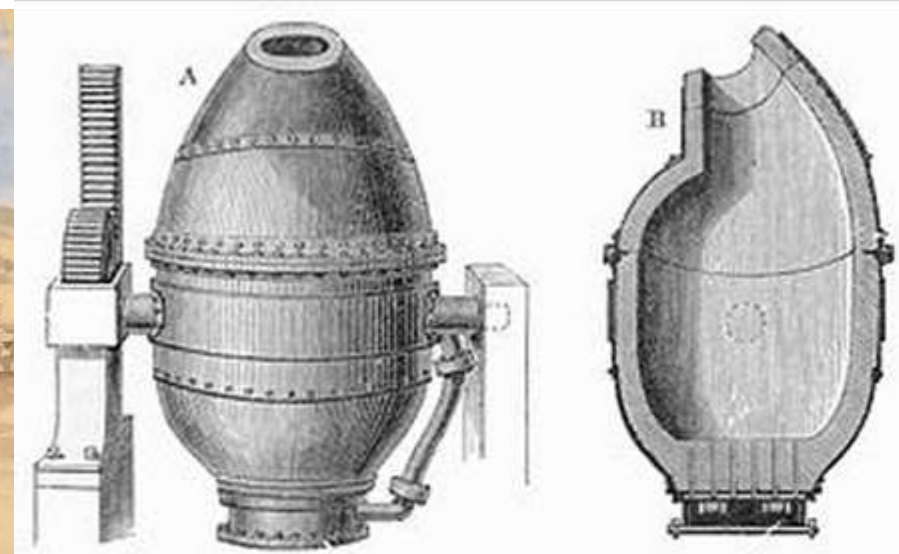


Late 19$^{th}$/early 20$^{th}$ Century locomotive

# Rise of American Steel Industry



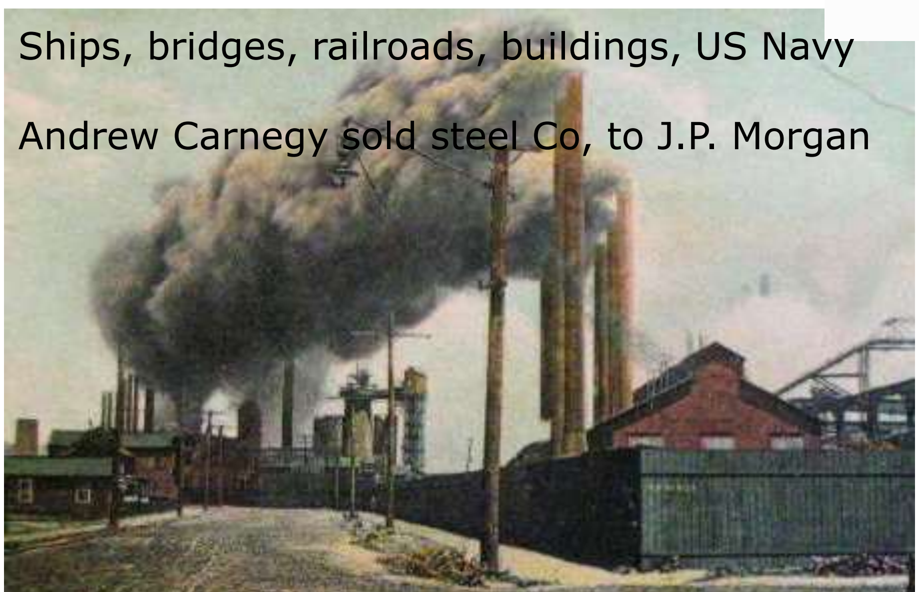
Bethlehem Steel Works
(Joseph Pennell, 1881)




Bessemer steel process 1851

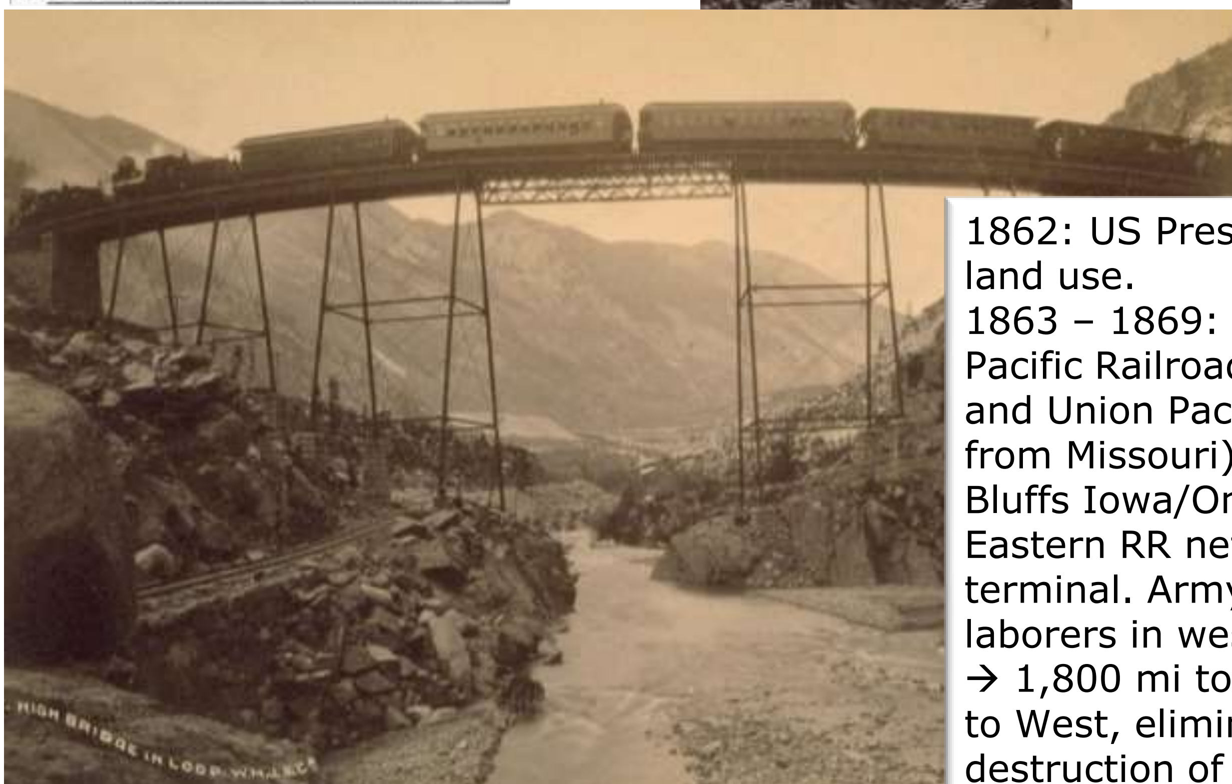
Ships, bridges, railroads, buildings, US Navy

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



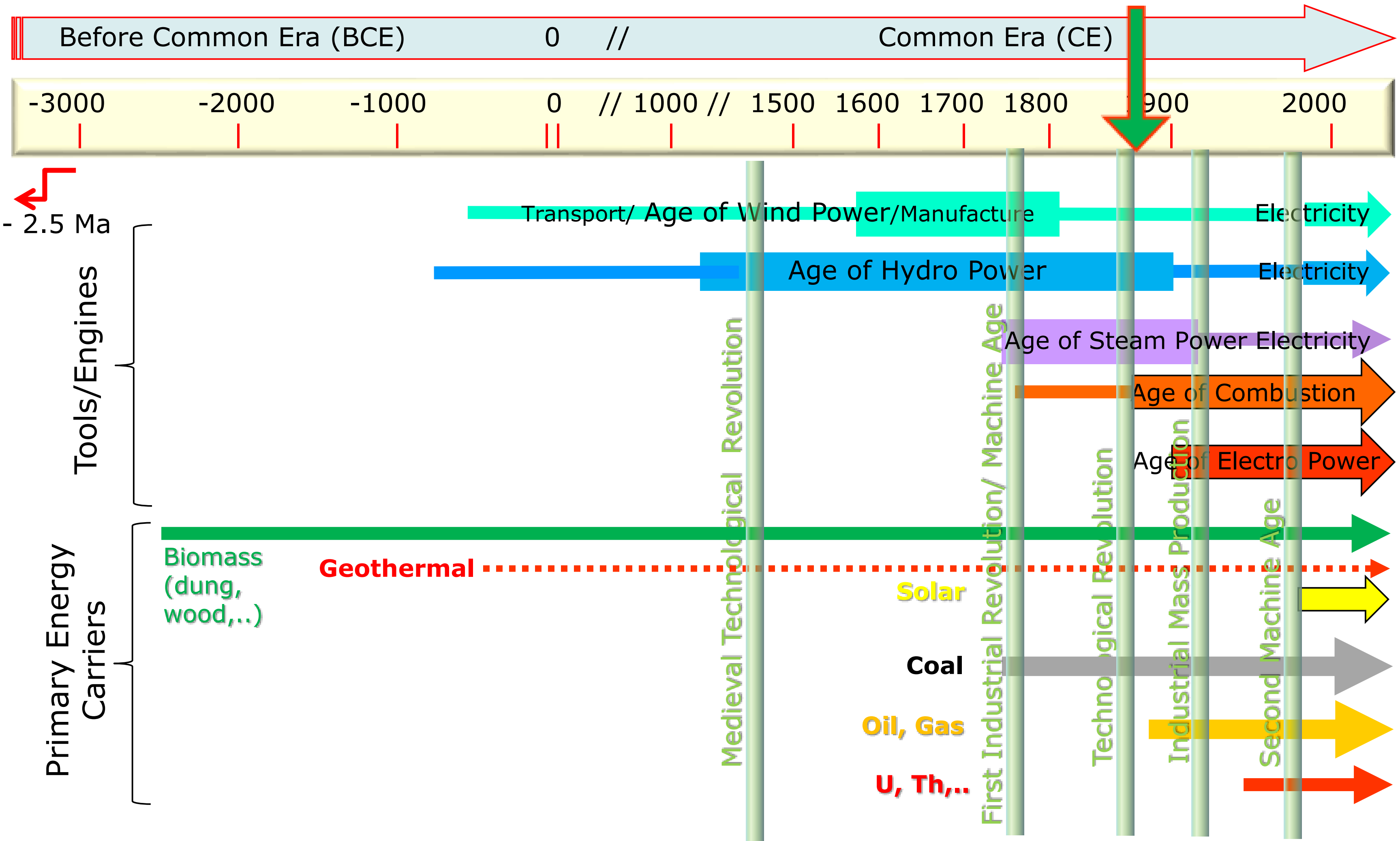
Workers in steel mill

# 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.

# Time Line Tools & Fuels (Western Cultures)




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

History in illustrative examples →