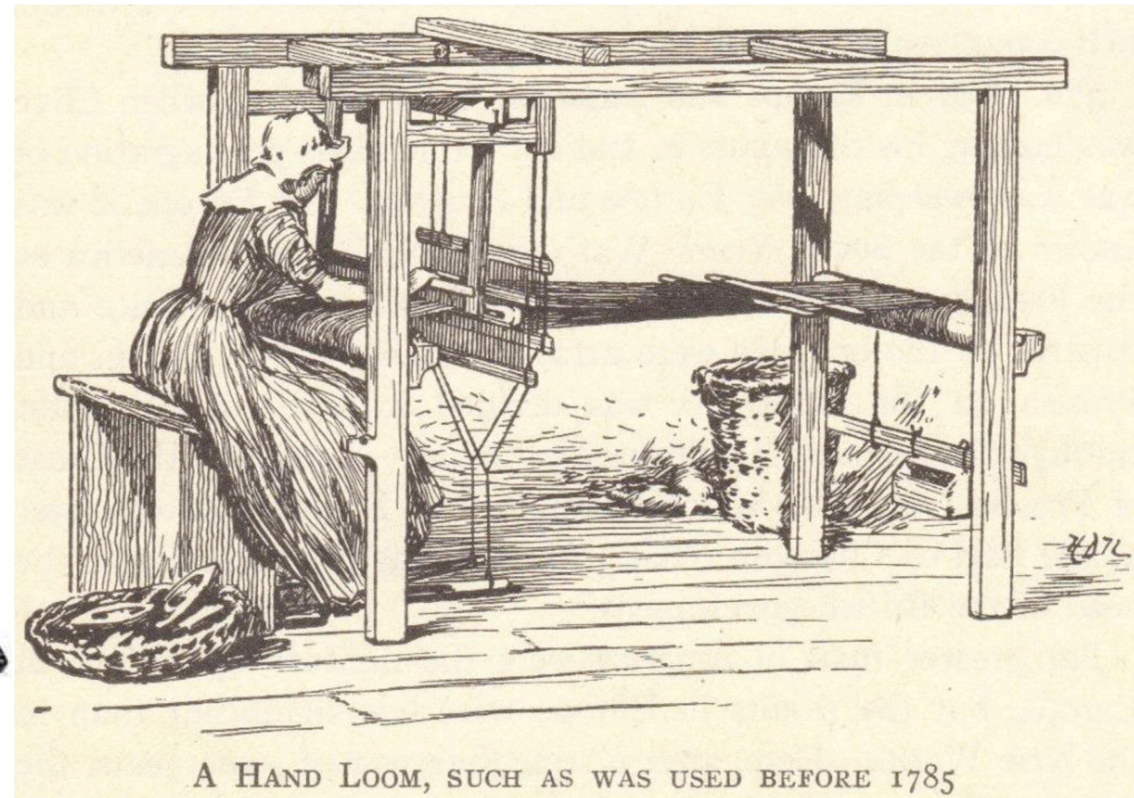
Lecture 8
GEOS24705

Industrial Revolution and transformation to the modern energy system

Textiles were a home industry in the mid-1770s
(only milling had been mechanized)

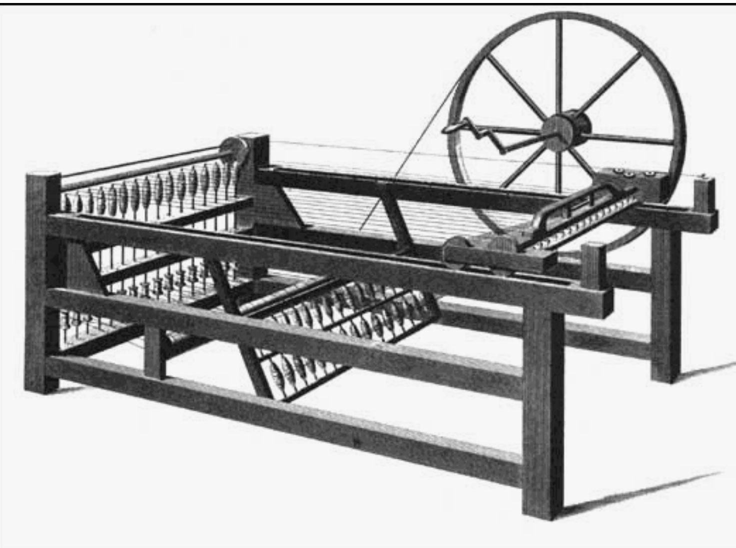
but extremely repetitive motions are well suited to mechanization

Jersey Spinning Wheel. *From: The Story of the Cotton Plant, Frederick Wilkinson, 1912, via Gutenberg.org*



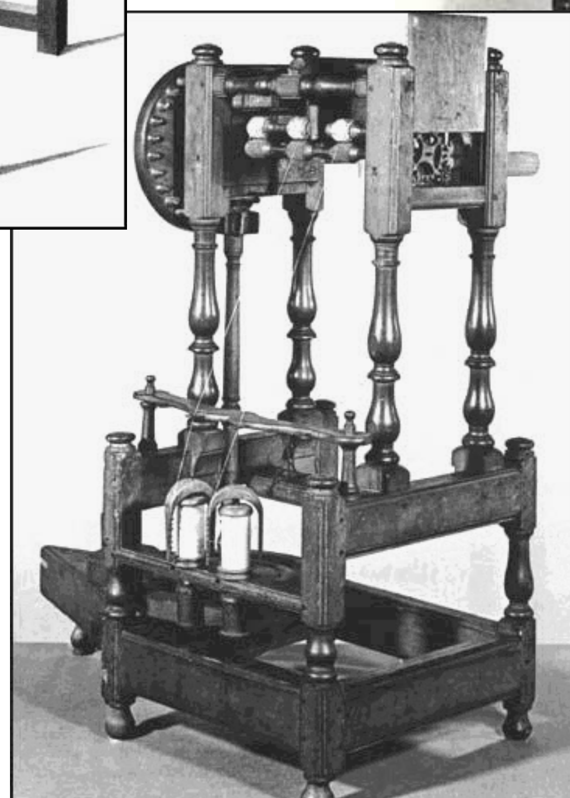
Source: unknown

Spinning was mechanized first, happened quickly



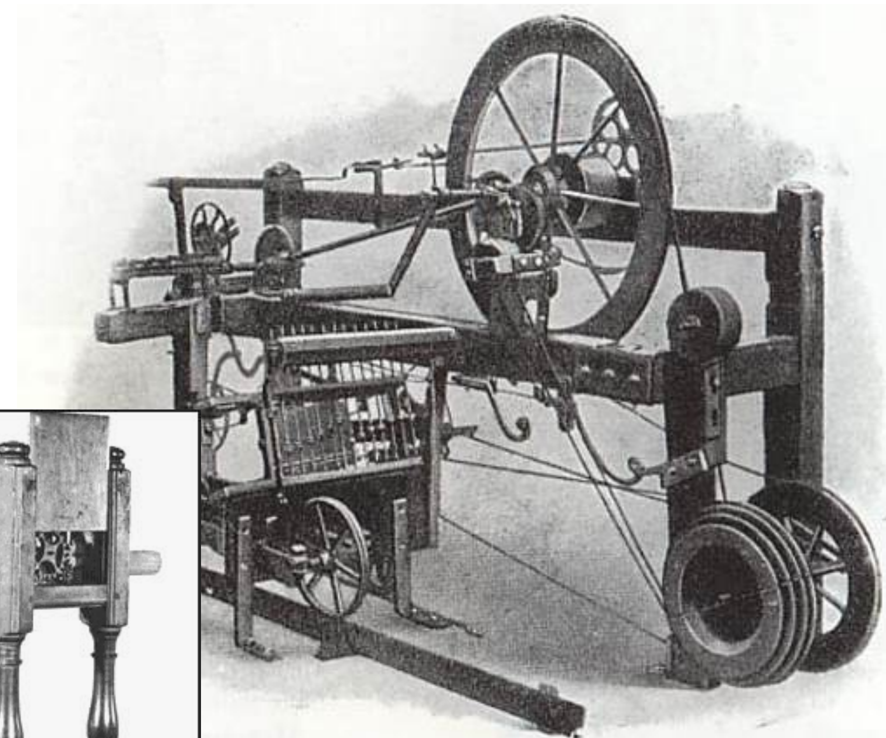
Spinning jenny, 1764
James Hargreaves

power: human



“Water frame” 1769
John Kay, Richard Arkwright

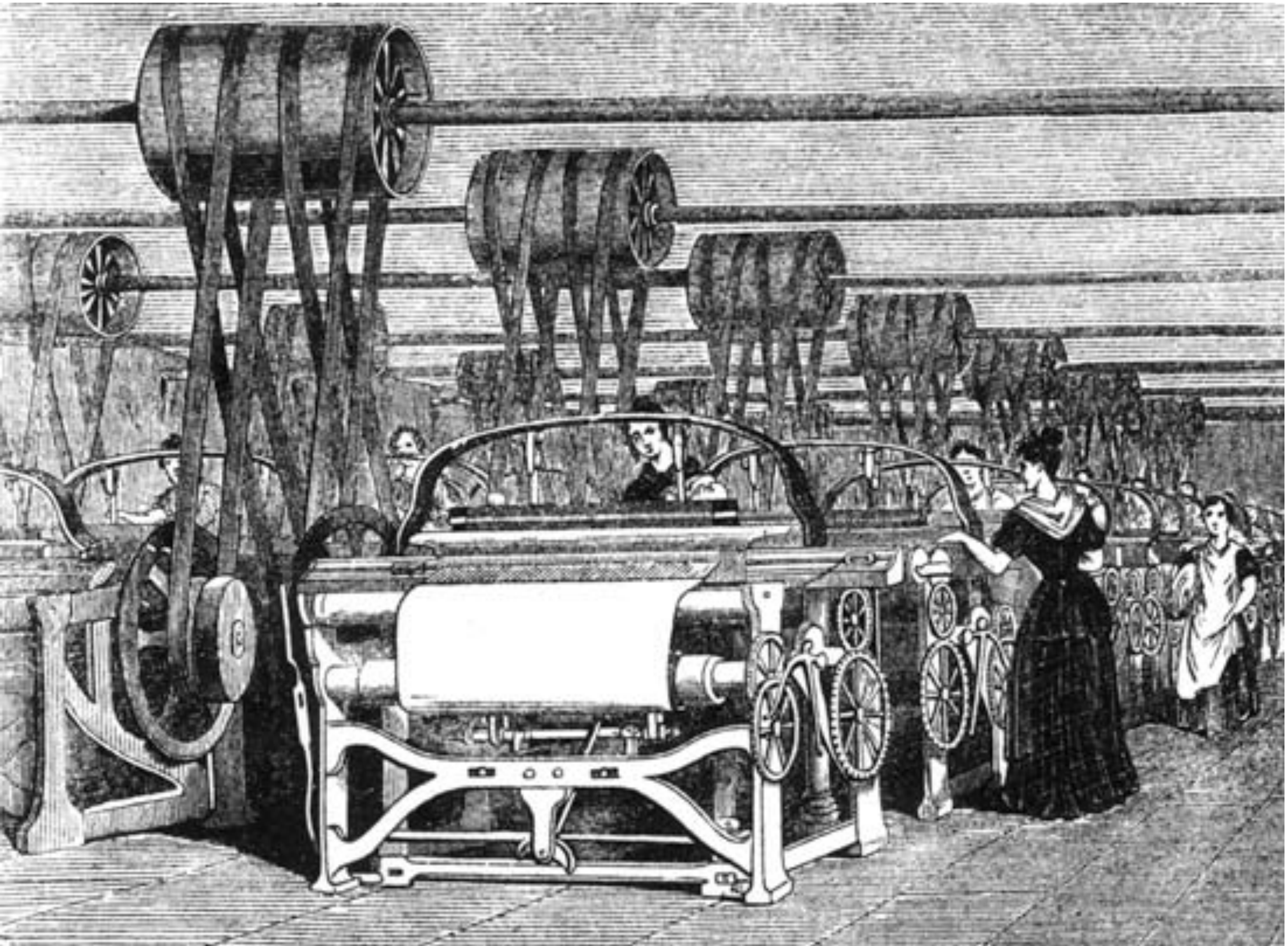
power: horses, then water



Spinning mule, 1779
Samuel Crompton

Power: water
fully automated by 1830

Weaving mechanization came next



Power loom, 1787
Edmund Cartwright

Power: water

Steam engines used used in mines and ironworks at this time

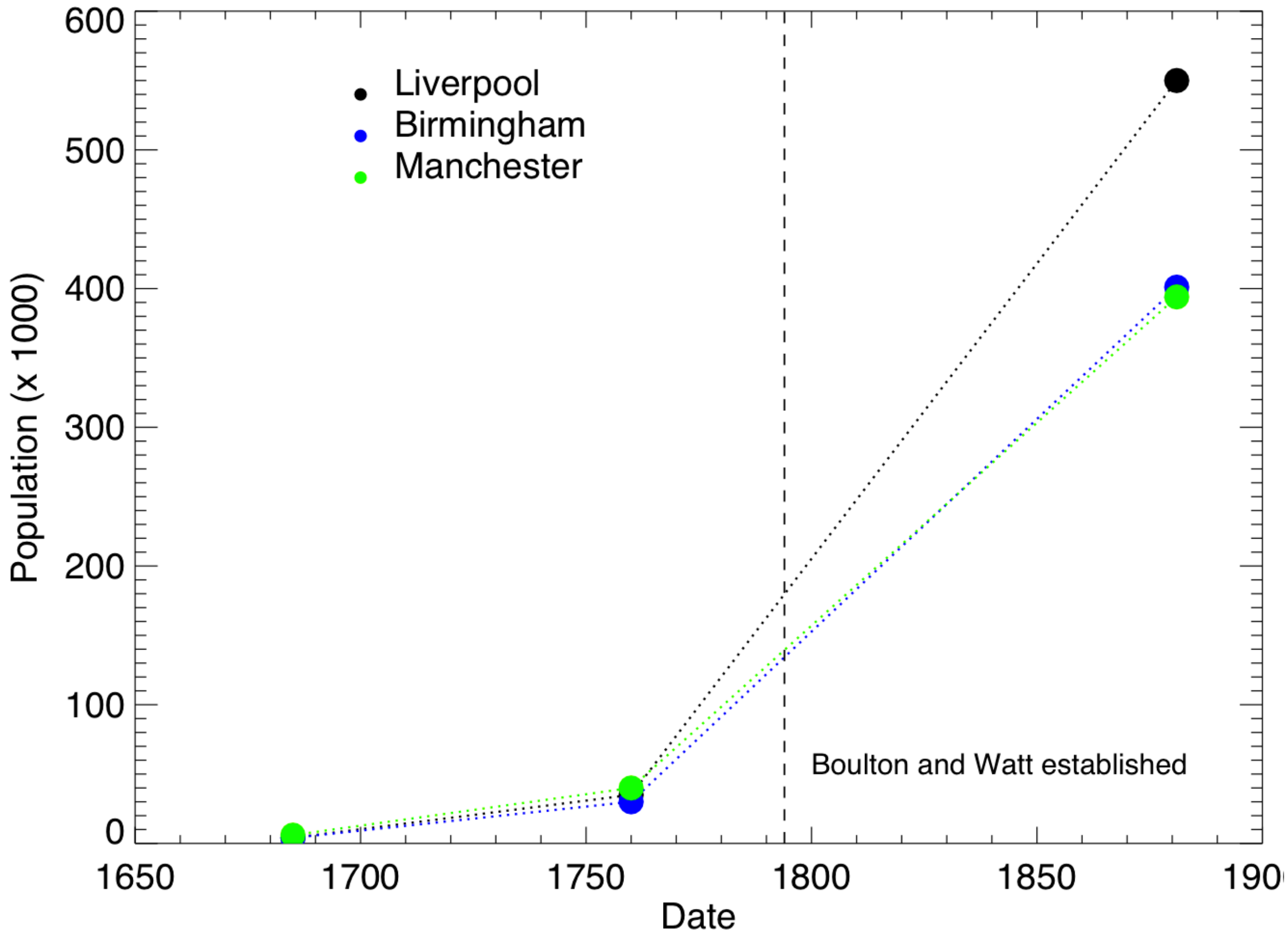
by 1829 there are nearly 50,000 power looms in England

Led to major social disruption…home weaving could no longer compete. Rural livelihoods were cut off, forcing migration

Power looms, 1844
Source: Getty Images

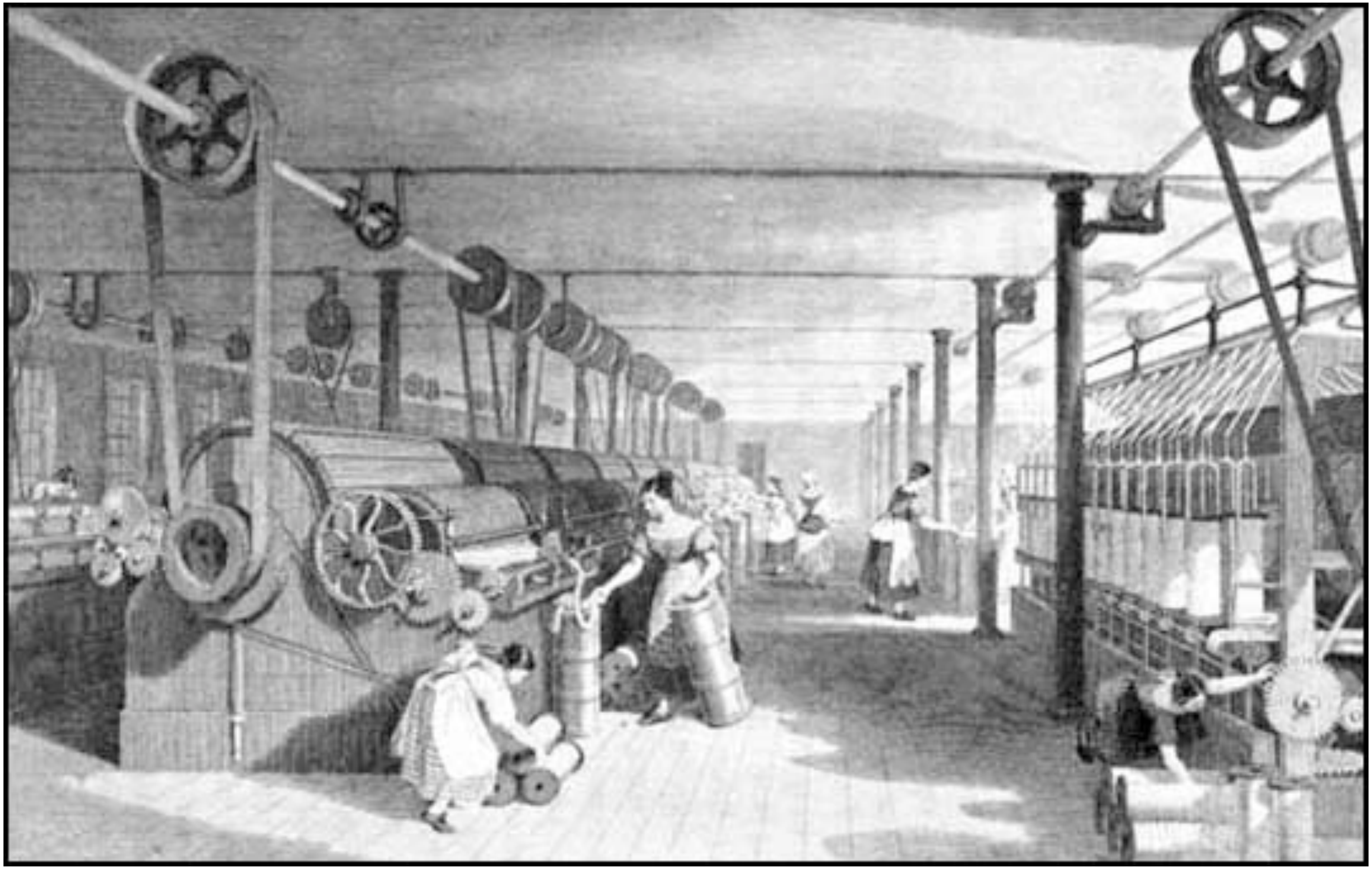
Rapid depopulation of countryside, move to cities

1696: 10% population urban / 1881: 70% urban



Source: *Data from Toynbee, "Lectures on the Industrial Revolution in England, 1884,*
in turn drawn from a. Macaulay's History of England c. 3. b. Defoe's Tour (1725) c. Arthur Young (1769) d. Macpherson's Annals of Commerce (1769) e. Levi's History of British Commerce

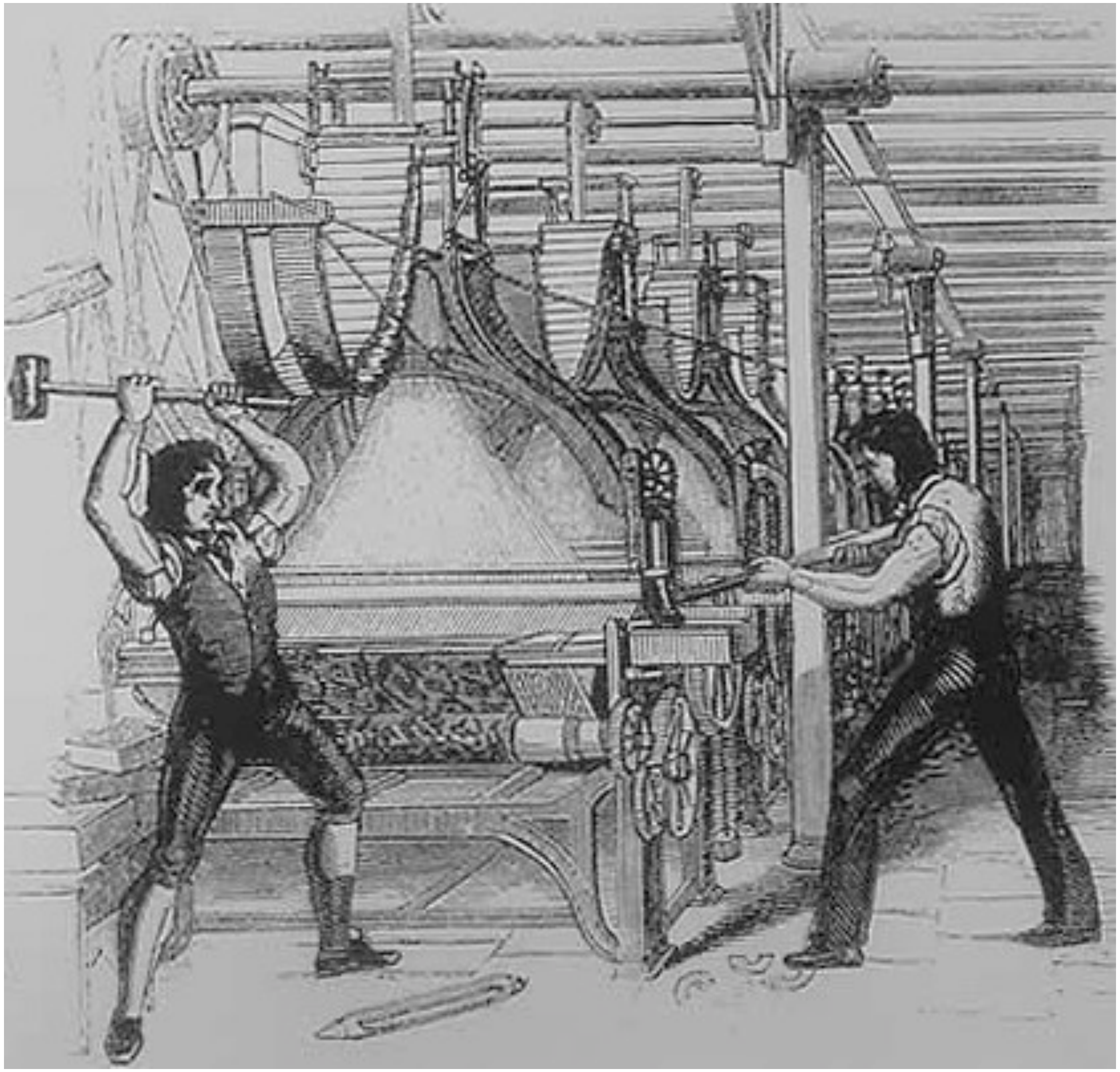
Textile production in England changed social structure of labor



Women and children left the home to work: women were cheap labor, small hands were valuable in operating machinery, and strength not required.

Looms, England, early 1800s, source unknown

The backlash against industrialization was strong



"Luddites" smashing a loom ("frame-breaking"), ca. 1812, *source unknown*

Ned Ludd breaks two knitting frames in 1779, becoming a folk hero

"Protection of Stocking Frames, etc. Act", 1788
penalty: 7-14 years transportation to colonies

"Luddites" began organized acts of sabotage of industrial system, 1811-1812

"Frame-Breaking Act", 1812
penalty: death

Much of mill labor was performed by children

Lewis Hine, children working in a textile factory in Cherryville, N.C.

Children were sent to the mills by their parents, because of: lack of money, lack of child care, or (speculation): new urban life produced new costs and desires

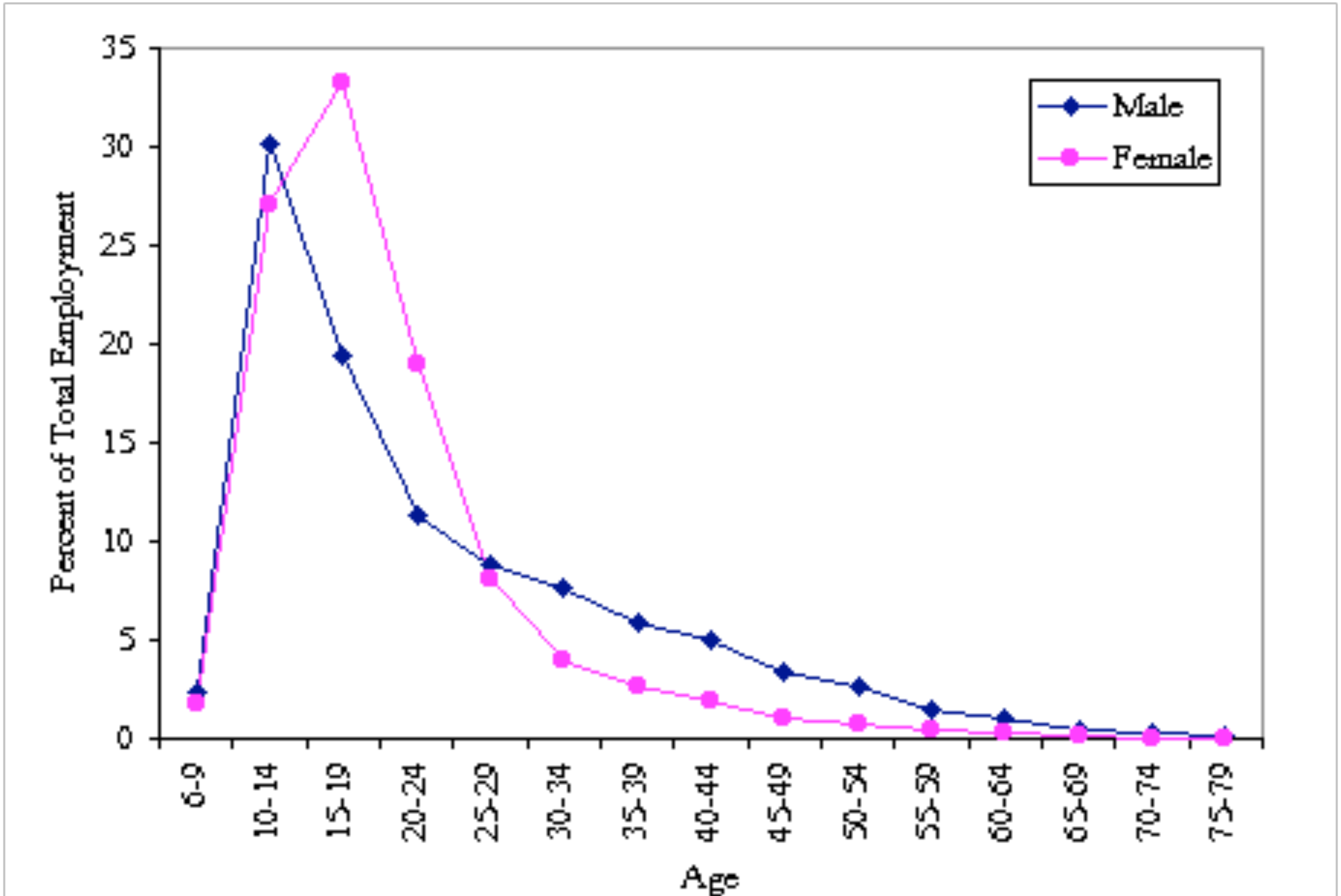
In U.S., too, much of mill labor was performed by children

Lewis Hine, 1912, *Addie Card, 12 years, Spinner in N. Pownal Spinning Mill*

Lewis Hine, 1911, *Breaker boys working in Ewen Breaker of Pennsylvania Coal Co.*

Even after first child labor laws, ***most*** factory workers are children

(First law: Labor in Cotton Mills Act, 1811, Britain, limits to 12 hours /day)



Source: "Report from Dr. James Mitchell to the Central Board of Commissioners, respecting the Returns made from the Factories, and the Results obtained from them." *British Parliamentary Papers*, 1834 (167) XIX. *(from Burnette, Joyce, EH.net)*

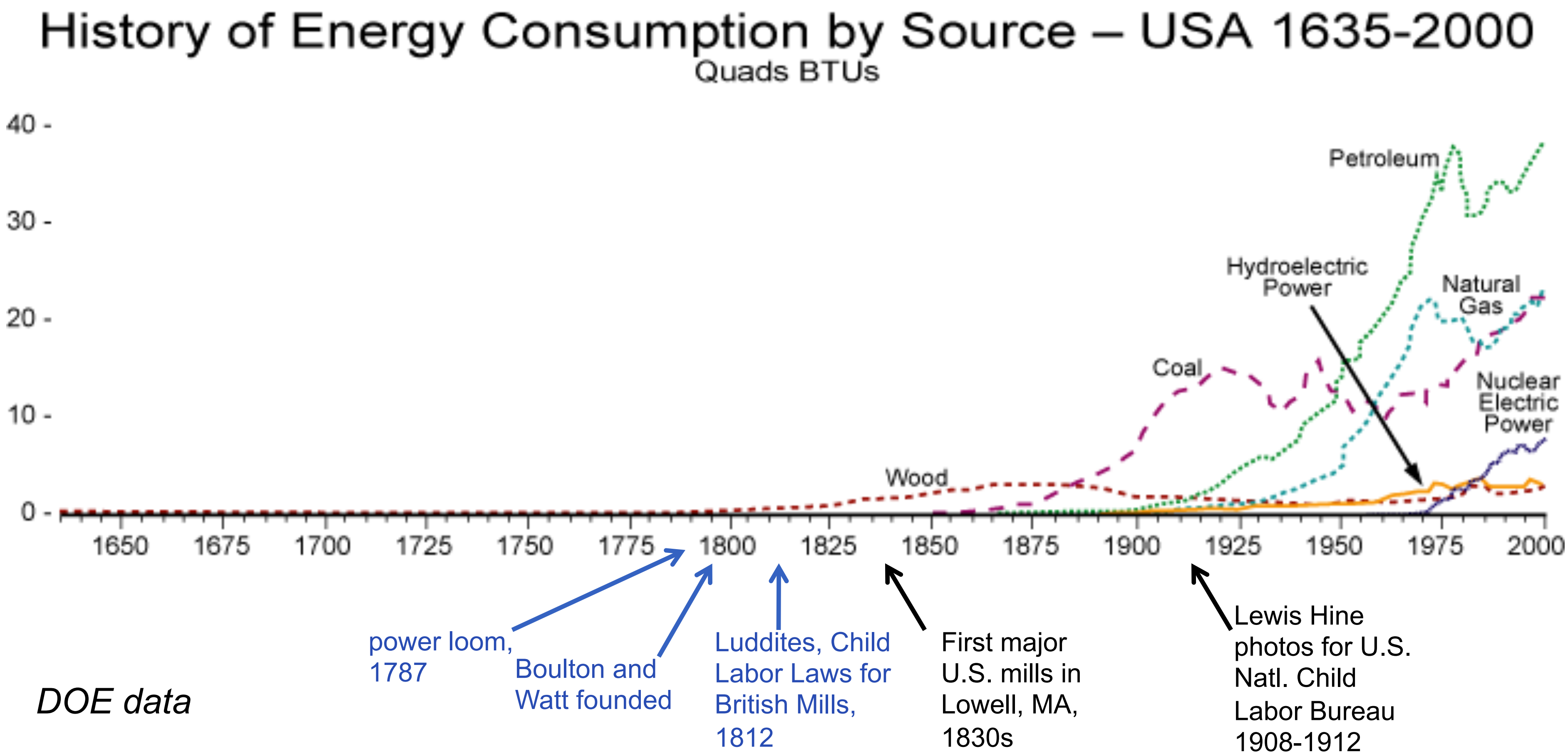
Water power soon superseded by coal and steam engines

Manchester from Kerstal Moor, 1840. *William Wylde. Painting of Manchester, England.*

U.S. industrialization came later than for Britain

U.S. was first colony of Britain, then independent but had little internal capital, no readily available coal, technology IP owned by Britain

Route to industrialization = industrial espionage: Francis Cabot Lowell, 1812



DOE data

Several things to consider

1) What does mill layout tell you about the economics of industrial production?

2) What trends in political and economic thought conditions occurred in mid-1800s Britain?

3) Why are these two things related?

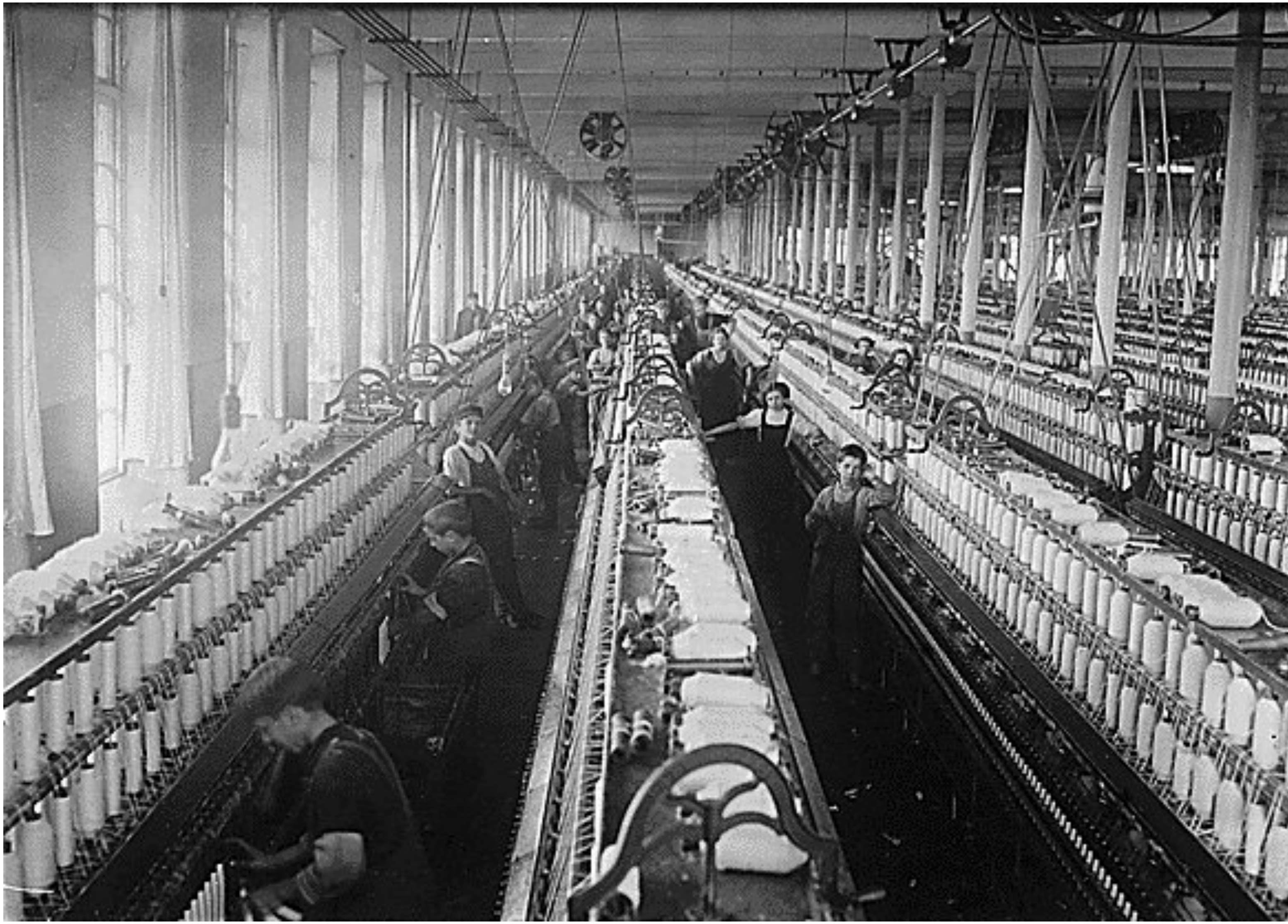
Several things to consider

1) What does mill layout tell you about the economics of industrial production?

2) What trends in political and economic thought conditions occurred in mid-1800s Britain?

3) Why are these two things related?

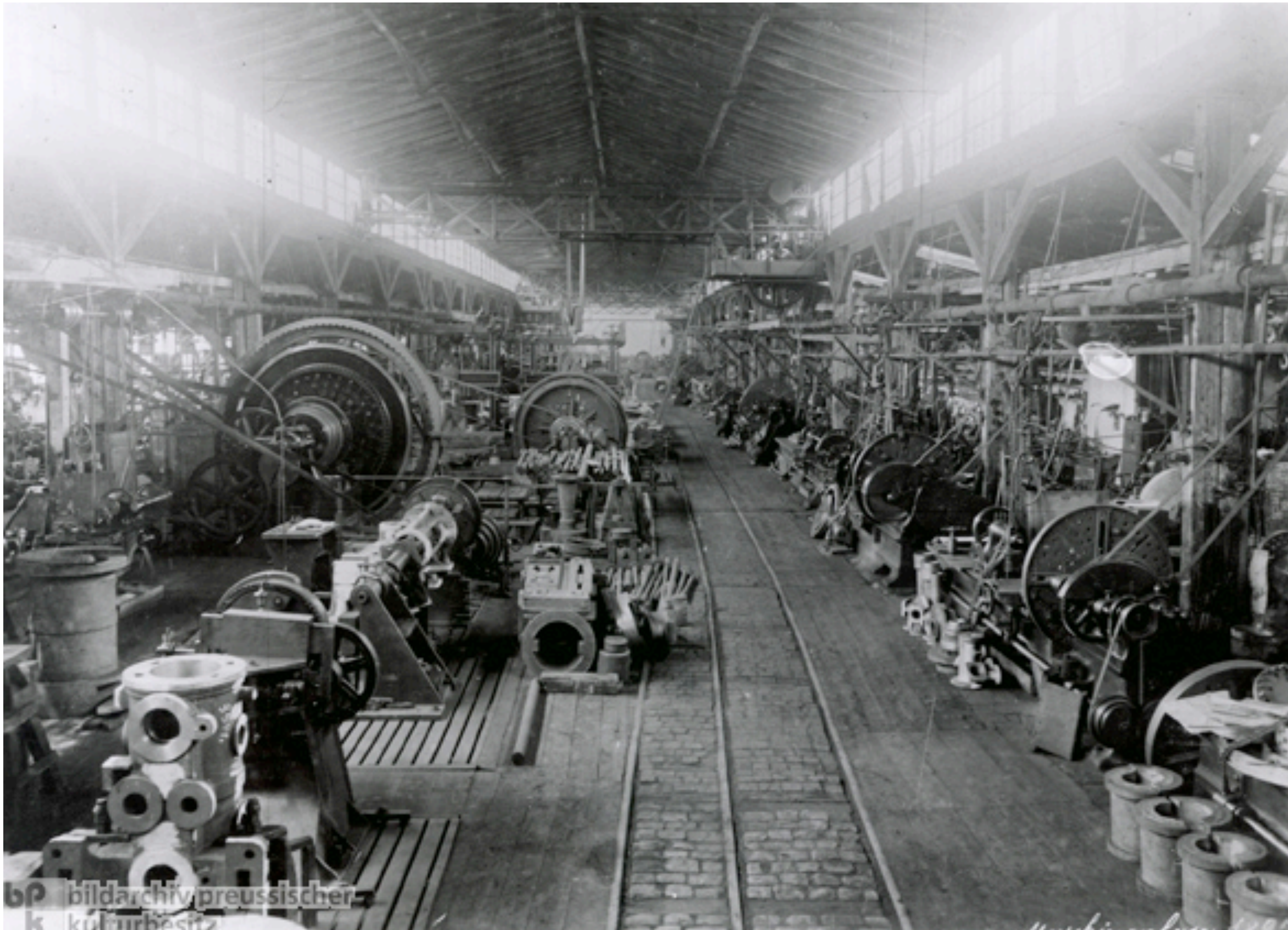
1800s: Mills get larger



Spinning mill, likely mid-late 1800s

(source unknown)

1800s: Mechanization comes to other industries



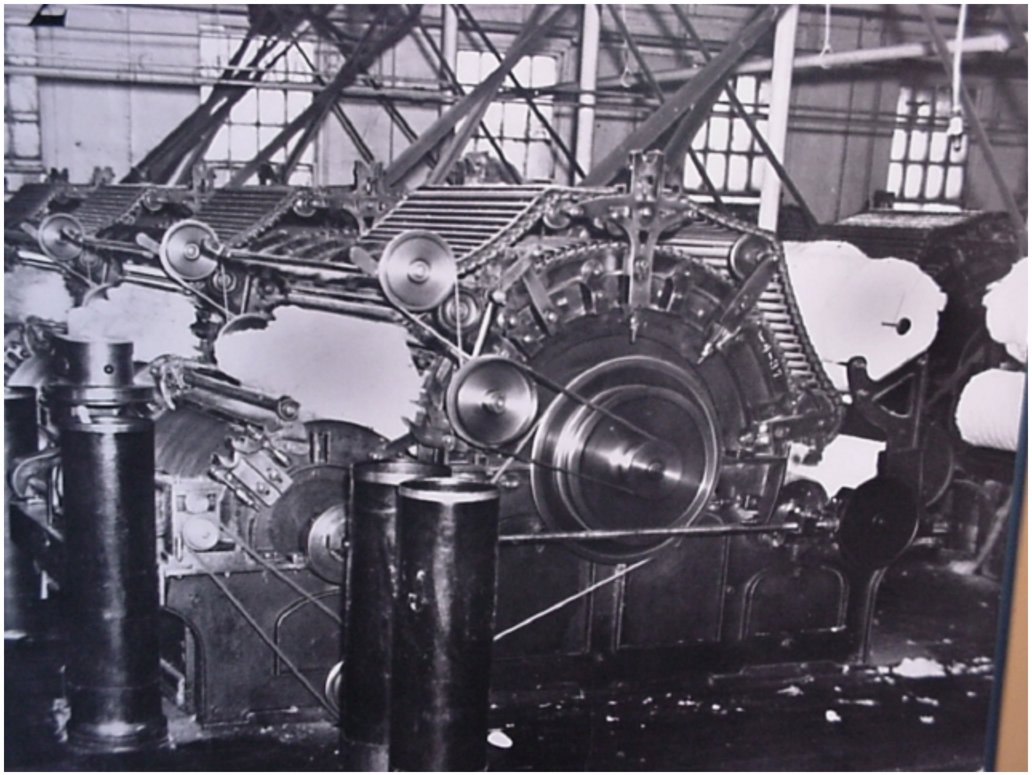
German machine shop driven by single steam engine

1800s: Mechanization comes to other industries

Machine shop, likely late 1800s

(source unknown)

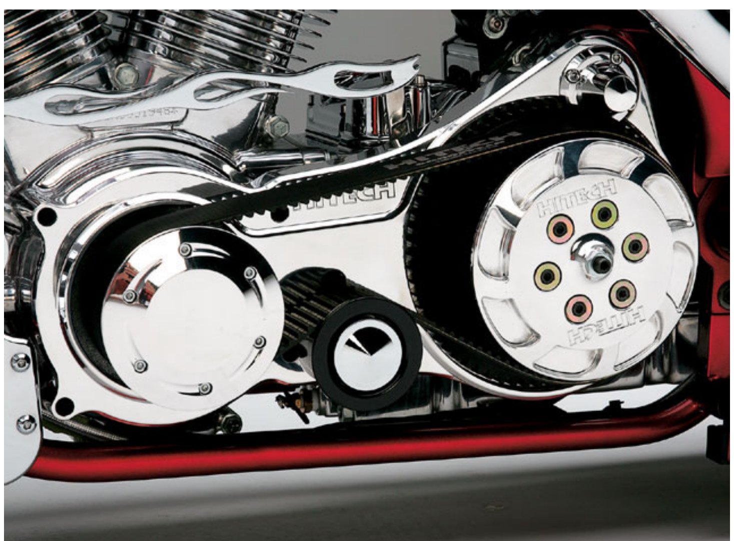
Belts transport rotational motion over long distances



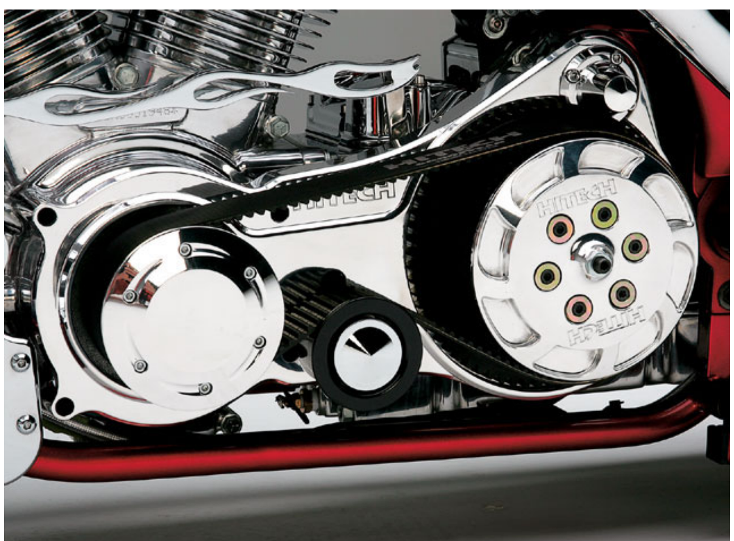
Mills at Lowell, MA, 1850s

Belt and chain drives in modern life

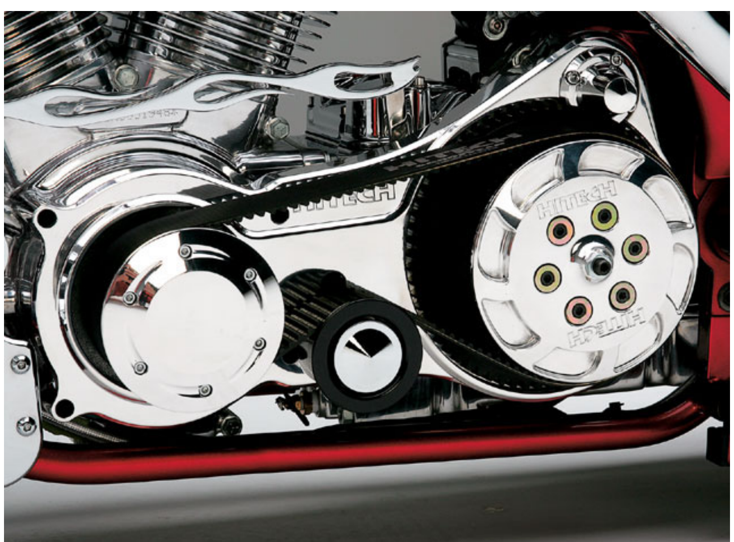
Belt and chain drives in modern life



Belt and chain drives in modern life



Belt and chain drives in modern life



Why do we use fewer belt drives now?

Because we don't carry kinetic energy directly anymore - we turn kinetic energy into electrical energy and transport that instead.

Several things to consider

1) What does mill layout tell you about the economics of industrial production?

2) What trends in political and economic thought conditions occurred in mid-1800s Britain?

3) Why are these two things related?

What did the absence of electricity mean for economic organization in the 1800s?

- No hand-worker could compete with mechanization and use of industrial power. All production in factories.
- Because kinetic energy can't be carried over long distances, every factory had to have its own power source
- *Therefore:* to be a producer you had to own your own power plant
- *Therefore:* capital required to start a business was extremely high. High labor productivity only possible with big capital investment.

Remember numbers from PS: £2000 for Watt engine, 2p/hour labor

The two technological leaps of the Industrial Revolution that bring in the modern energy era

1. *"Heat to Work"*

   Chemical energy → mechanical work via mechanical device

   Use a temperature gradient to drive motion

   Allows use of stored energy in fossil fuels

   Late 1700's: commercial adoption of steam engine

2. *Efficient transport of energy: electrification*

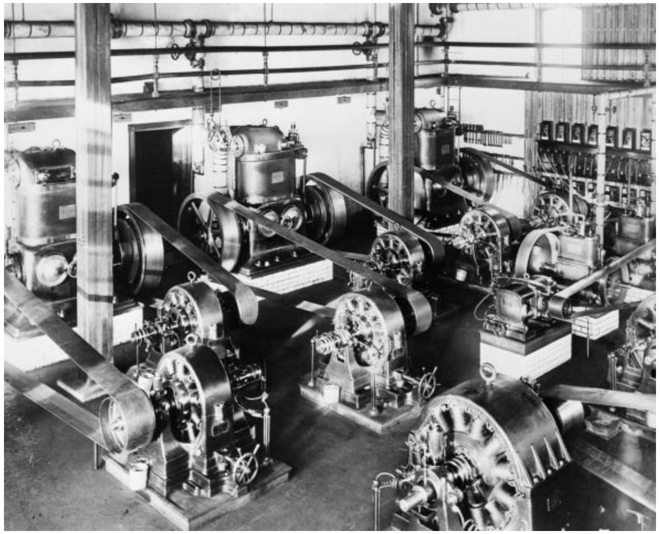
   Mechanical work → electrical energy → mech. work

   Allows central generation of power

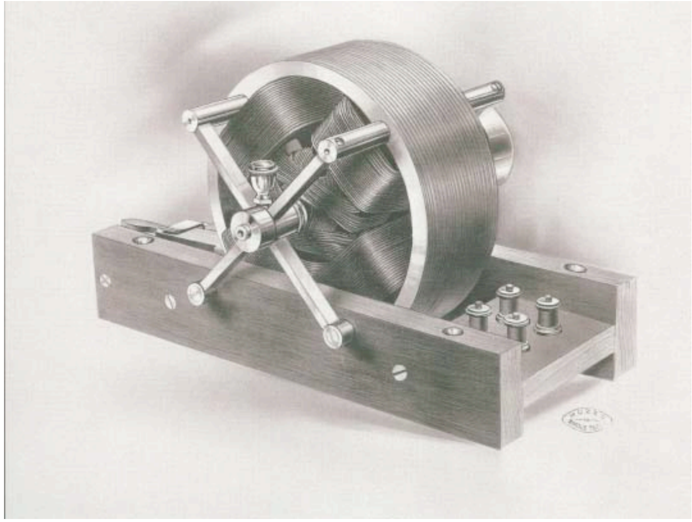
   Late 1800s: rise of electrical companies

A generator and a motor provide a way to move kinetic energy from one location to another

Kinetic ------(generator)----------> Electrical --------(motor)--------> Kinetic

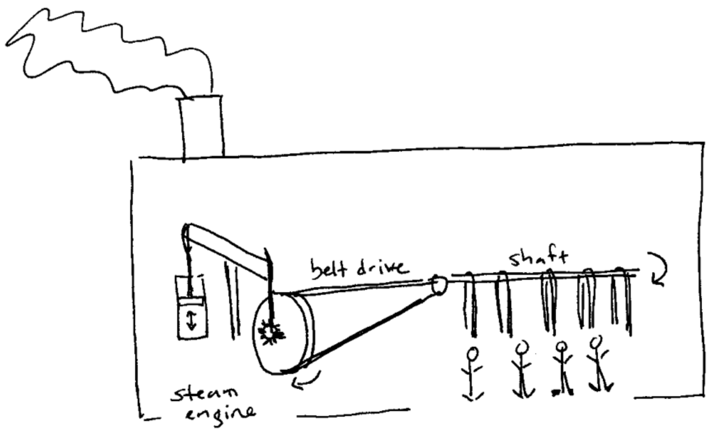


Westinghouse generators, 1888

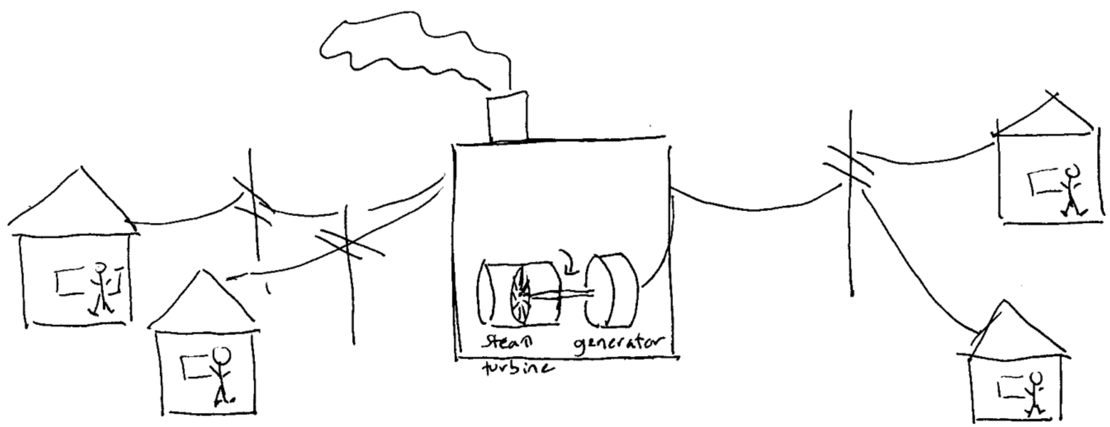


Tesla induction motor, 1888

Can electric motors reduce the terrible capital requirements of the 19th century?



Pre-electrification – must own power plant, all workers in one place. Power = power



Post-electrification – dispersed work possible, and workers now own the means of production (if utilities are public).

Main use of electricity is take rotational motion in one place and "move" it somewhere else

Power to the people….

"Communism is Soviet power plus the electrification of the whole country".

-- V. I. Lenin

"Lenin to the 8th All-Russian Congress of Soviets", Dec. 1920

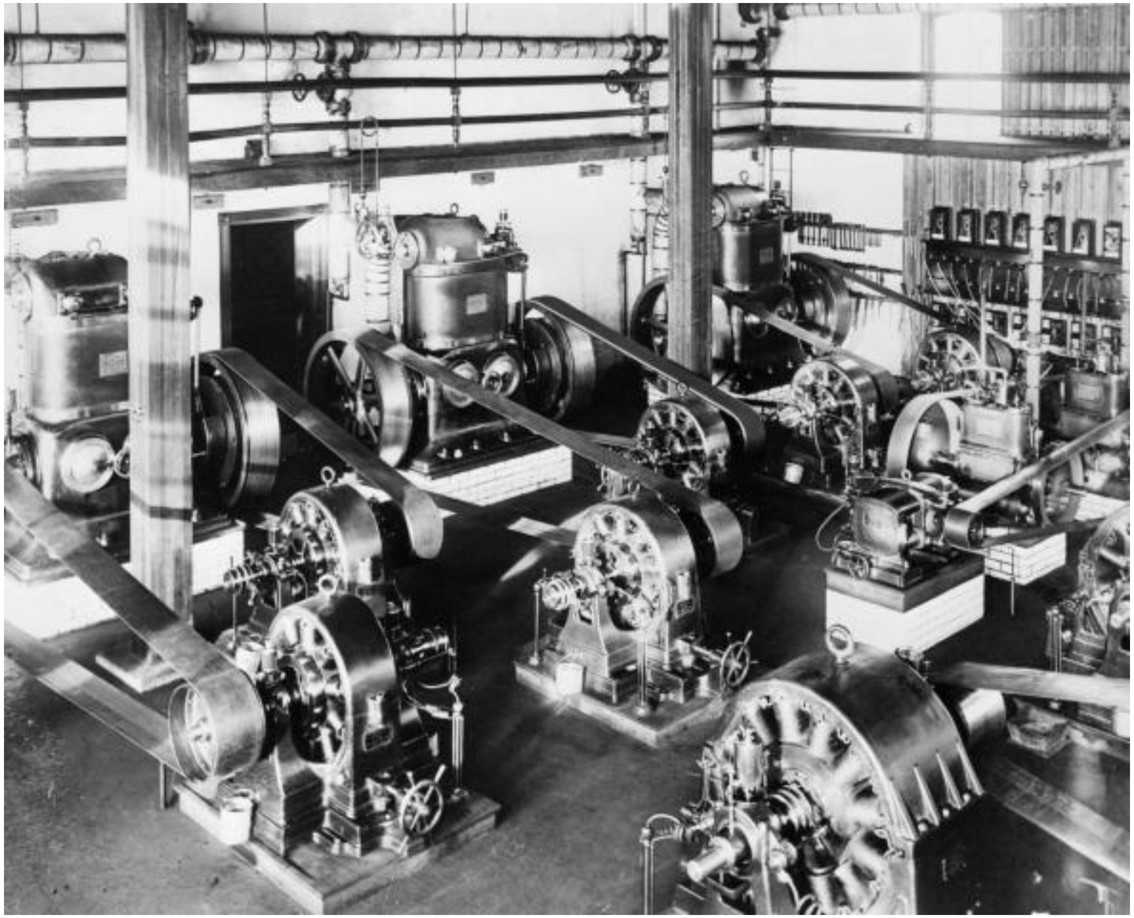
Soviet poster, 1925

Electric generation offers means to transfer power

Physics principles:

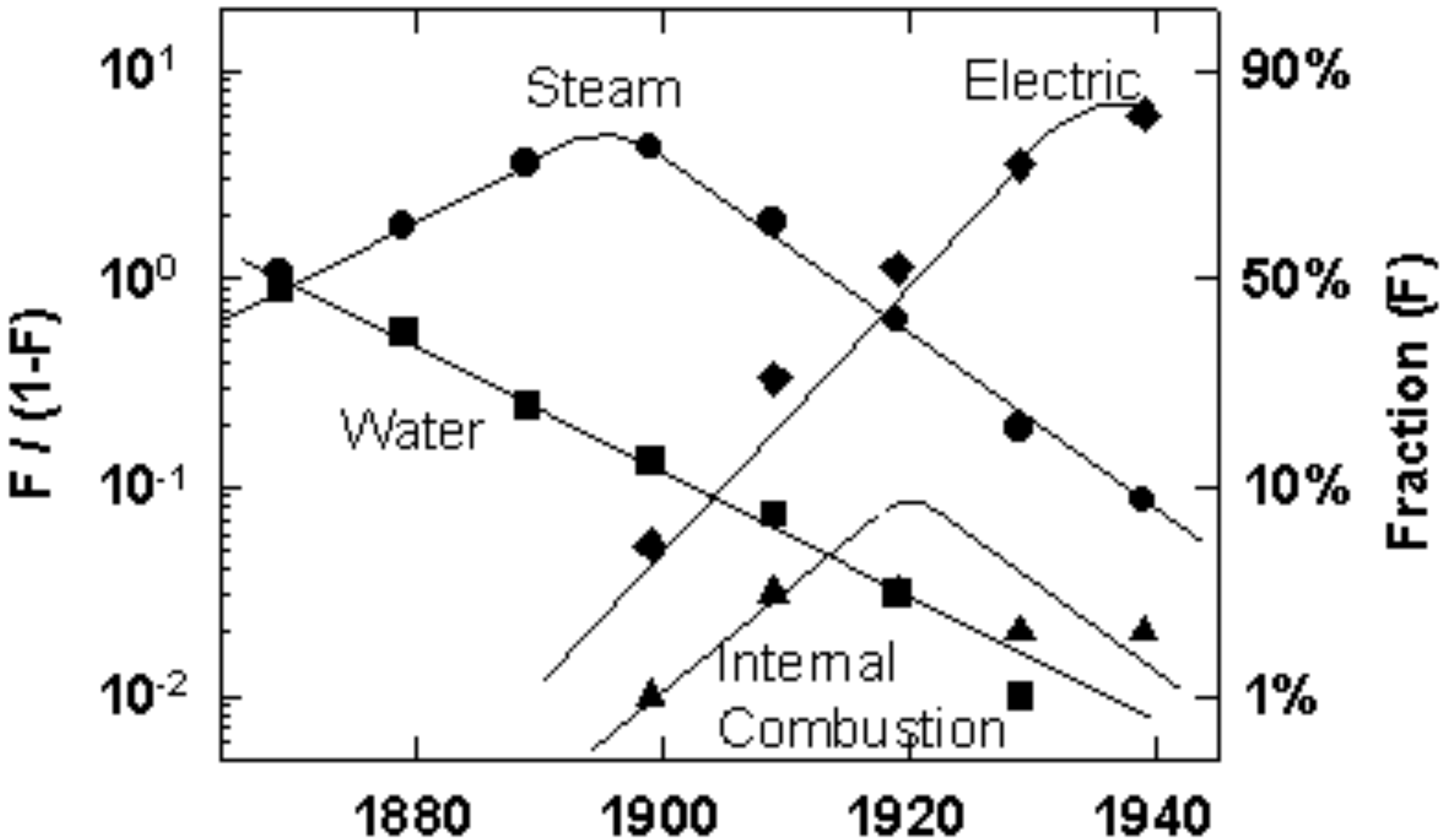
1) **Generator**
   Turning something *(in the presence of a magnetic field)* **can make electricity** *(i.e., convert kinetic energy to electrical energy).*

1) **Motor**
   Electrical energy *(given the presence of a magnetic field)* **can turn something** *(i.e. convert electric energy to kinetic energy)*



Westinghouse commercial AC generating station, 1888

Electricity quickly (~50 years) becomes **dominant means of delivering kinetic energy** for factories and stationary motors



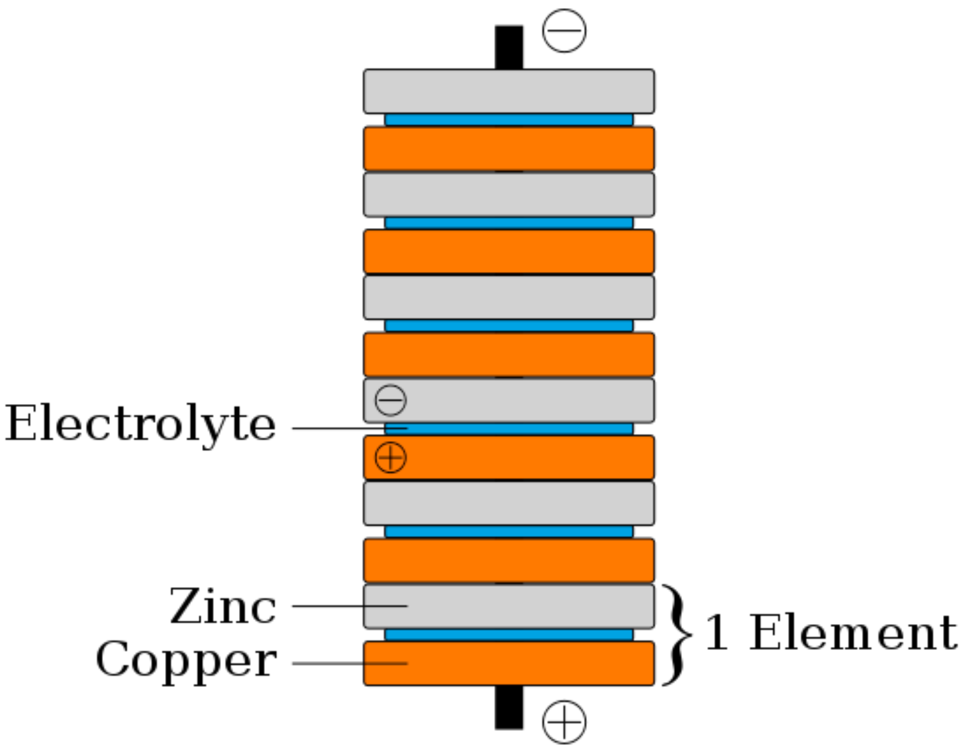
Sources of Power for Mechanical Drives in the United States.

Data Source: Warren D. Devine, Jr., "From Shafts to Wires: Historical Perspective on Electrification," *Journal of Economic History* 43 (1983): 347_372; Table 3, p. 351.

From: Ausubel, J. Daedalus 125(3):139-169, 1996.

Batteries invented before use for electricity

Allessandro Volta – demonstrated 1791, "Voltaic pile" 1800



Voltaic pile was stack of different metals (Zn, Cu) soaked in brine (inspired by Galvani's accidental finding).

Chemical energy -> electrical energy: metal oxidizes

Images from: Wikipedia, Batteryfacts.co.uk

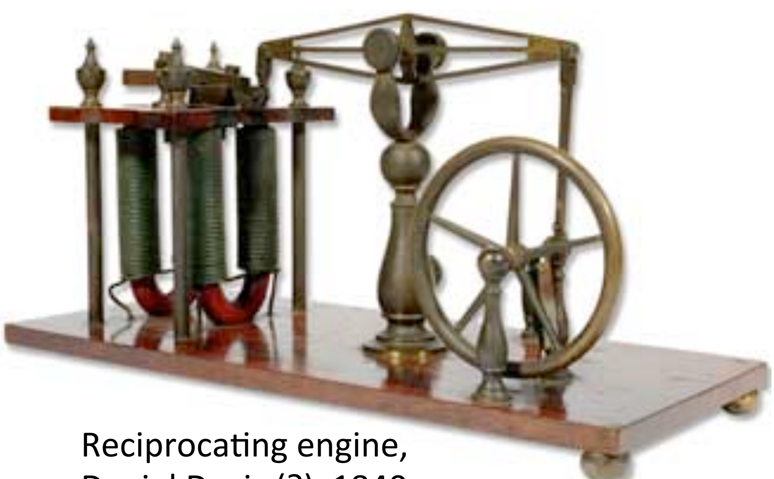
Electricity research started with motors

(first powered by batteries)

Rotating wire in Hg,
Faraday, 1830s

Rotating electromagnet,
Wm. Ritchie, 1833

Rotating electromagnet,
Wm. Sturgeon, 1838



Reciprocating engine,
Daniel Davis (?) 1840s

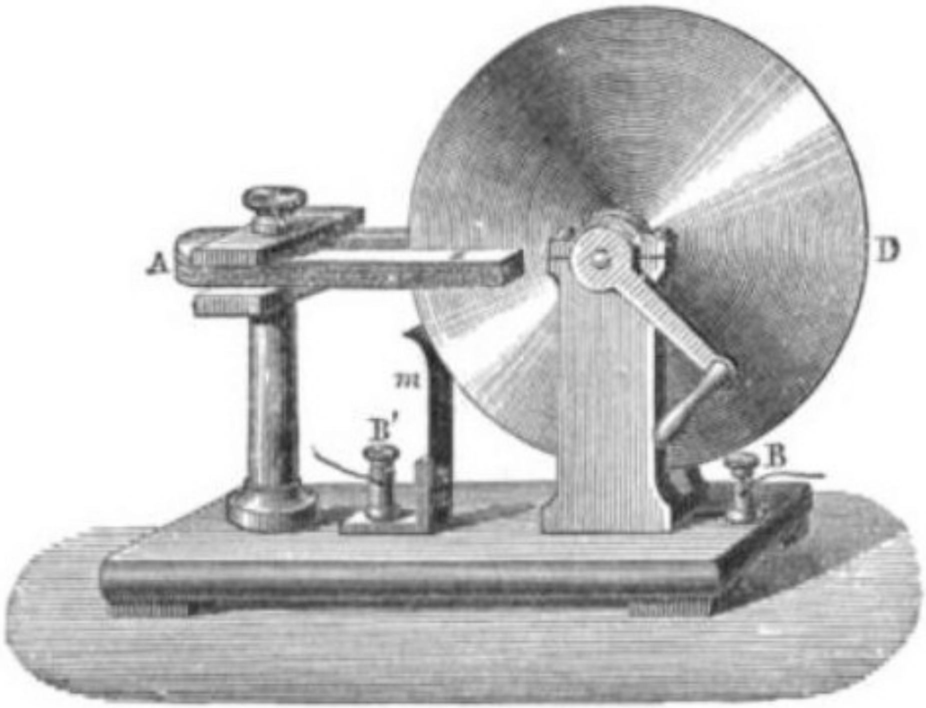
Revolving armature engine,
Daniel Davis 1848

DC electric fan, Edison 1898

Images from: Sparkmuseum

Generators followed quickly

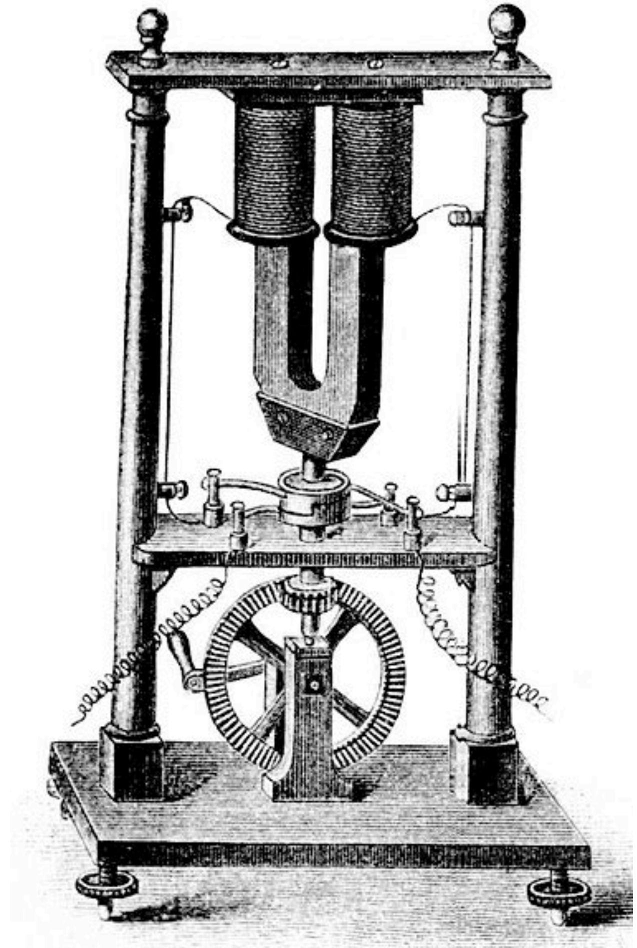
But only as physics demonstrations, no practical use



Faraday's generator, 1831

A metal disk spinning between poles of a magnet

Source: Wikimedia, original unknown



Pixii's dynamo, 1832

A magnet spinning under coils of wire

Commutated DC current

Source: Niethammer, F.; *Ein- und Mehrphasen-Wechselstrom-Erzeuger*; Verlag S. Hirzel; Leipzig 1906, via Wikimedia

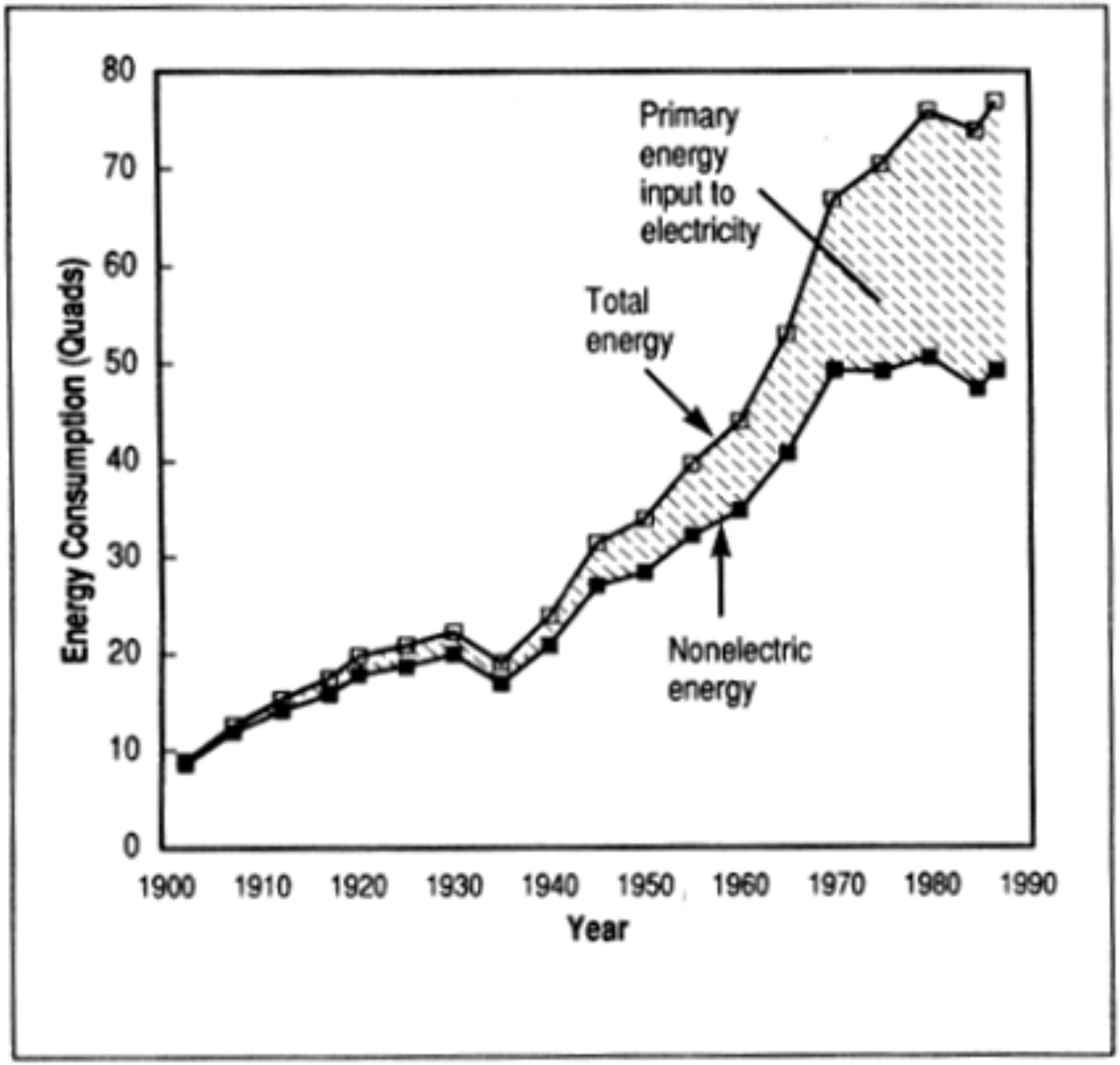
Use of heat engines preceded electricity by > 100 years

STEAM	ELECTRICITY
1690 Papin concept of steam engine	
1712 Newcomen reciprocating engine	
1765 Watt's improved engine	
	1800 battery (Volta, Davy)
1820's invention of steam locomotive	1820 electricity & magnetism related (Oersted)
1825 *Carnot calls steam engines the source of England's strength*	1821 first motor (Faraday)
	1831 first generator (Faraday)
	1866 dynamo (Siemens)
	1870s dynamo used for arc furnaces
1884 steam turbine (Parsons)	1880s lightbulb, first distribution (Edison)
	1883 AC motor (Tesla)
	1893 Chicago World's Fair electrified with Tesla's AC power (25 Hz)
	1920 Lenin calls to electrify Russia

First use is for lighting: Electric lighting common only a decade after invention

W.L. Sontag, 1895, *"The Bowery at Night"*

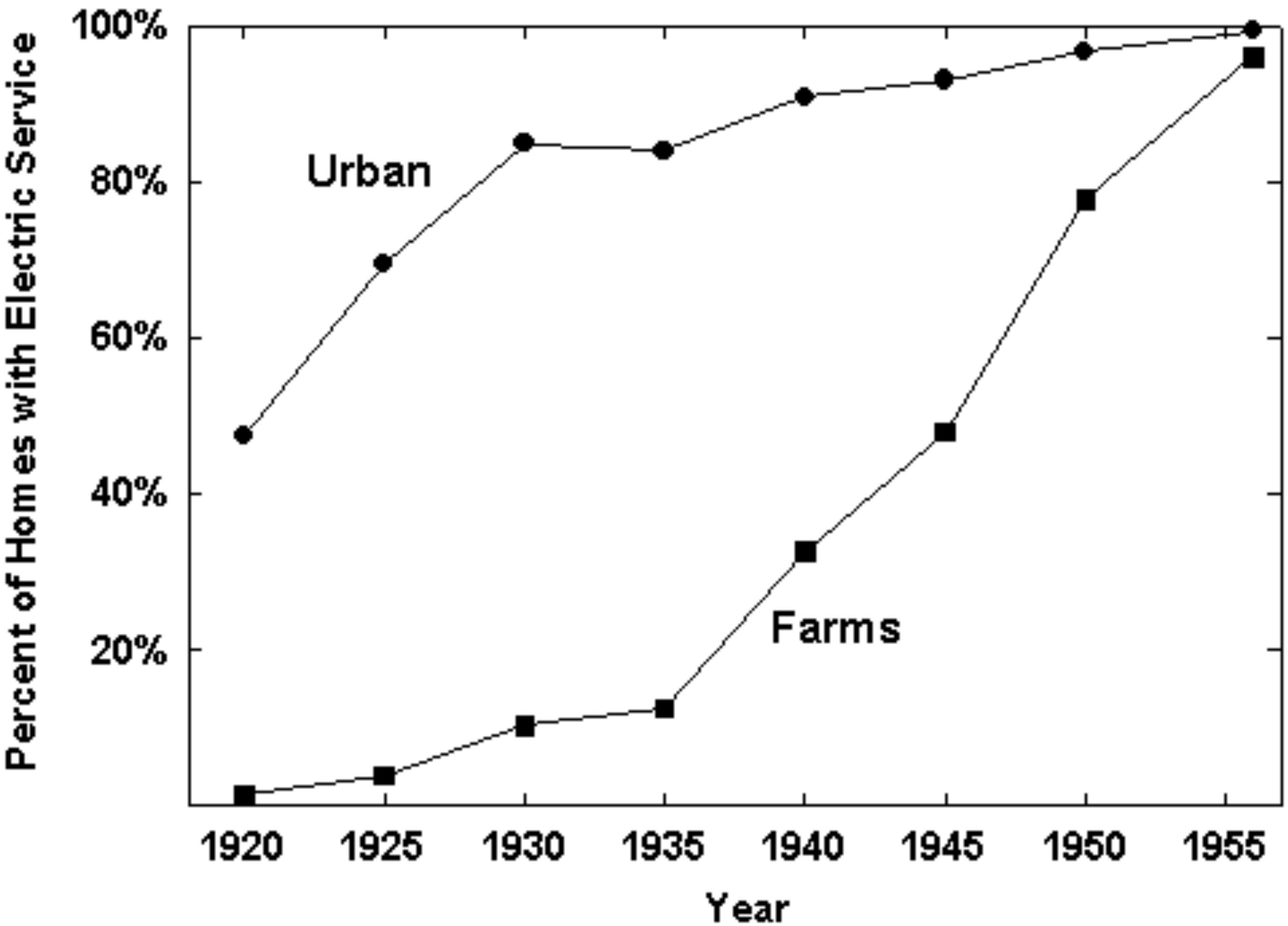
Electricity still a minor component of U.S. energy use til 1970s



from 1970 on growth in U.S. energy use goes to electricity

Figure source: Vaclav Smil, "Energy in World History". Data source: U.S. DOE

Home electrification takes time

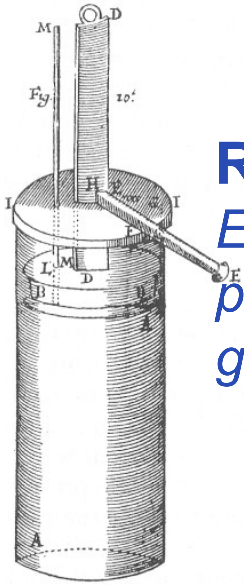


From: Ausubel, J. Daedalus 125(3):139-169, 1996.

Electrical energy is not primary energy source – is converted from some other energy type.

- rotational motion turns electrical generator
- how is that rotational motion created?
- *with a heat engine*

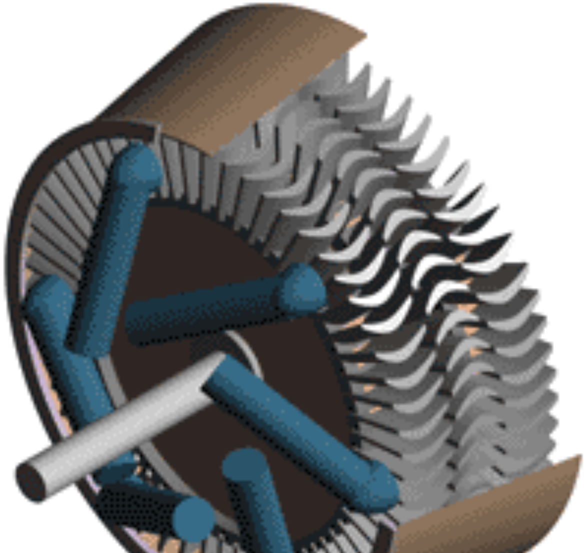
Three major types of engines



Reciprocating engine
Expanding gas drives piston up in cylinder, giving linear motion

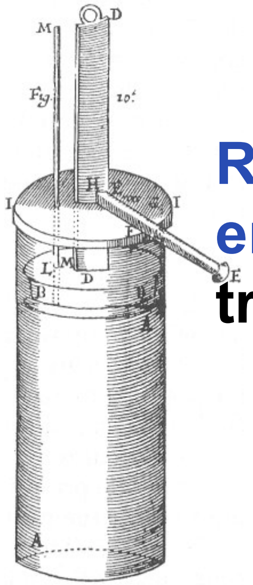
Jet engine *Most gas ejected at high pressure to produce linear motion*

(+ some drives blades to produce rotation and drive compressor)



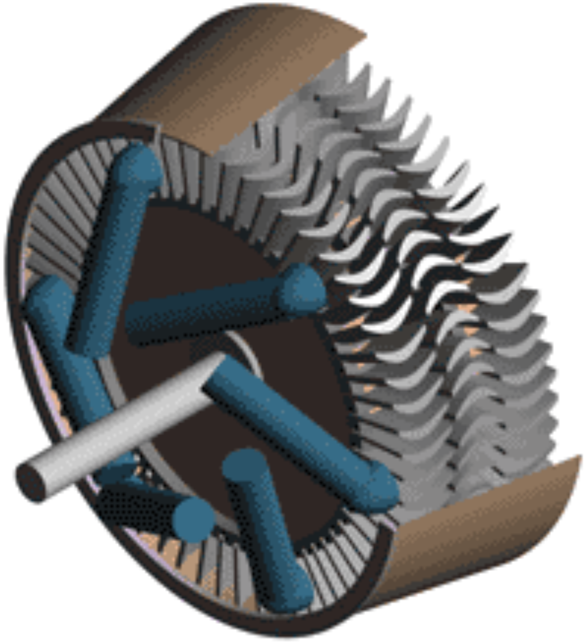
Turbine *Expanding gas drives blades to produce rotation*

Engine uses



Reciprocating engine: transportation

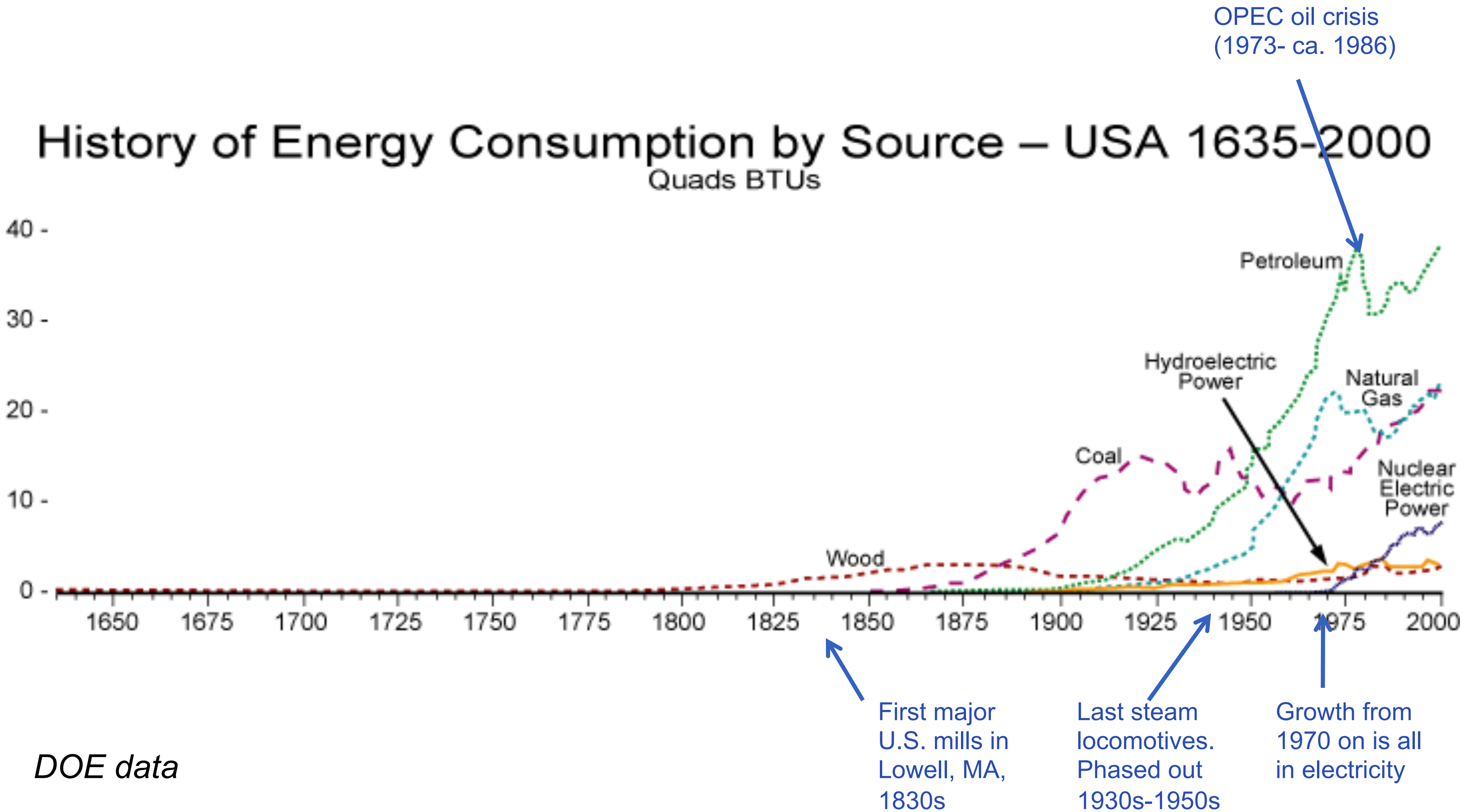
Jet engine: ***transportation***



Turbine: ***electricity generation***

Explosive growth in energy usage in U.S. from 1880s to present

from 1970 on growth is mostly due to electricity



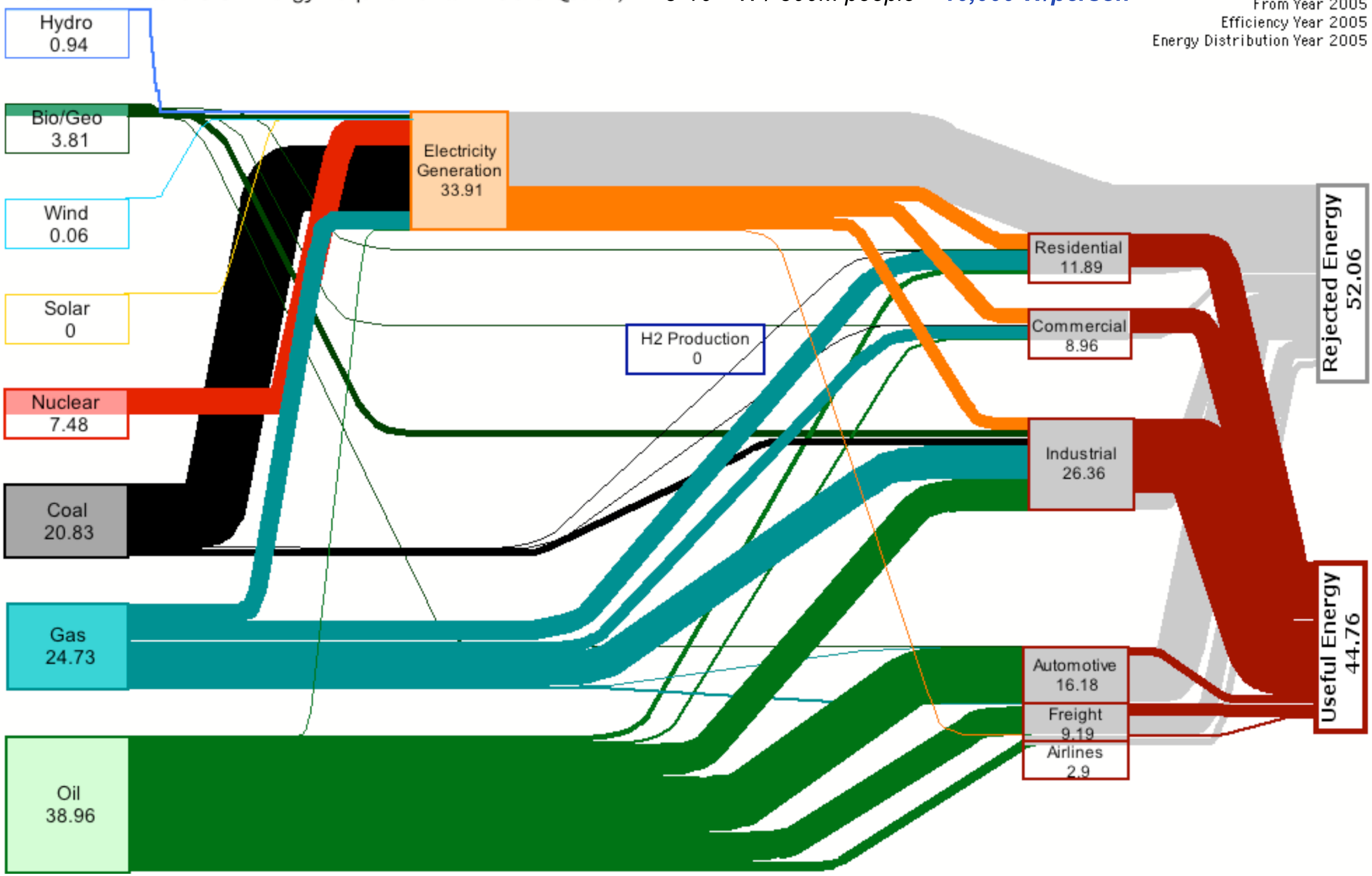
DOE data

Now electricity is 1/3 of U.S. power usage

U.S. energy use, 2005

from LLNL, in quads/yr : 1 Q / yr ~ 10^{18} J / yr ~ 30 GW

Estimated Future U.S. Energy Requirements ≈ 96.8 Quads) = $3 \cdot 10^{12}$ W / 300M people = ***10,000 W/person***



Electricity generation by heat engines is inherently inefficient

2nd Law of Thermodynamics

For heat engines, limitation is

Carnot efficiency:

$\varepsilon = 1 - T_C / T_H$

For a turbine using 600 K steam, cooled by room temperature (300 K), the limiting efficiency of the turbine is

$\varepsilon = (600 - 300) / 600 = 50\%$

In fuel-fired electricity production half the input energy is *inevitably* lost

Conversions	Energies	Efficiencies
Large electricity generators	M → e	98–99
Large power-plant boilers	c → t	90–98
Large electric motors	e → m	90–97
Best home natural-gas furnaces	c → t	90–96
Dry-cell batteries	c → e	85–95
Human lactation	c → c	85–95
Overshot waterwheels	m → m	60–85
Small electric motors	e → m	60–75
Large steam turbines	t → m	40–45
Improved wood stoves	c → t	25–45
Large gas turbines	c → m	35–40
Diesel engines	c → m	30–35
Mammalian postnatal growth	c → c	30–35
Best photovoltaic cells	r → e	20–30
Best large steam engines	c → m	20–25
Internal combustion engines	c → m	15–25
High-pressure sodium lamps	e → r	15–20
Mammalian muscles	c → m	15–20
Traditional stoves	c → t	10–15
Fluorescent lights	e → r	10–12
Steam locomotives	c → m	3–6
Peak crop photosynthesis	r → c	4–5
Incandescent light bulbs	e → r	2–5
Paraffin candles	c → r	1–2
Most productive ecosystems	r → c	1–2
Global photosynthetic mean	r → c	0.3

From V. Smil, "Energies", 1999