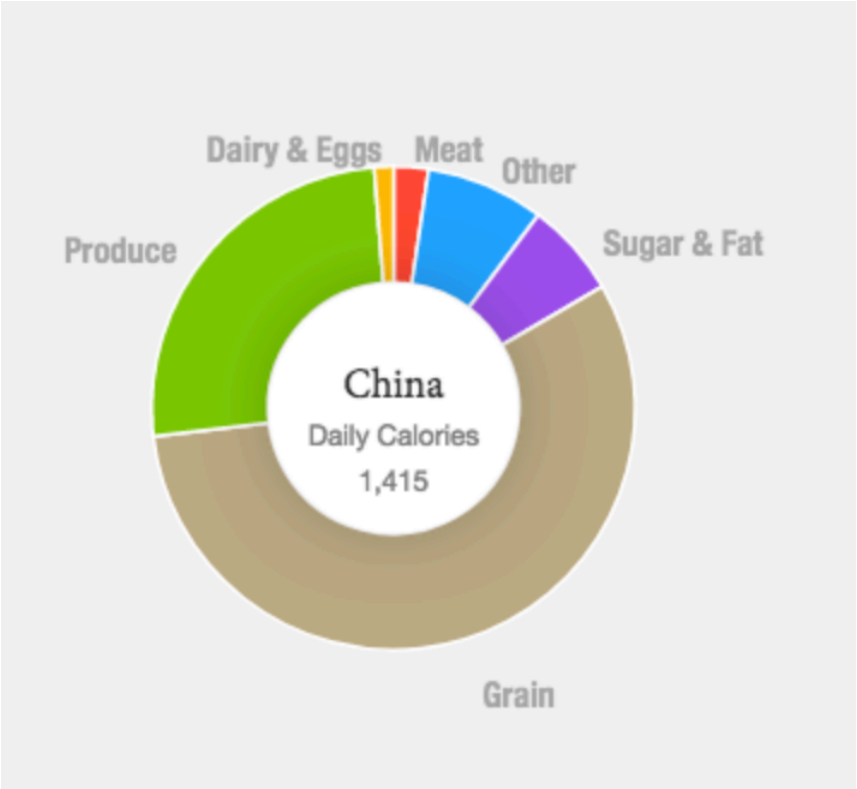
GEOS 24705 / ENST 24705 / ENSC 21100

2018

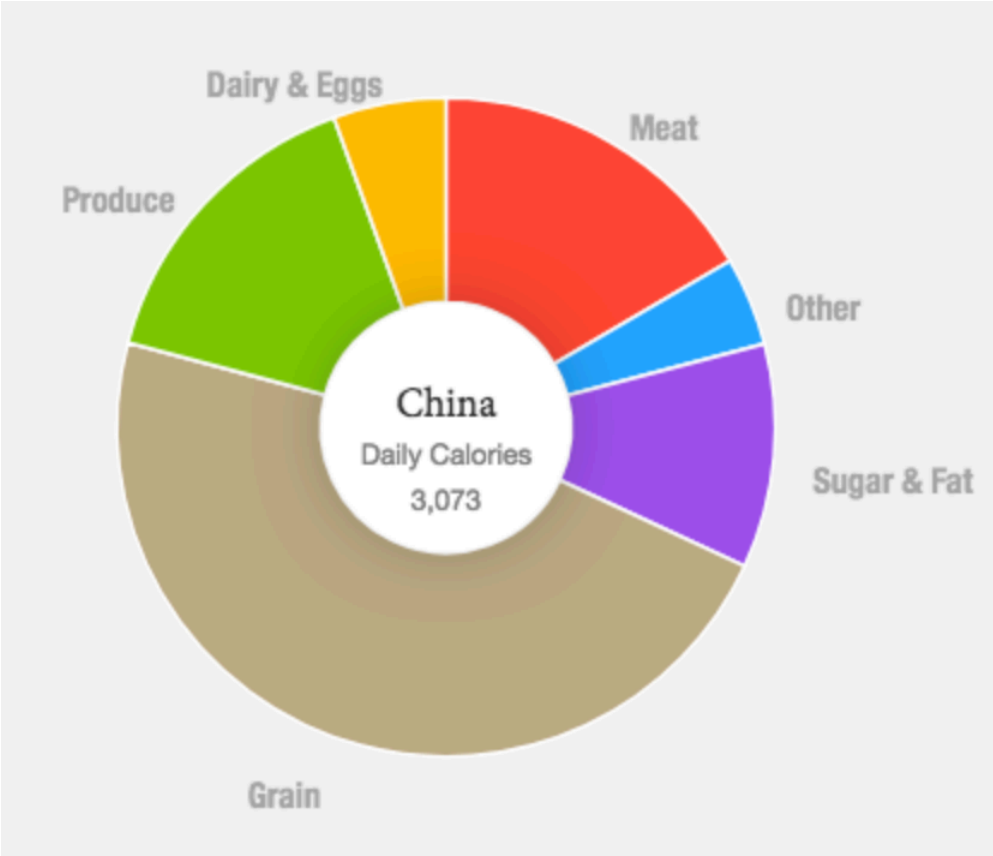
Lecture 5

Agriculture, History of Energy Use I

Yield growth in agriculture means people now eat more



China 1961



China 2011

From National Geographic: *https://www.nationalgeographic.com/what-the-world-eats/*

Yield growth in agriculture extends to meat production

NATIONAL CHICKEN COUNCIL

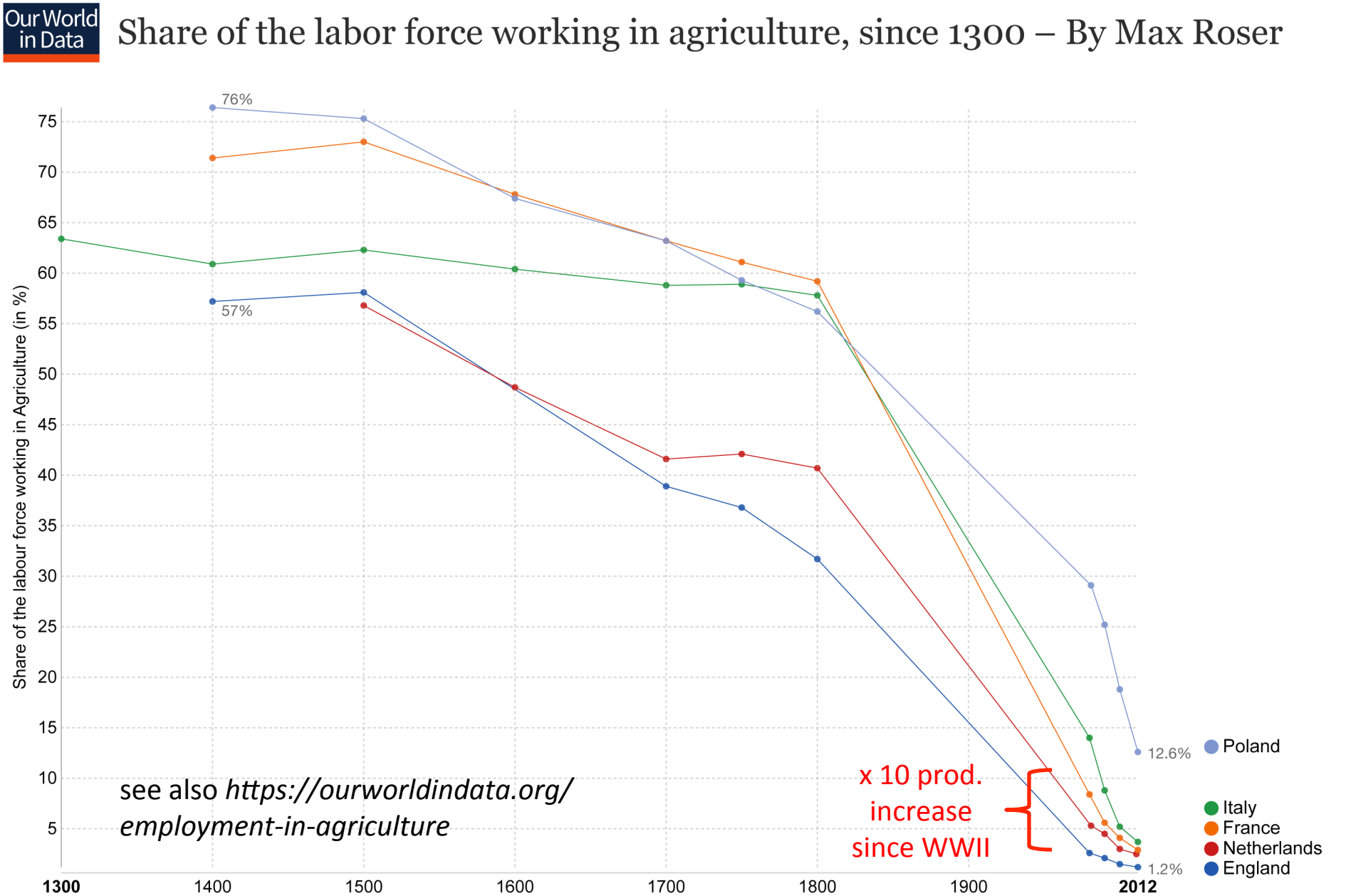
Year	Market Age *average days*	Market Weight *pounds, liveweight*	Feed to Meat Gain *pounds of feed to one pound of broiler, liveweight*	Mortality *percent*
1925	112	2.5	4.7	18
1935	98	2.86	4.4	14
1940	85	2.89	4	12
1945	84	3.03	4	10
1950	70	3.08	3	8
1955	70	3.07	3	7
2012	47	5.85	1.9	3.7
2013	47	5.92	1.88	3.7
2014	47	6.01	1.89	4.3
2015	48	6.12	1.89	4.8
2016	47	6.16	1.86	4.5
2017*	47	6.18	1.85	4.4

Chicken now takes only 2x as much feed as final weight

Cows are still ~ x10, i.e. higher impact food

http://www.nationalchickencouncil.org/about-the-industry/statistics/u-s-broiler-performance/

Innovations mean fewer people needed to farm



Data source: Pre 1800 is from Allen (2000), "Economic Structure and Agricultural Productivity in Europe, 1300-1800". Newer data from the World Bank.
The interactive data visualization is available at OurWorldinData.org. There you find the raw data and more visualizations on this topic.

History of human energy use

First use of non-human energy relates to food

Fire for cooking:

definitely 300-400K years ago *(Homo sapiens* and *neanderthalensis)* potentially 1M years ago *(Homo erectus)*

Animals for pulling and transportation:

1000s of years (used first for food, then used for work)

In earliest human history the only “engines” were people

Maize farmer, somewhere
in Africa, 2007
Source: CIMMYT

In earliest human history the only “engines” were people

Ploughing by hand,
Uganda

In most of the world, people adopted more powerful "bio-engines" for plowing and planting

Diderot & d`Alembert eds, Encyclopédie méthodique. Paris 1763-1777 & 1783-87.

Harvesting is a complex motion, difficult to automate

Wheat harvest, Hebei Province, China, 2007 *(source: www.powerhousemuseum.com)*

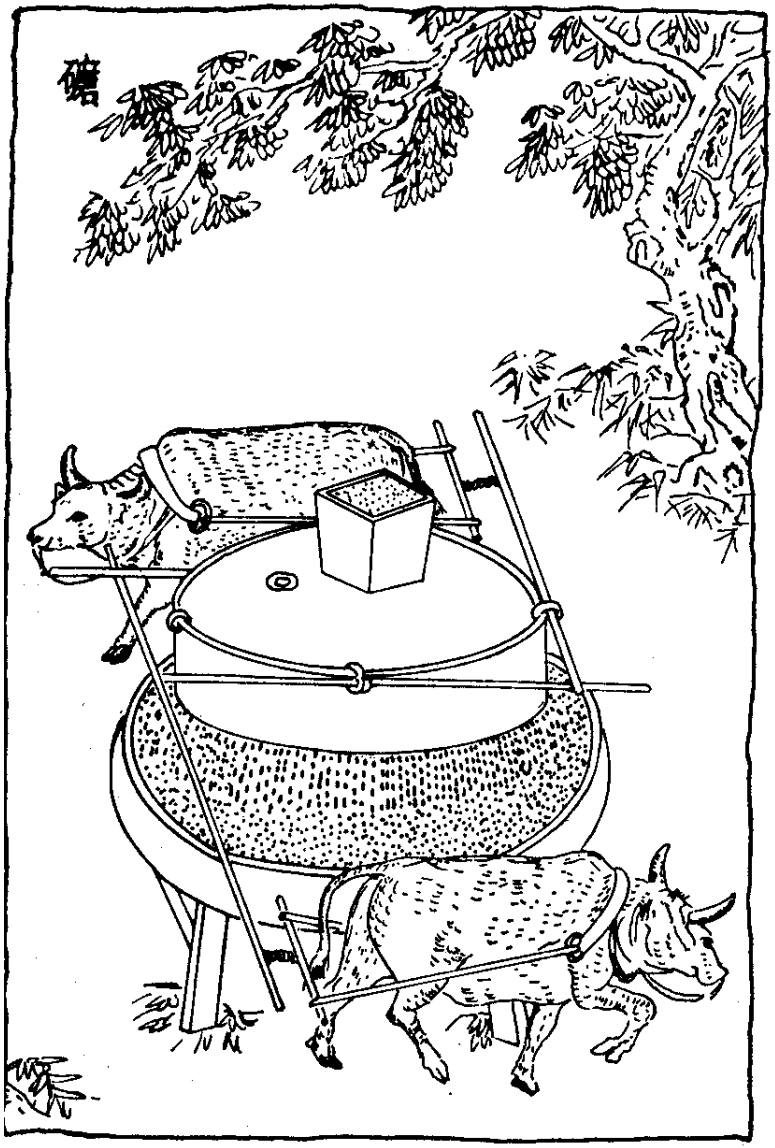
The combine allowed harvesting to be animal-powered too

Horse drawn combine, likely 1910s-20s. *Source: FSK Agricultural Photographs*

Combine “combines” functions: cuts and threshes grain

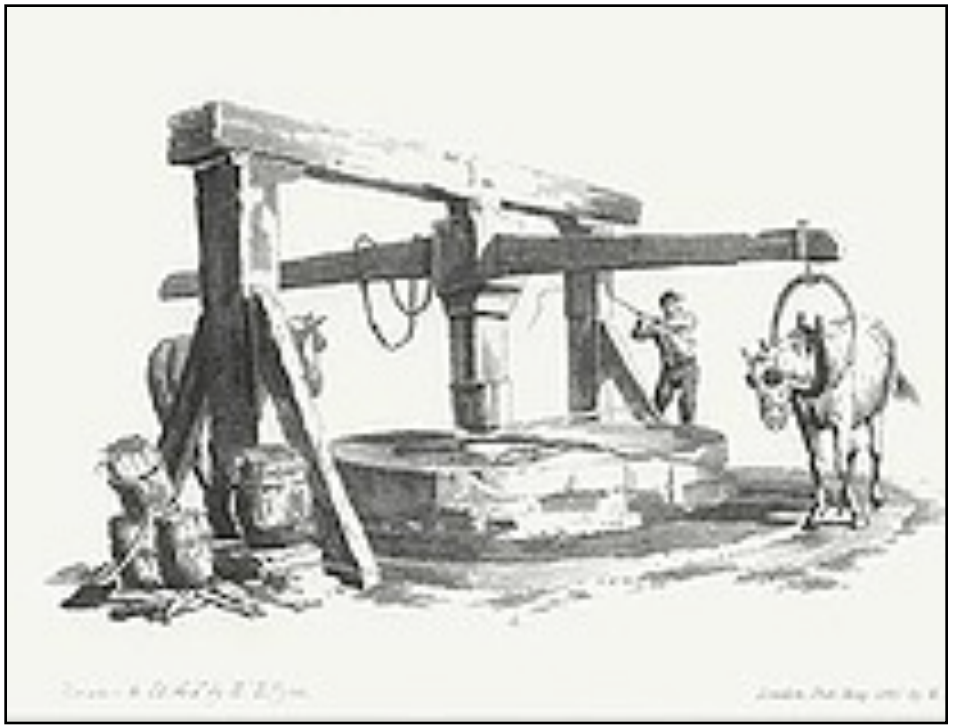
Horse-drawn combine, Almira, WA, 1911. *W.C. Alexander. Source: U. Wash. library*

Rotation: animal powered wheels have a long history



China, from the encyclopedia “Tiangong Kaiwu”, by Song Yingxing (1637)

First use: grinding



Clay millers, W.H. Pyne, London (1806)

Human powered wheels persisted into the modern era

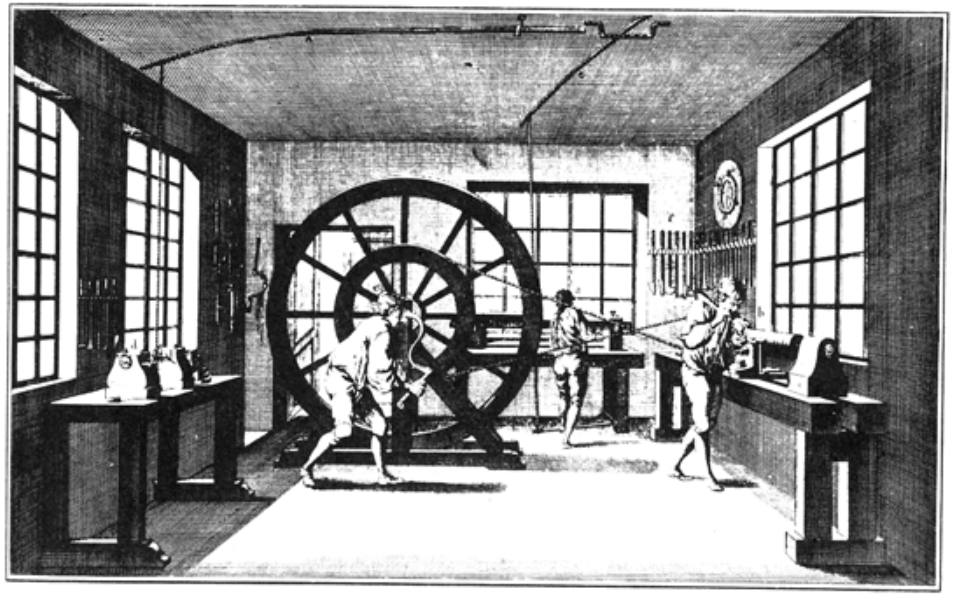


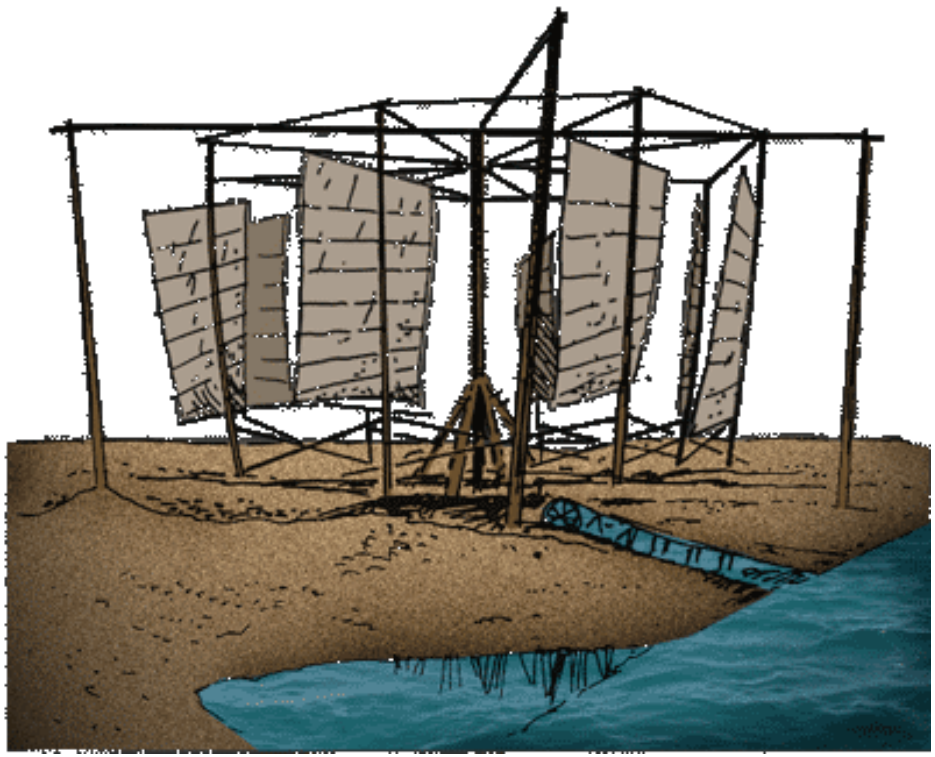
FIGURE 4.5 The great wheel powered by a crank in a mid-eighteenth-century French workshop to turn a metal-working lathe. The smaller wheel was used for working with larger diameters and vice versa. In the background of this picture a man works on a foot-powered lathe machining wood. *Source:* Reproduced from Diderot and D'Alembert (1769–1772).

Lathe, late 1700s

Japanese water pump, still used in 1950s

Rotational motion is a fundamental industrial need ….
Grinding is not the only use of rotational motion.

Other sources of mech. work: *wind and water*



Persian windmill
7th century (634-644 AD) or later

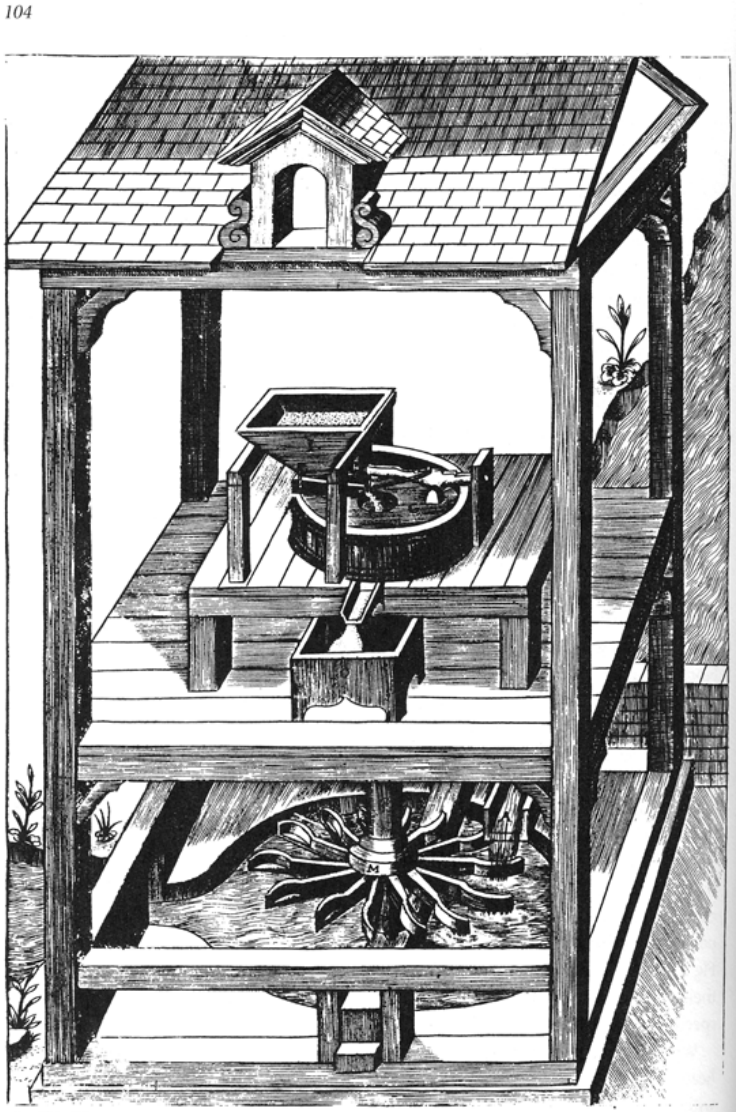


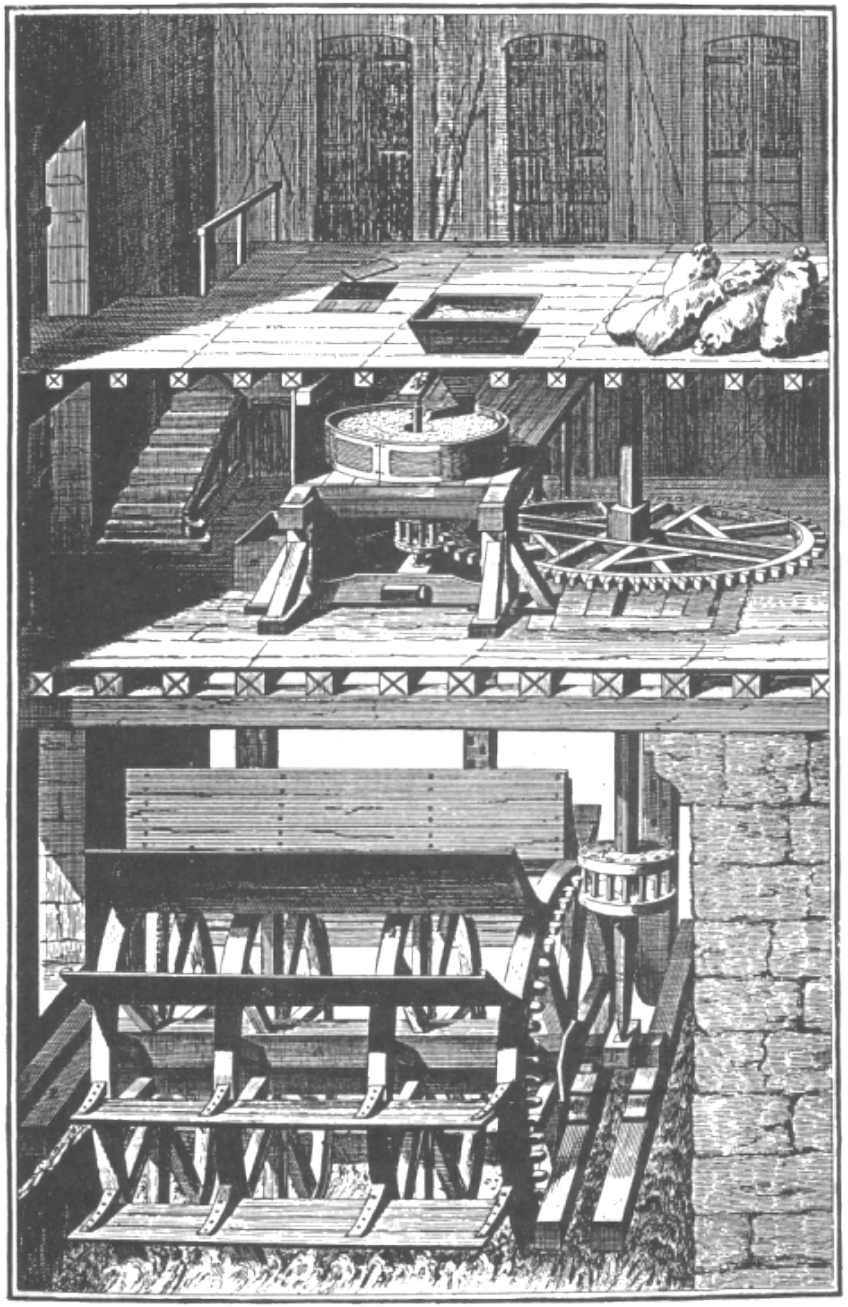
FIGURE 4.8 The horizontal waterwheel, also called a Greek or Norse wheel, was powered by the impact of running water and rotated the runner stone directly. *Source:* Reproduced from Ramelli (1588).

Waterwheel
1500s or earlier

Energy transformation:
kinetic energy → kinetic energy

Very early a switch was made from vertical to horizontal axes

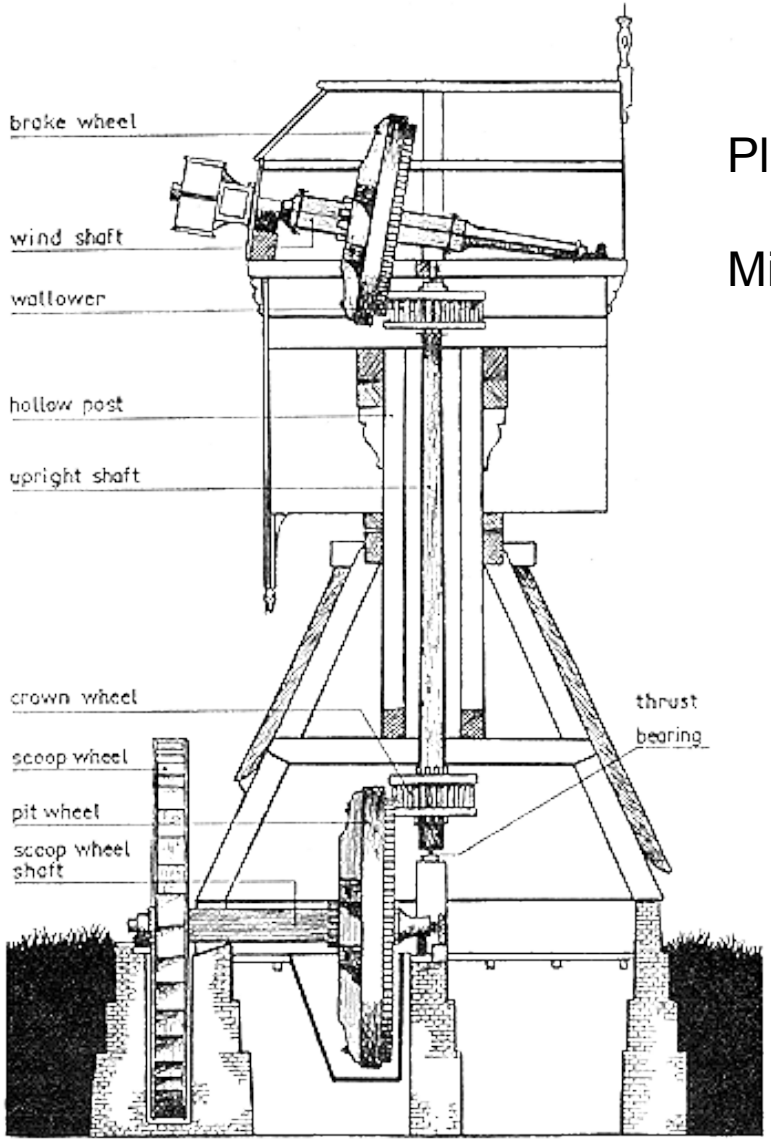
Pitstone windmill, believed to be the oldest in Britain.



Horizontal-axis waterwheel

Pluses & minuses for horizontal axes?

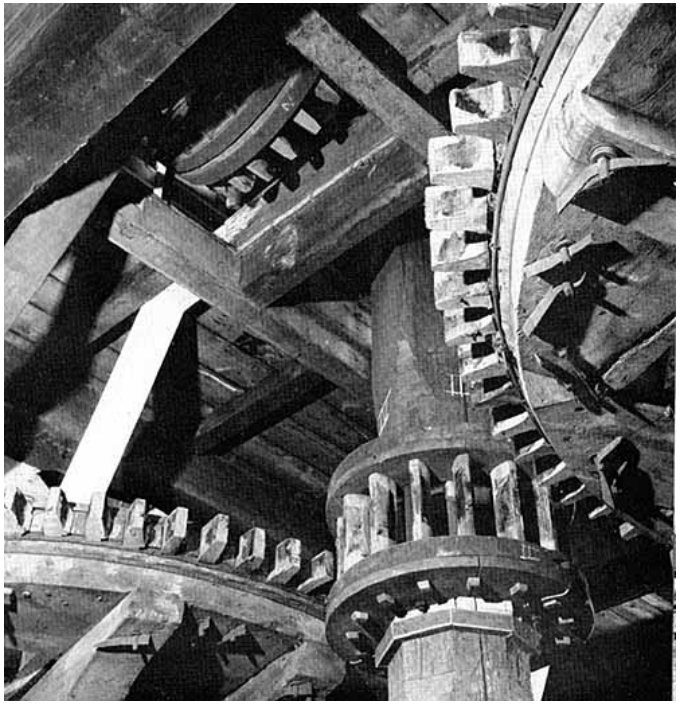
Pluses & minuses for horizontal axes?



Post mill diagram, *from* ***The Dutch Windmill****, Frederick Stokhuyzen*

Plus: * increased efficiency (both wind & water)

Minus: * complicated gearing to alter axes
* must rotate windmill to match wind dir.



Industrial windmil cogs

What were the needs for mechanical work by mills?

anything besides grinding grain?

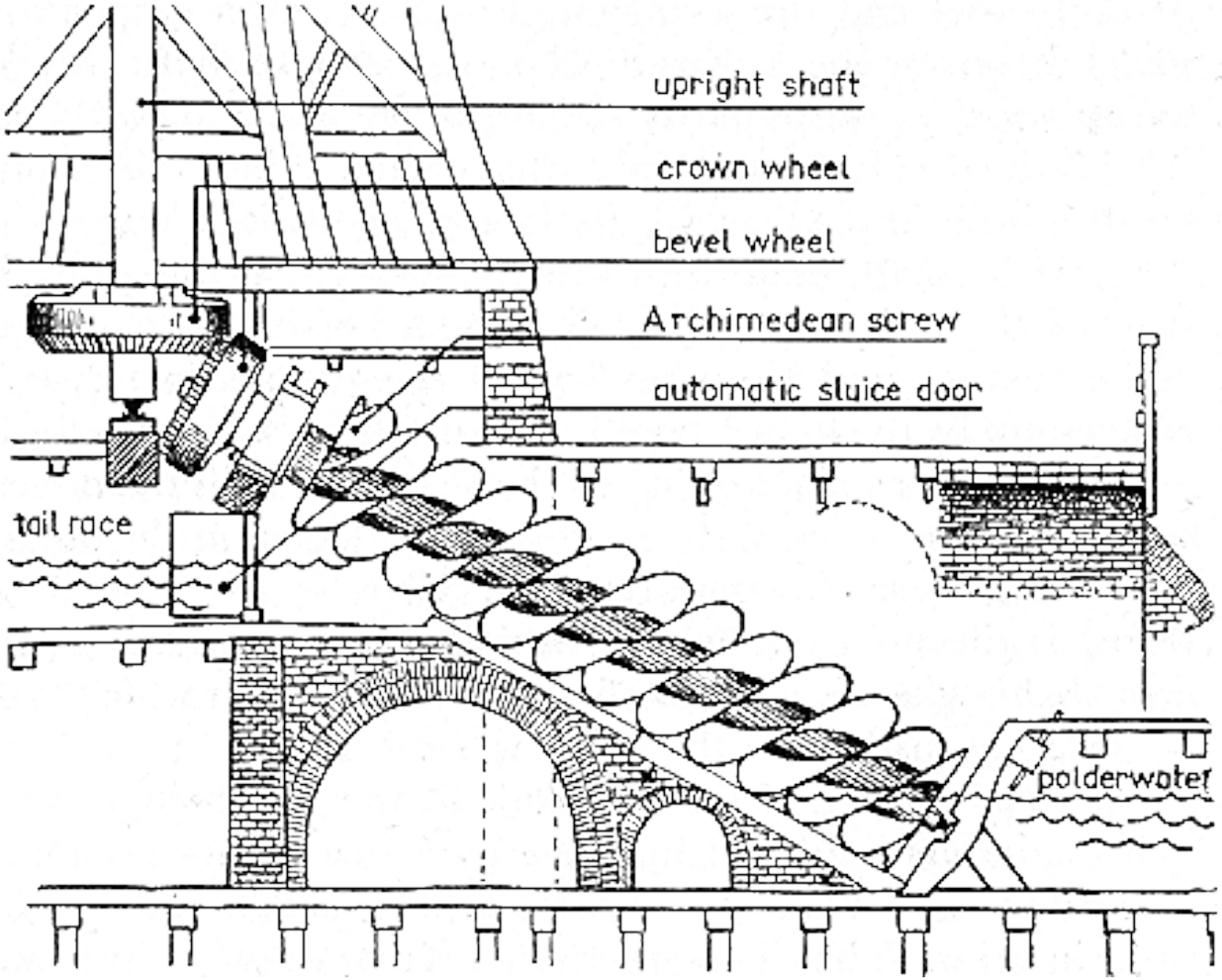
Why so many windmills along rivers?

.... to pump water from the fields

Source unknown

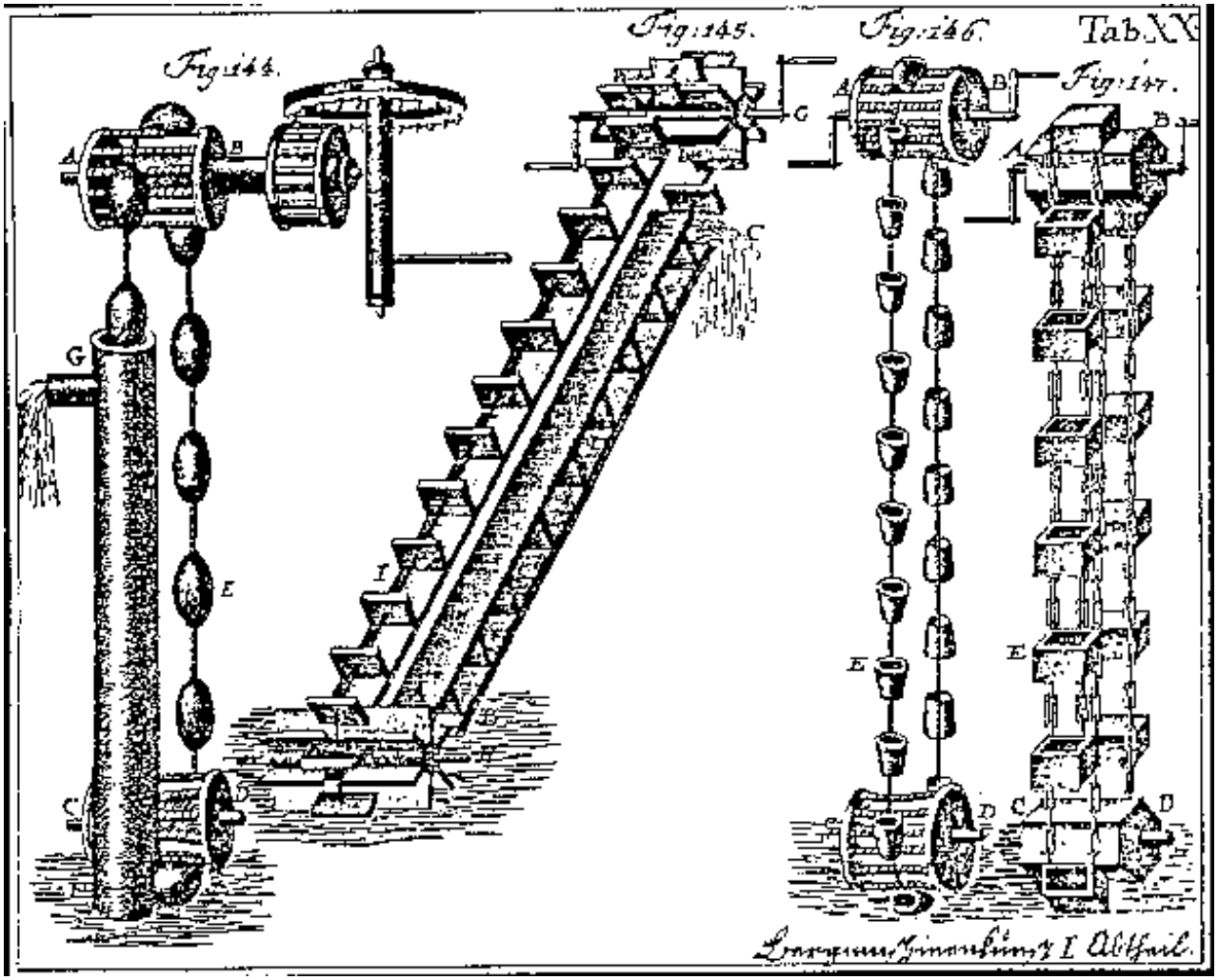
Luyken, 1694

Pumping can be done with rotational motion alone…



Dutch drainage mill using Archimedes' screw
*from **The Dutch Windmill**, Frederick Stokhuyzen*

Pumping can be done with rotational motion alone…



Bucket chain pumps are seen as early as 700 BC.

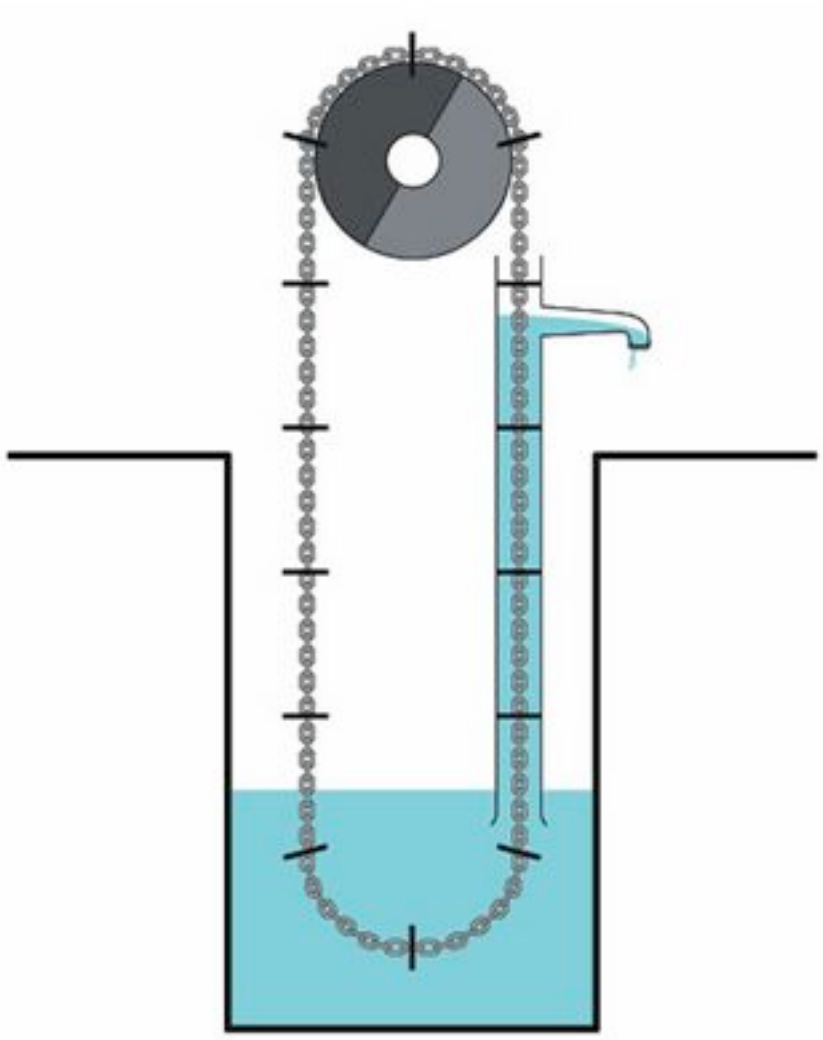
Common in ancient Egypt, Roman empire, China from 1st century AD, Medieval Muslim world, Renaissance Europe.

Chain pumps, including bucket chain pumps (R)

From Cancrinus, via Priester, Michael et al.

"Tools for Mining: Techniques and Processes for Small Scale Mining"

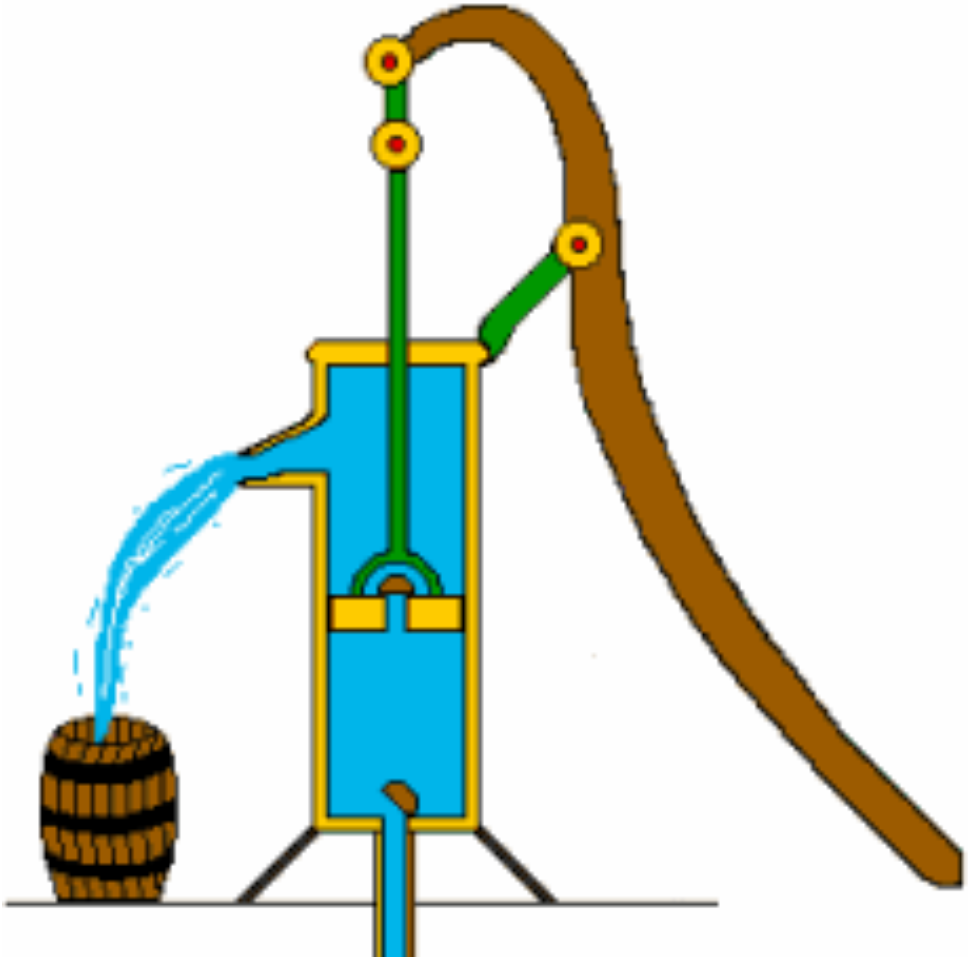
Chain pumps need not involve buckets



Chain pump cutaway

From Lehman's

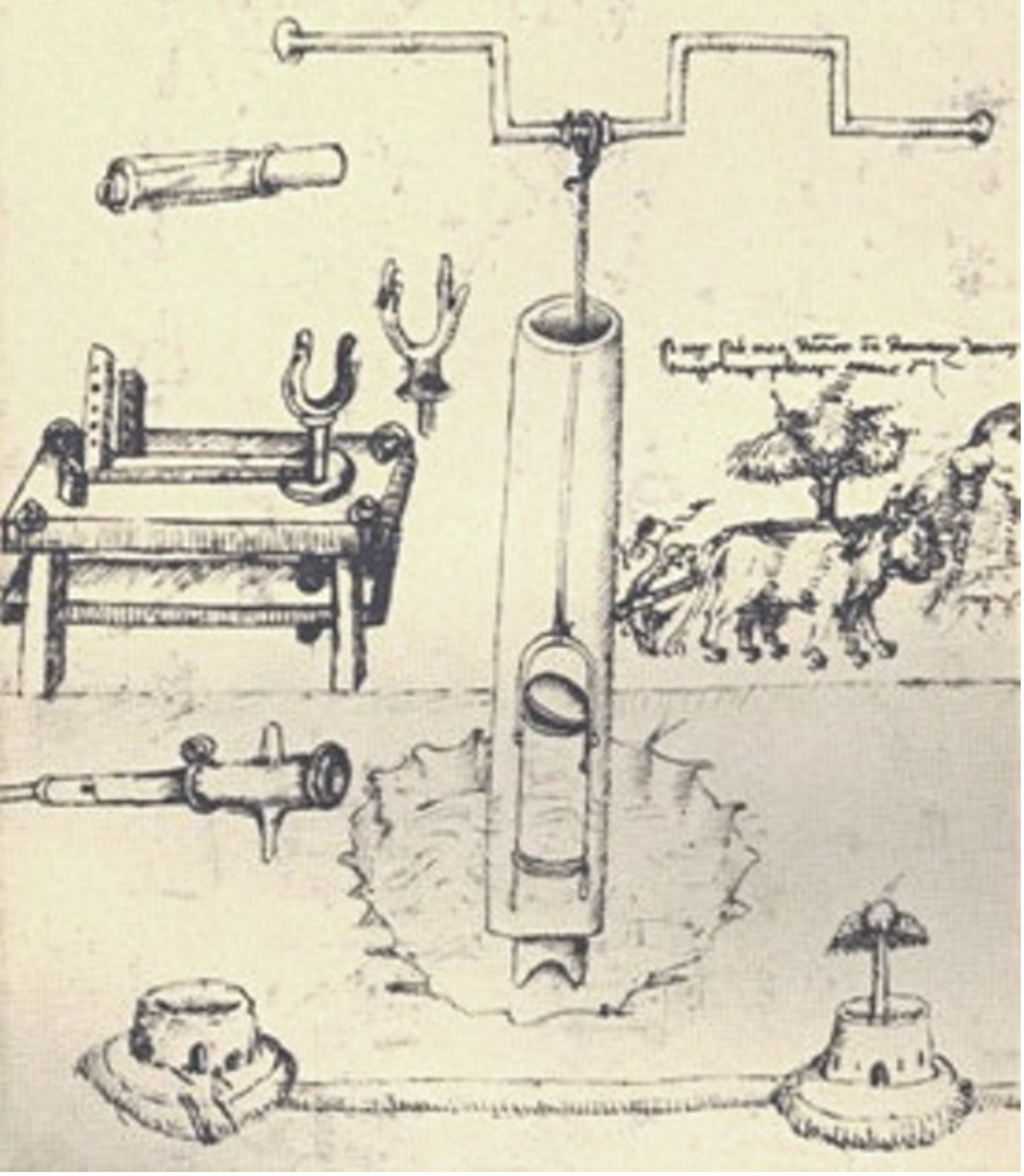
…but linear motion allows more efficient pumping



Same technology used today in oil wells

The lift pump

Animation from **Scuola Media di Calizzano**



First recorded piston pump is in Renaissance

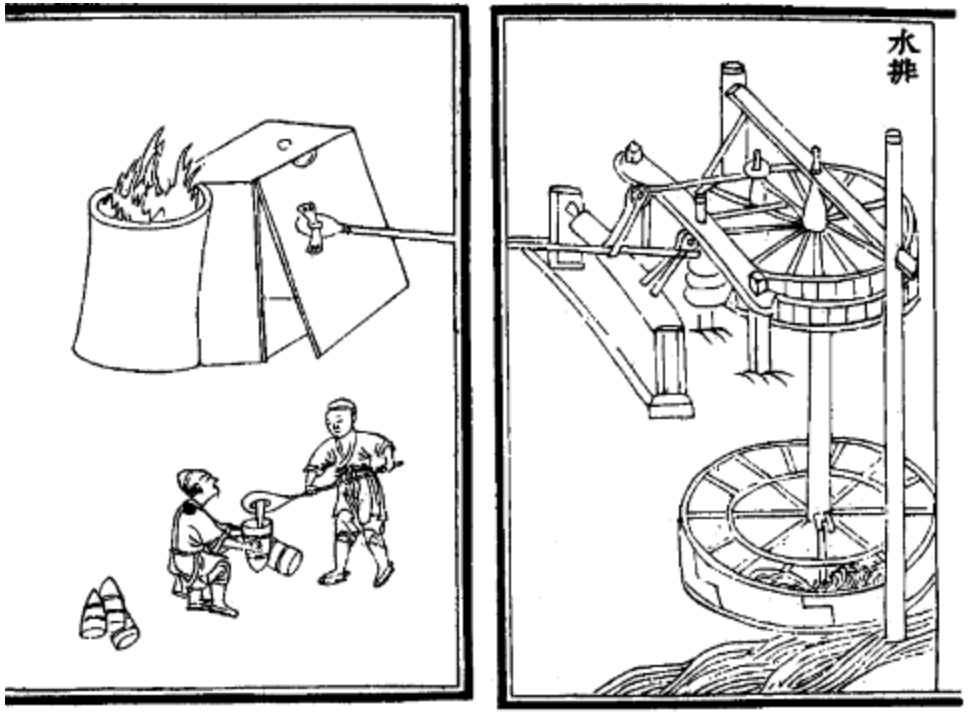
Taccola, 1450
Siena, Italy

De ingeneis 1433
(Concerning engines)
De machinis 1449
(Concerning machines)

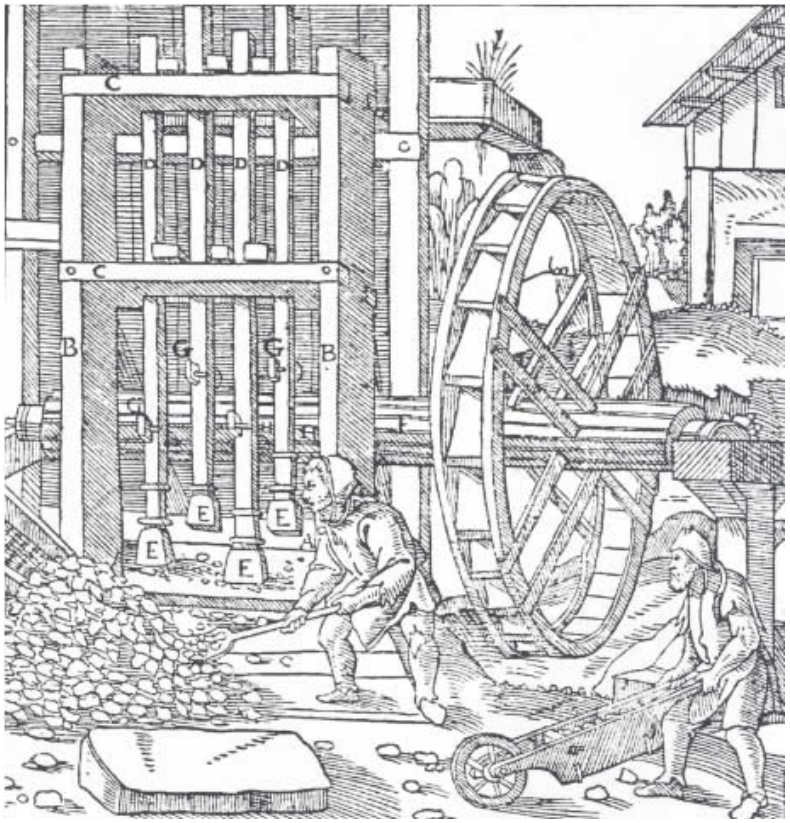
piston pumps don't replace bucket chains in England until 1700s

reproduction from: Donald Routledge Hill: *A history of engineering in classical and medieval times*

Linear motions were needed very early in industrial history

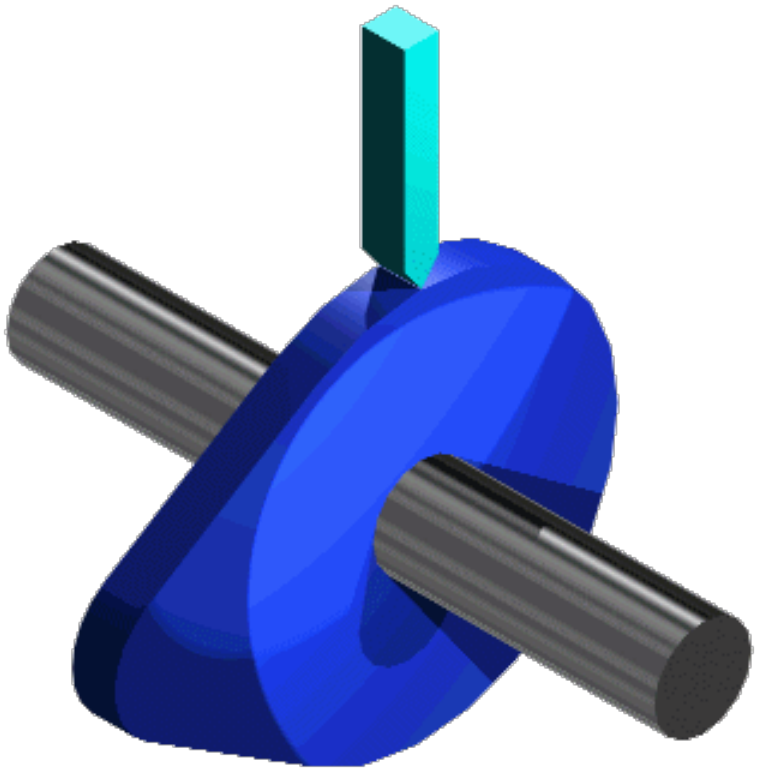


Chinese bellows, 1313 A.D.



European hammer mill w/ cam coupling, 1556 A.D.

The cam converts rotational to linear motion

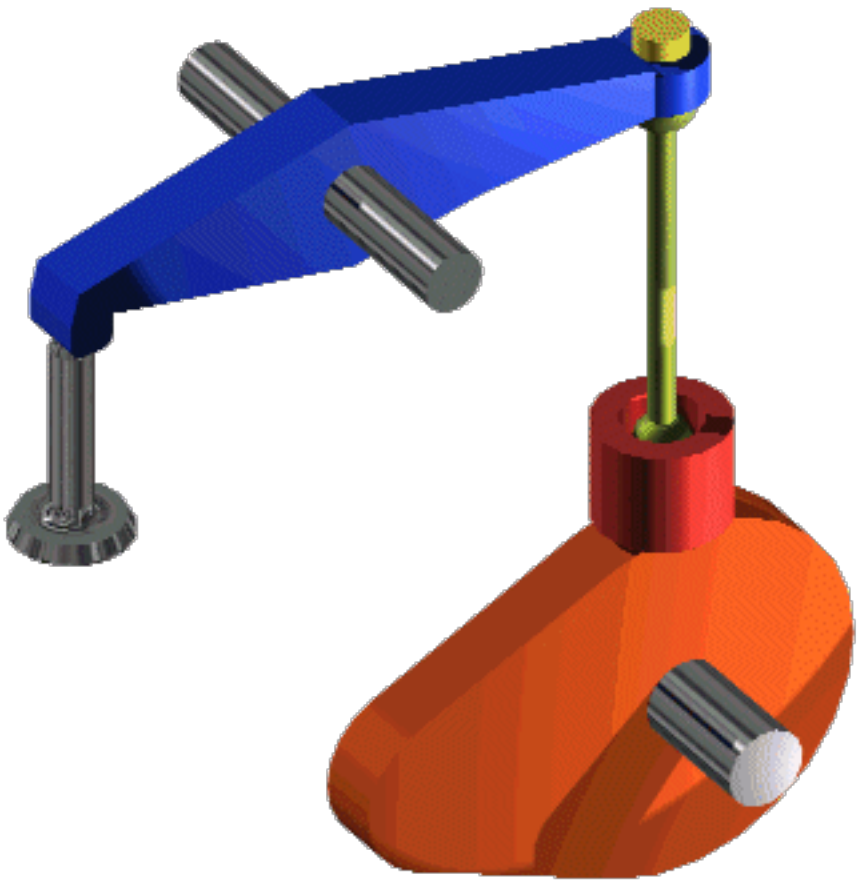


The noncircularity of the cam creates a push at only one part of the cycle

The knife-edge cam

Animation from **the University of Limerick**

The cam converts rotational to linear motion

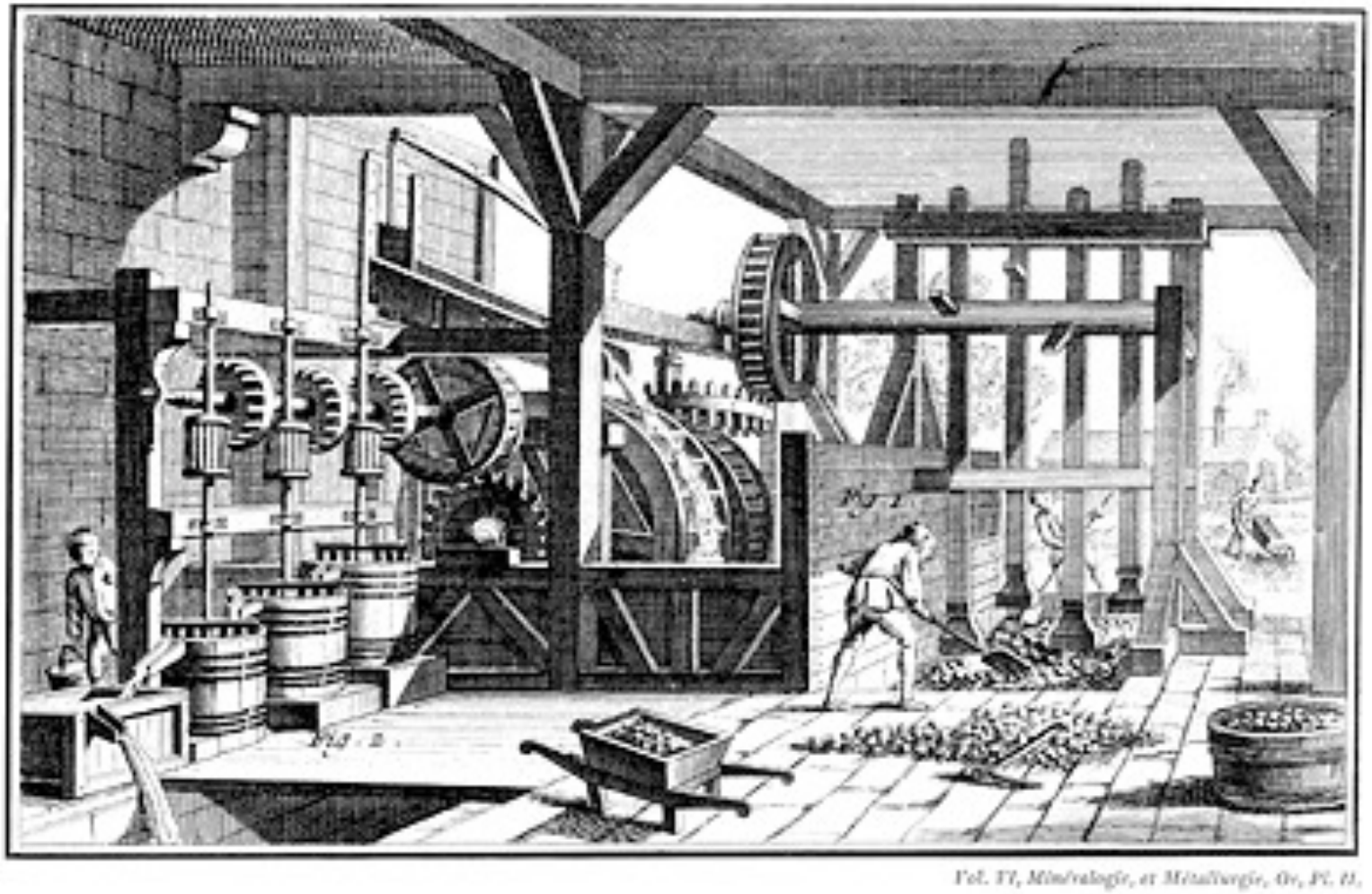


The noncircularity of the cam creates a push at only one part of the cycle

The rocker arm & camshaft

Animation from **the University of Limerick**

Gears and cams let one wheel drive multiple machines



Gold refining, France. *D. Diderot & J. Le Rond d`Alembert eds, Encyclopédie méthodique. Paris 1763-1777 & 1783-87.*

Uses powered by wind & water include:

Rotational

Linear (reciprocating)

Linear (non-reciprocating)

Uses powered by wind & water include:

Rotational

- Grindstones
- Pumps
- Winches
- Bucket lifts
- Spinning wheels
- Lathes, borers, drilling machines *(first use)*

Linear (reciprocating)

- Hammer-mills
- Beaters
- Bellows
- Saws
- Looms

Linear (non-reciprocating)

- Boats

Uses powered by wood include

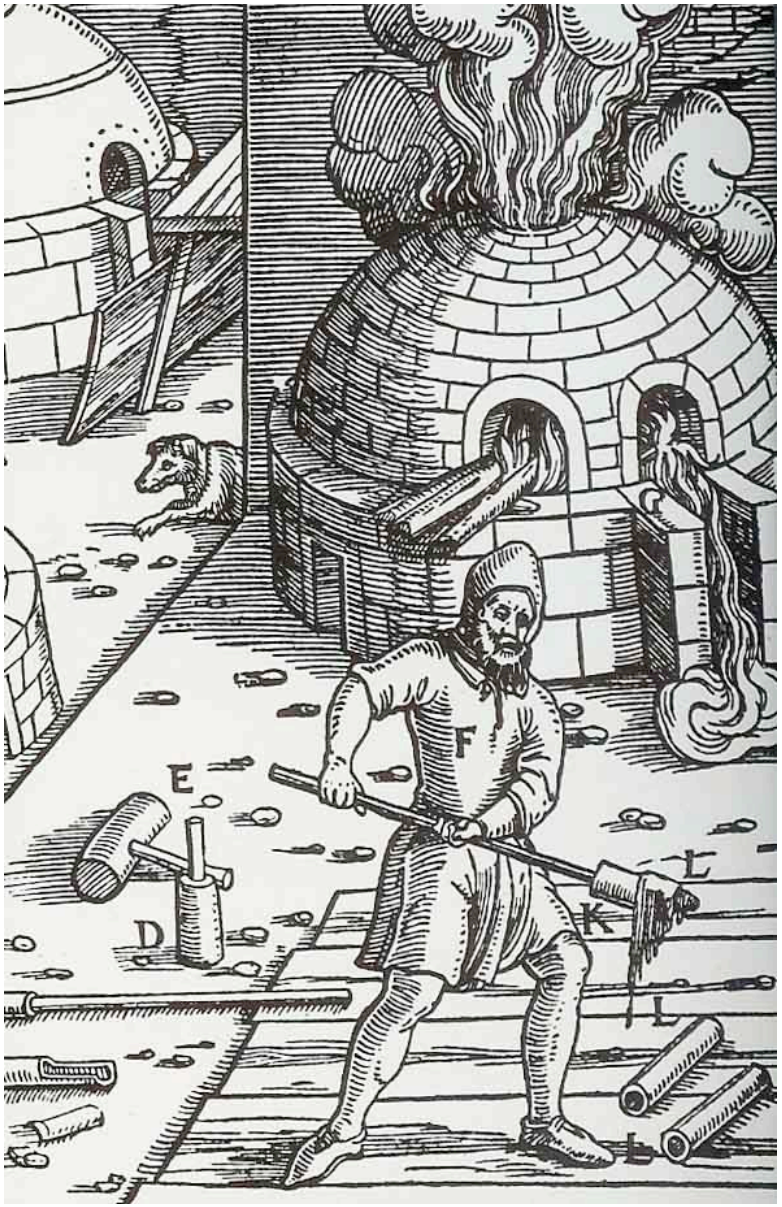
Fuel burnt for

Uses powered by wood include

Fuel burnt for

- Heating
- Metallurgy
- Glass-making
- Brewing (drying the malt)
- Baking
- Brick-making
- Salt-making
- Tiles and ceramics
- Sugar refining

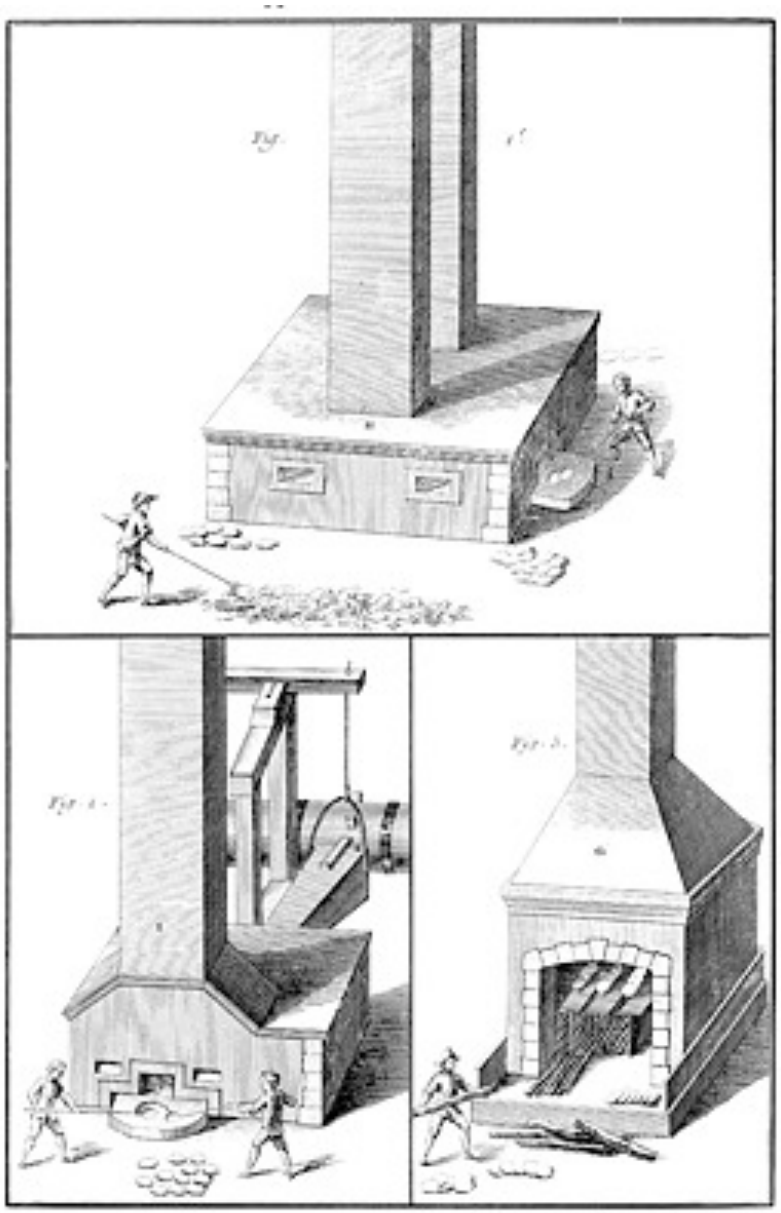
Heating: industrial furnaces grow larger and larger



1500s

Georg Acricola "De res metallica", Book XII (*"Manufacturing salt, soda, alum, vitriol, sulphur, bitumen, and glass"*), 1556.

Heating: industrial furnaces grow larger and larger



1700s

Copper foundry, France

D. Diderot & J. Le Rond d`Alembert eds, Encyclopédie méthodique. Paris 1763-1777 & 1783-87.

The heat-to-work barrier

the 18th century technological impasse

All technology involved only two energy conversions

- Mechanical motion → mechanical motion
- Chemical energy → heat

There was no way to convert chemical energy to motion other than muscles (human or animal)

– *no engine other than flesh*

The end of wood

the 18th century resource crisis

The energy crisis in 1700s Europe

1700s

"When the fuel situation became difficult in France in the eighteenth century, it was said that a single forge used as much wood as a town the size of Chalon-sur-Marne. Enraged villagers complained of the forges and foundries which devoured the trees of the forests, not even leaving enough for the bakers' ovens."

--- F. Braudel, *The Structures of Everyday Life, 1979.*

The energy crisis hit Britain first

1400s "Aeneas Sylvius (afterwards Pope Pius II), who visited Scotland… in the middle of the fifteenth century, mentions …that he saw the poor people who begged at churches going away quite pleased with stones given them for alms. 'This kind of stone … is burnt instead of wood, of which the country is destitute."

1600 "Within a few years after the commencement of the seventeenth century the change from wood fuel to coal, for domestic purposes, was general and complete."

--- R. Galloway, *A History of Coal Mining in Great Britain, 1882.*

Coal-use in Britain is early

1600

FALSTAFF
What is the gross sum that I owe thee?

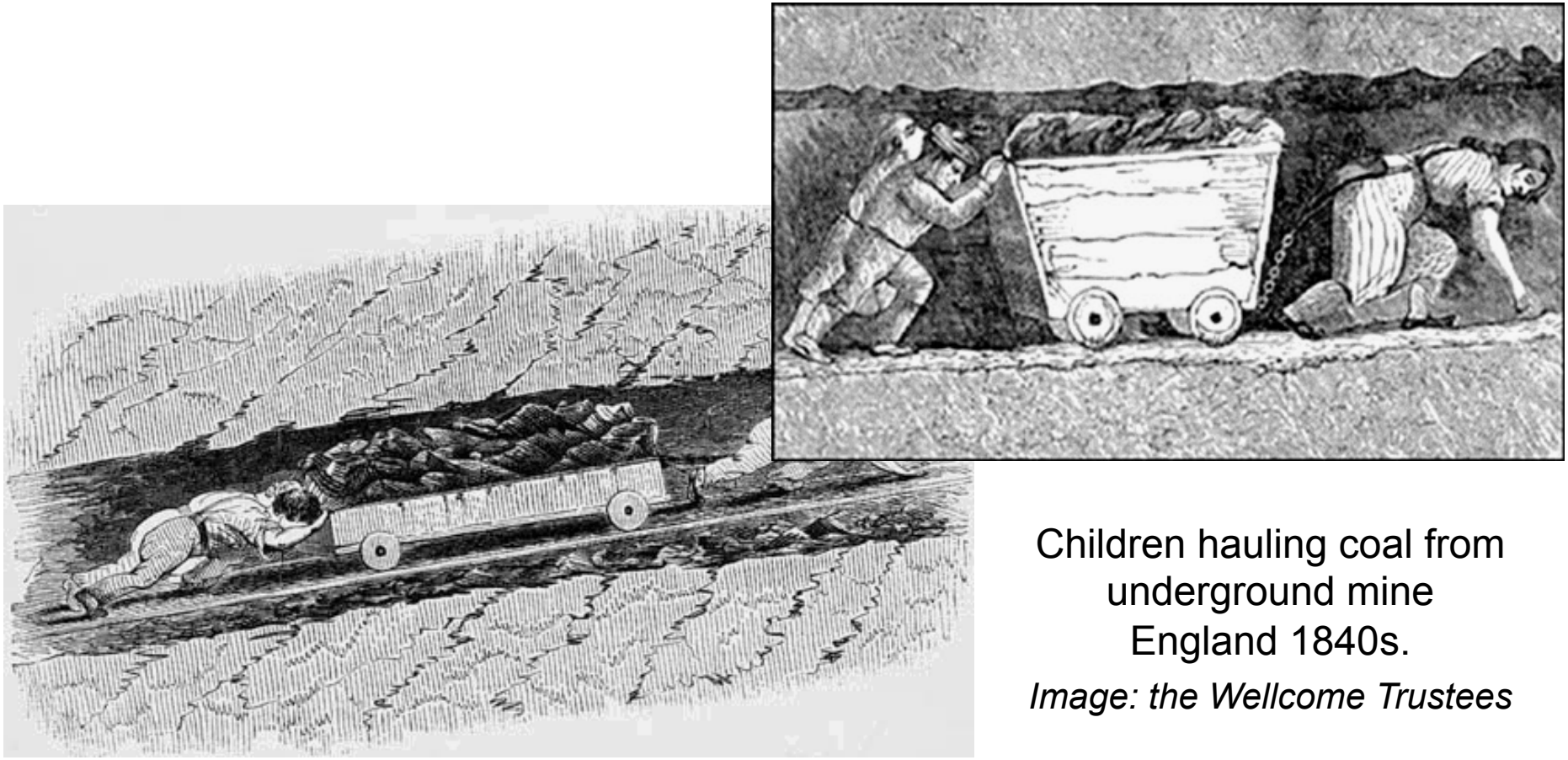
MISTRESS QUICKLY
Marry, if thou wert an honest man, thyself and the money too. Thou didst swear to me upon a parcel-gilt goblet, sitting in my Dolphin-chamber, at the round table, by a **sea-coal** fire, upon Wednesday in Wheeson week, when the prince broke thy head for liking his father to a singing-man of Windsor, thou didst swear to me then, as I was washing thy wound, to marry me and make me my lady thy wife. Canst thou deny it? ...

--- W. Shakespeare, *Henry IV Part II*

Sea-coal: washes up on beach from exposed seams

2013, London *Daily Mail*: “sea-coalers” lose access to beach they have used for centuries

Switch to underground mining as surface exposures are exhausted

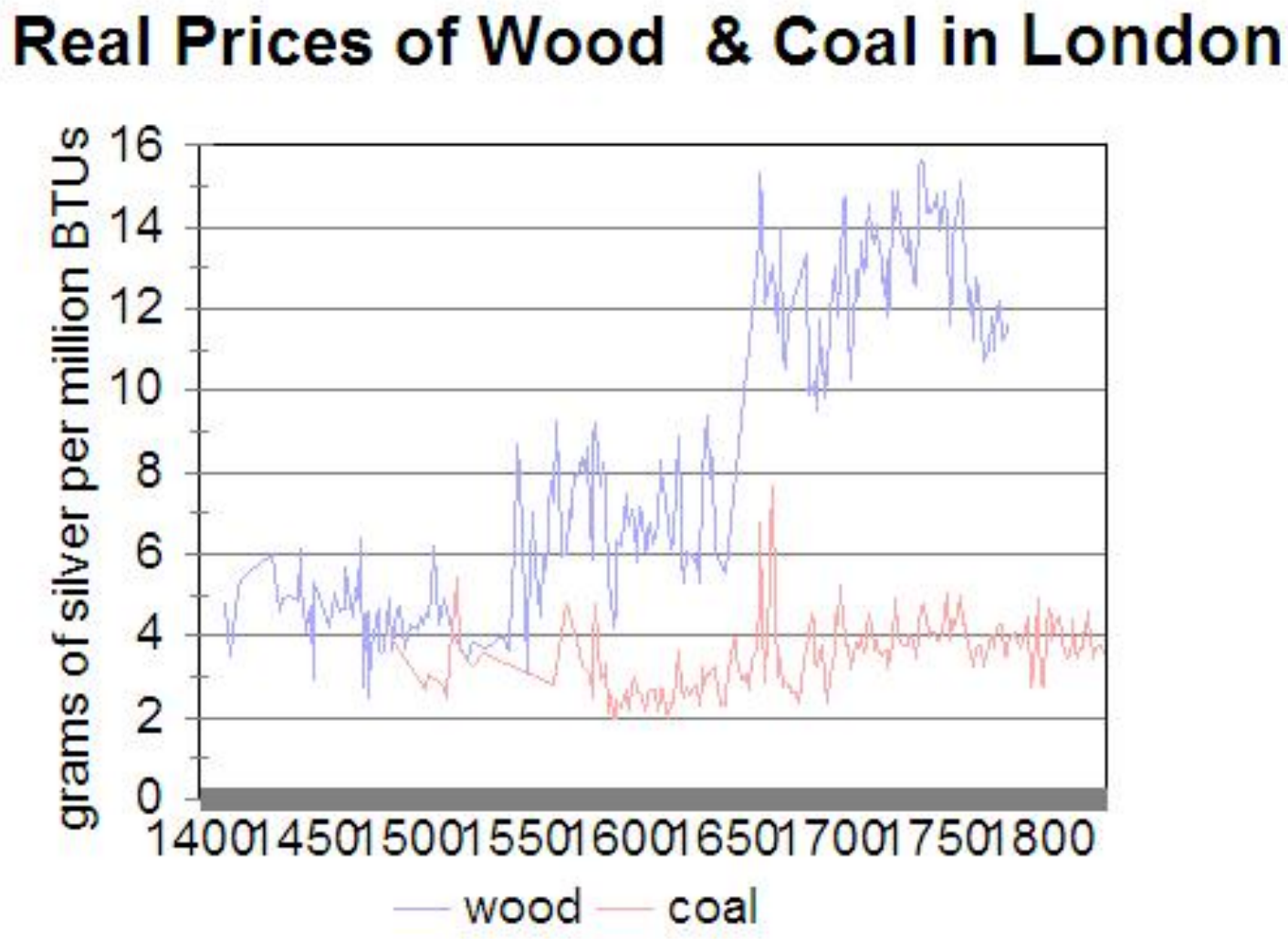


Children hauling coal from underground mine England 1840s.

Image: the Wellcome Trustees

First shaft coal mines in England early 1600s, common by 1750

Wood → coal: changing an energy system



Robert Allen, *The British Industrial Revolution in Global Perspective*

The 2nd British energy crisis: flooding of the mines

1600s

"The miners, no less than the smelters, had their difficulties during the seventeenth century, but of a totally different kind; for while the latter were suffering from too little fire, the former were embarrassed by too much water… the exhaustion of the coal supply was considered to be already within sight. In 1610, Sir George Selby informed Parliament that the coal mines at Newcastle would not last for the term of their leases of twenty-one years."

--- R. Galloway, *A History of Coal Mining in Great Britain, 1882.*

Early complaints about renewables

"In the year 1708 a plan was projected in Scotland for draining collieries by means of windmills and pumps... one John Young, a millwright of Montrose... had been sent to Holland at the expense of the town to inspect the machinery there... Wind mills were erected at several collieries, but though they were powerful their action was found to be too intermittent; the mines being drowned and all the workmen thrown idle during long periods of calm weather. "

--- R. Galloway, *A History of Coal Mining in Great Britain, 1882.*

The 18th century European energy crisis has 3 parts

1. **Fuel became scarce even when only used for heat**

   Wood was insufficient, & coal was getting hard to extract

   Surface "sea coal" → deep-shaft mining below the water table

2. **There were limited ways to make motion**

   No way to make motion other than through capturing existing motion or through muscle-power.

3. **There was no good way to transport motion**

   Water and wind weren't necessarily near demand

The only means out of the energy crisis was coal

– *but to mine the coal required motion for pumps.*

The revolutionary solution = break the heat → work barrier