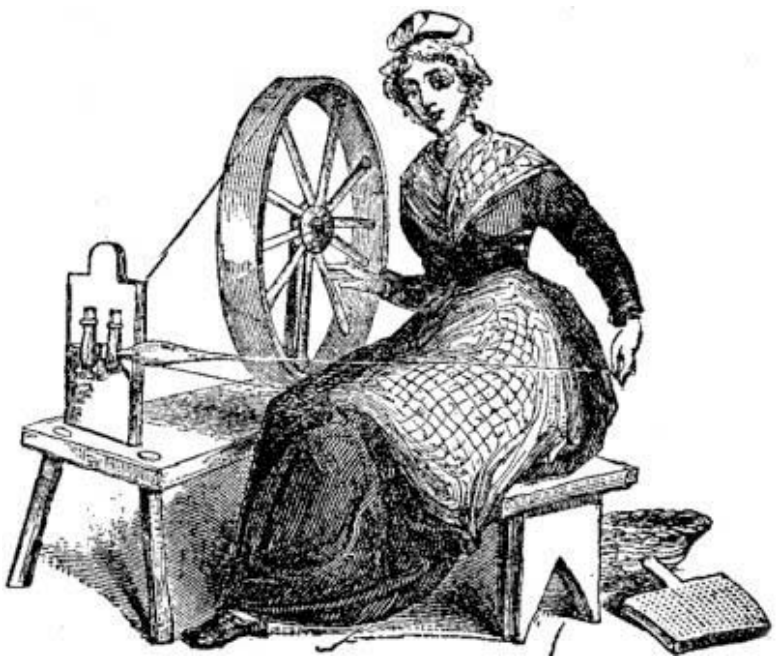
The Industrial Revolution and the Transition to the Modern Energy System

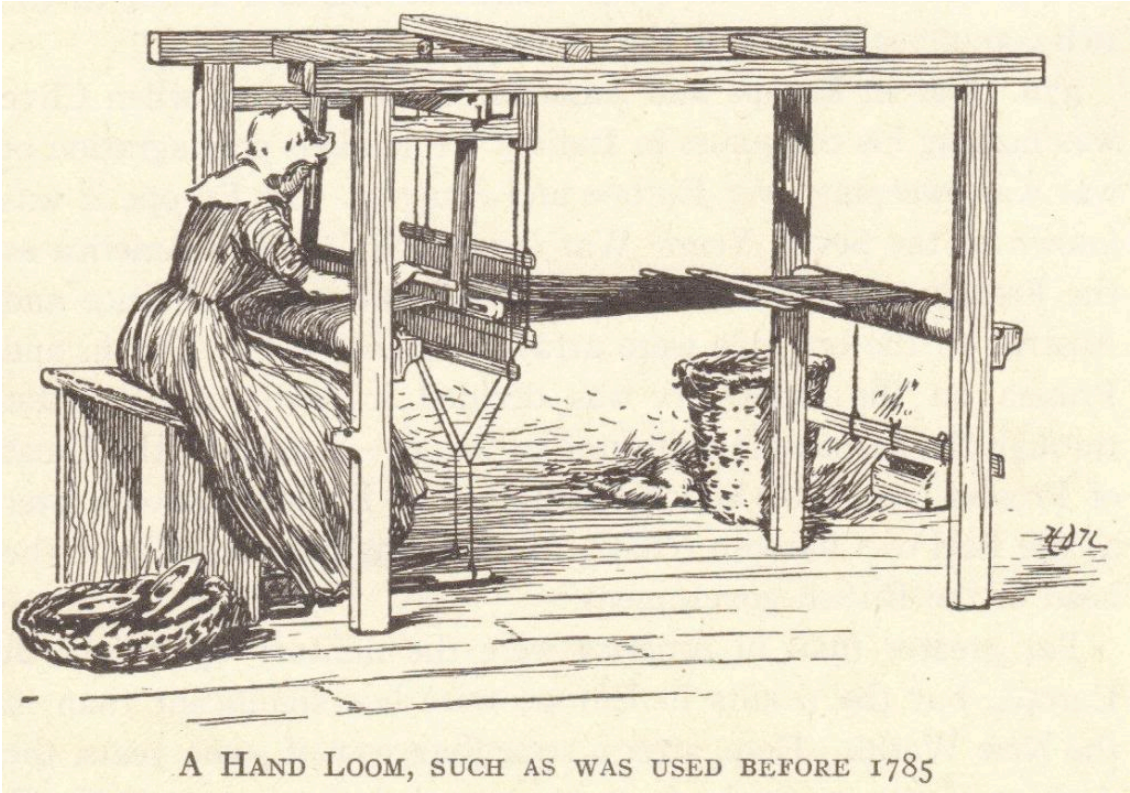
GEOS 24705/ ENST 24705

Textile production in England was first sector to be mechanized

(after milling, that is, that had been mechanized for centuries)



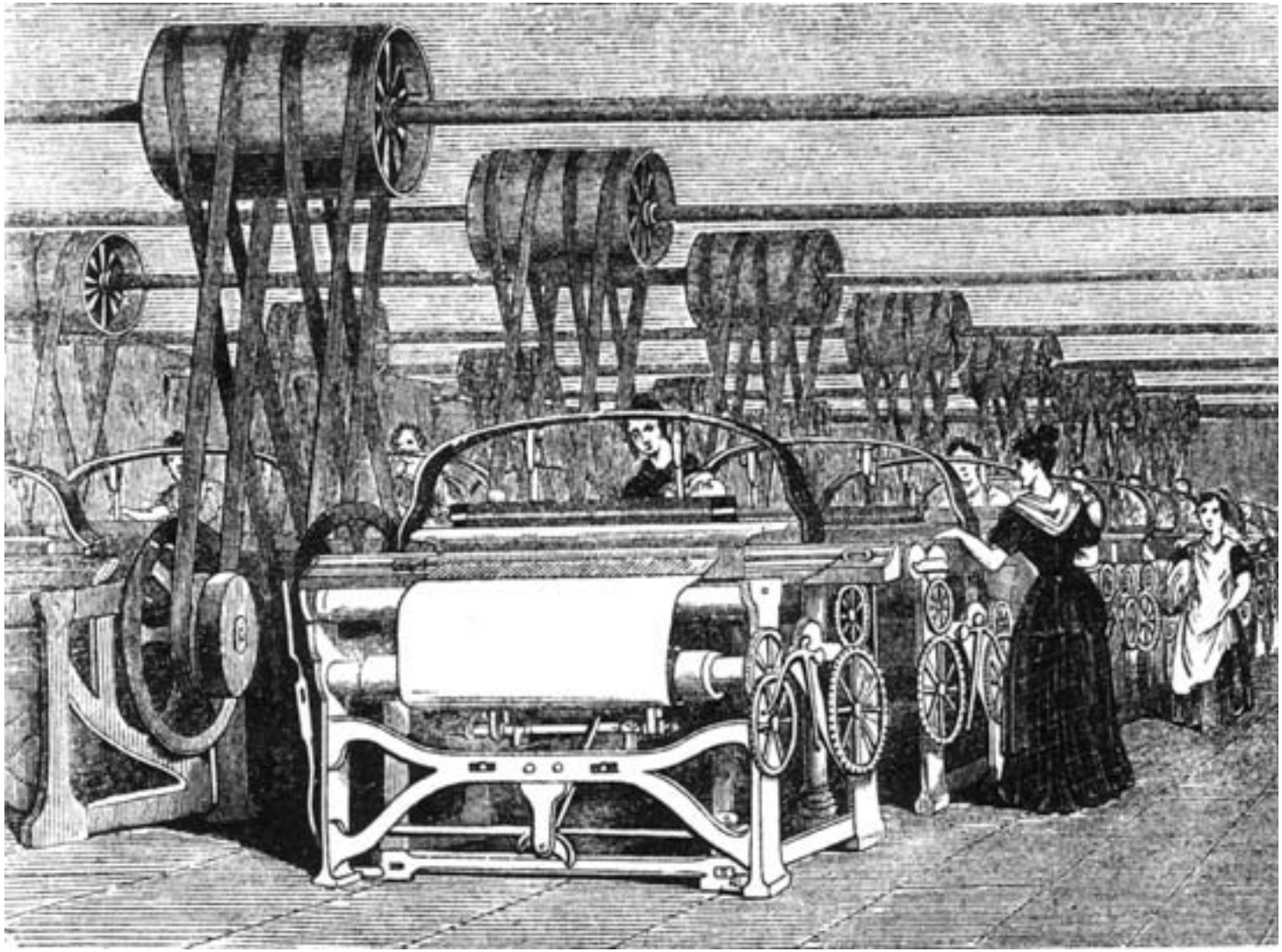
Jersey Spinning Wheel.
From: The Story of the Cotton Plant, Frederick Wilkinson, 1912, via Gutenberg.org



Source: unknown

Extremely repetitive motions well suited to mechanization

Textile production in England was first sector to be mechanized



Spinning first:

Spinning jenny, 1764

"Water frame" 1769

Spinning mule, 1779

(all before significant use of steam)

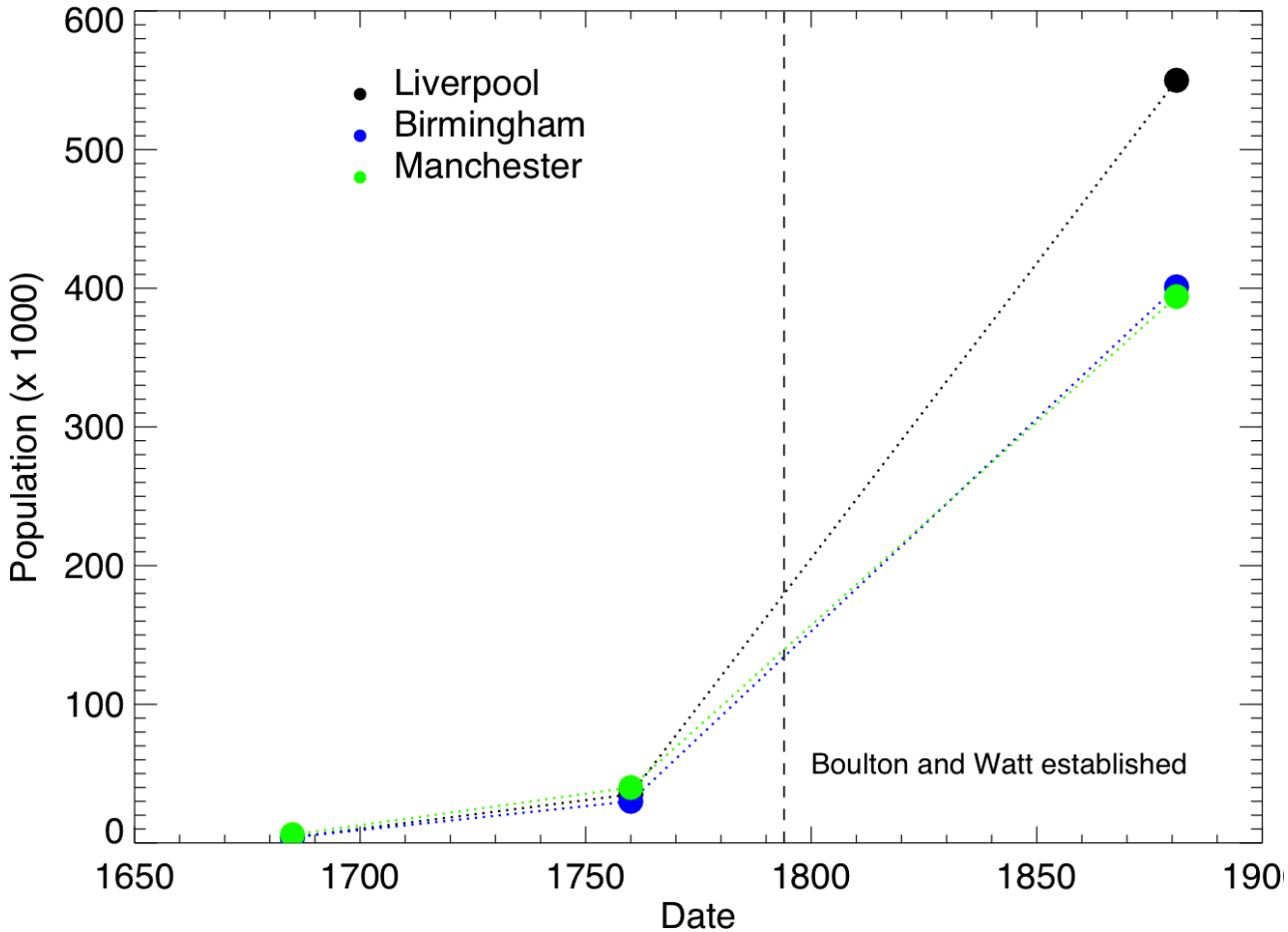
Looms followed later

and led to major social disruption… home weaving could no longer compete, and rural livelihoods were cut off, forcing migration

Power looms, 1844 Source: Getty Images

Rapid depopulation of countryside, move to cities

1696: 1/10th 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

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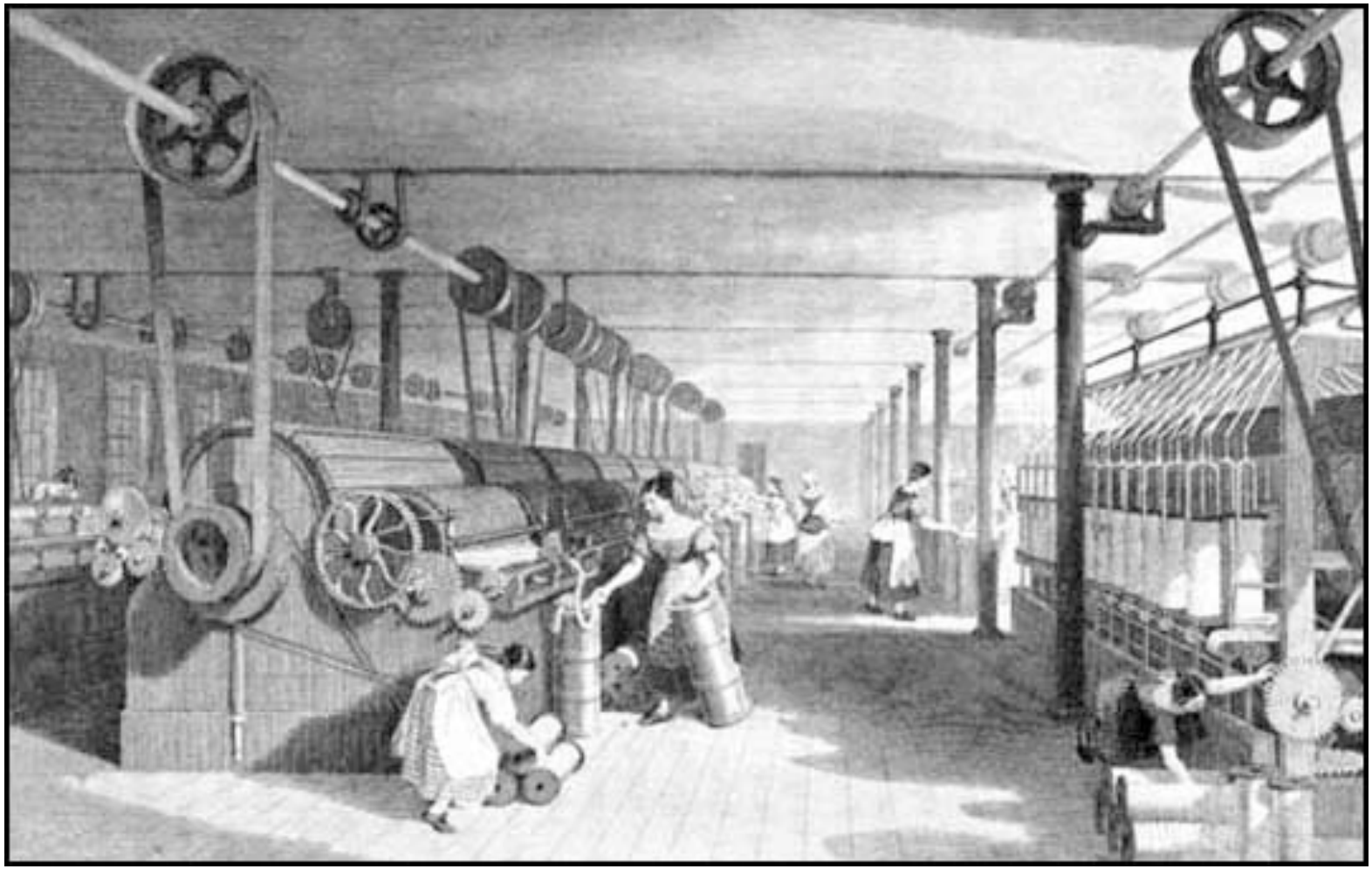
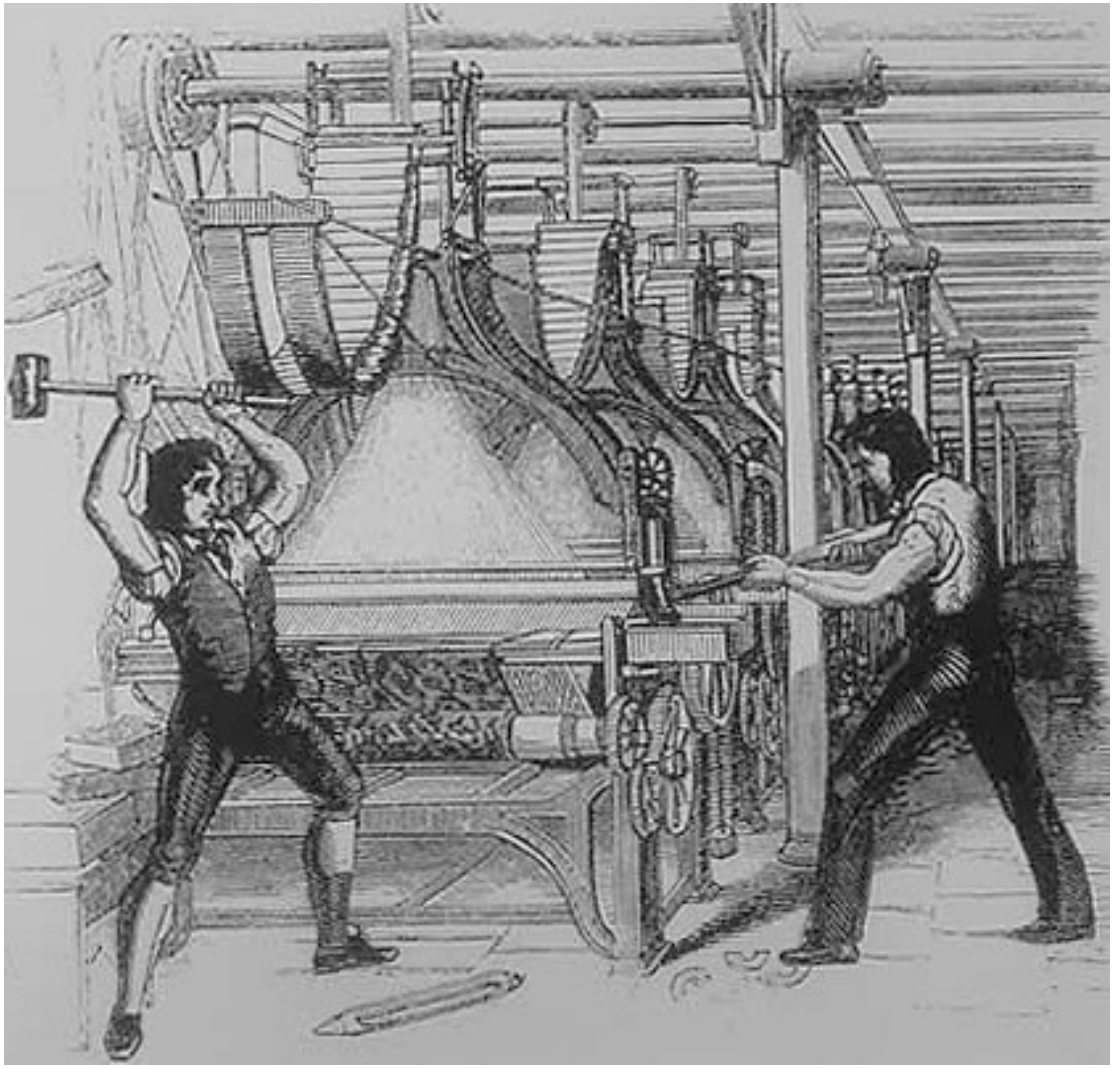


Social disruption included pulling women out of the home (women were cheap labor, small hands were valuable in operating machinery, and strength not required)

Looms, England, early 1800s, source unknown

The backlash against industrialization was strong



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

Machine-breaking criminalized in England as early as 1721 (penalty = transportation to colonies)

(Note from above that industrialization began under water power 50 years before steam….

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

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

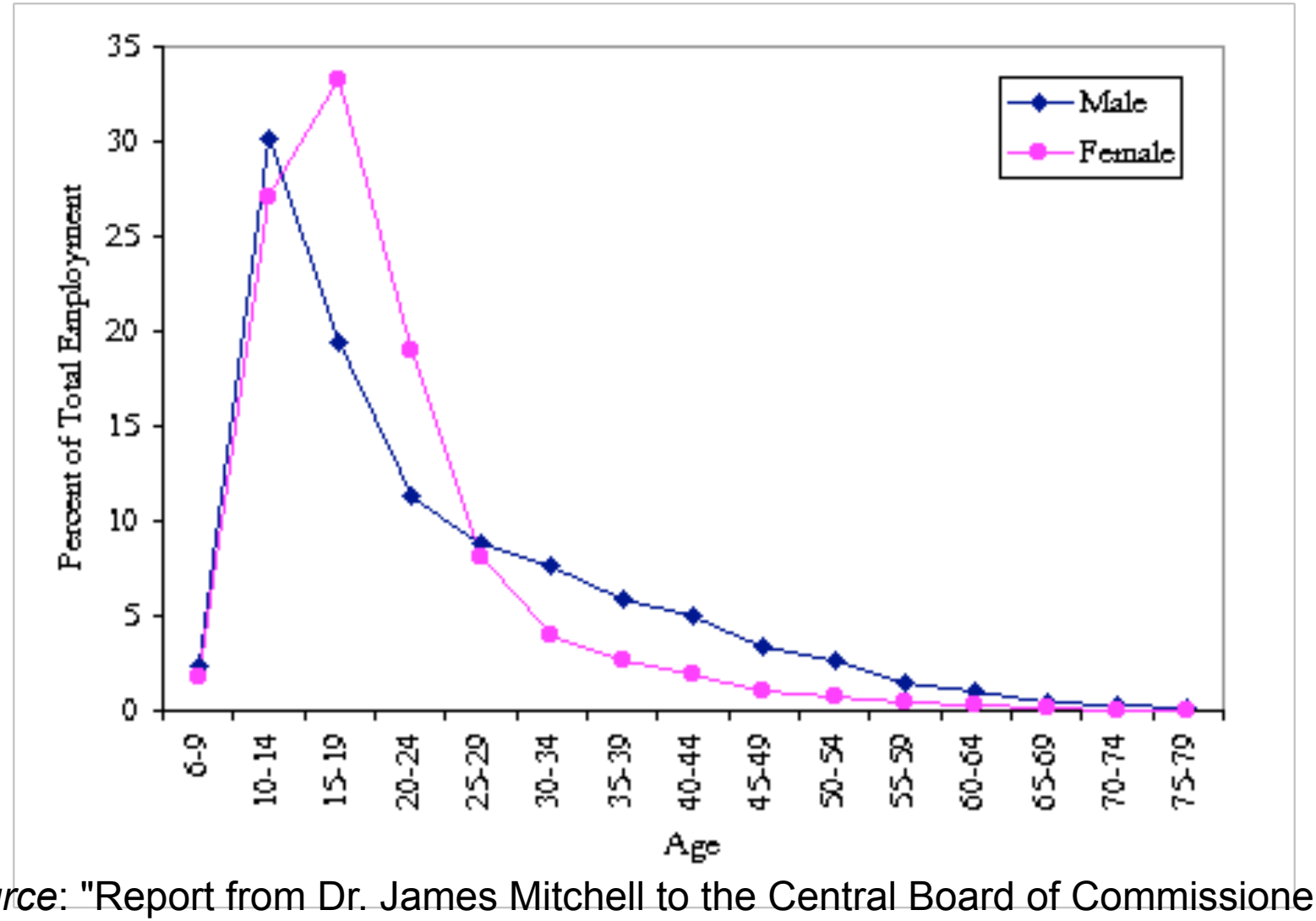
Frame-Breaking Act of 1812 made frame-breaking punishable by death

Much of mill labor was performed by children

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 *(source unknown)*

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

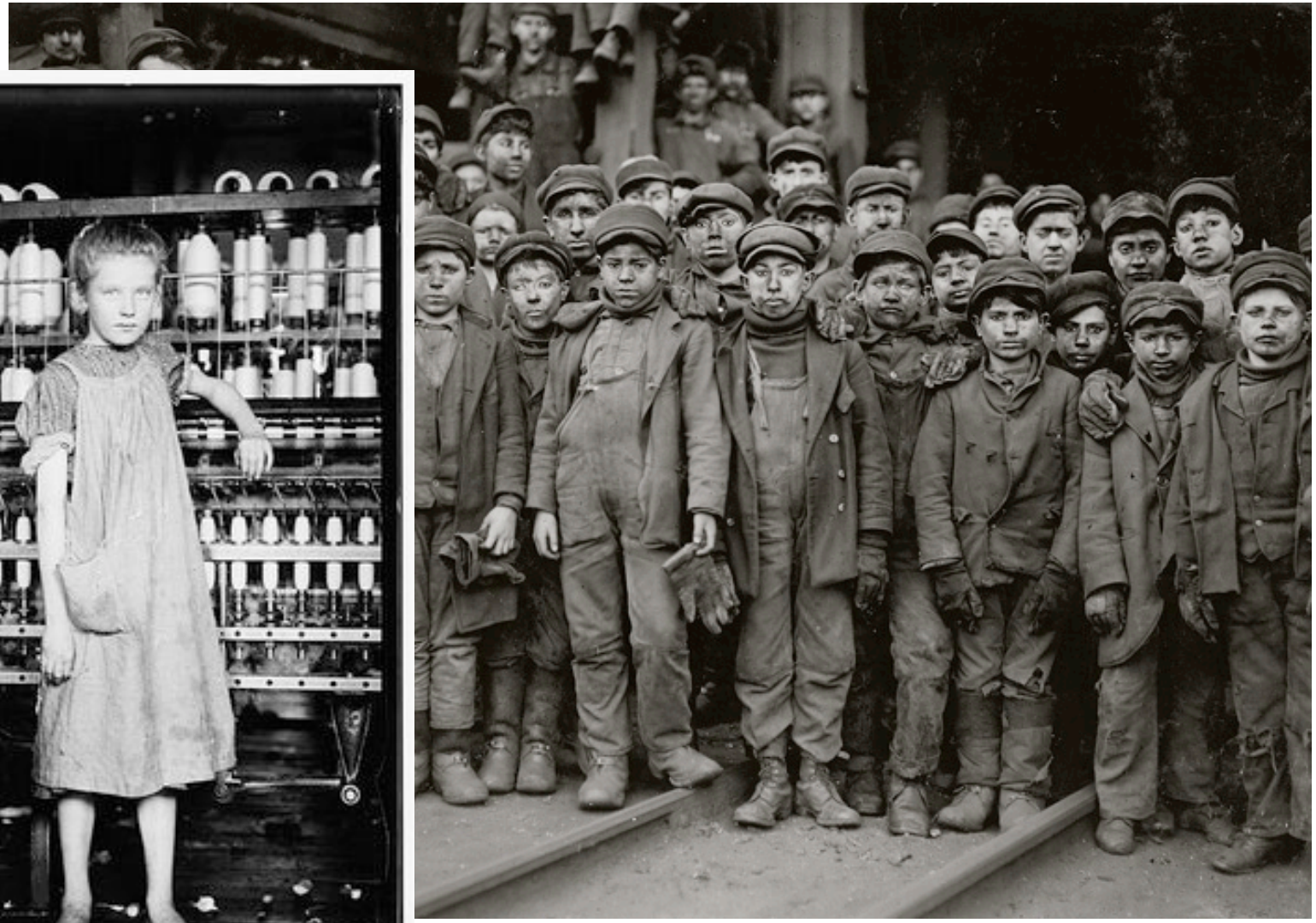
(First law: Labor in Cotton Mills Act, 1811, Britain, limits to 12 hours /day)



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)*

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*

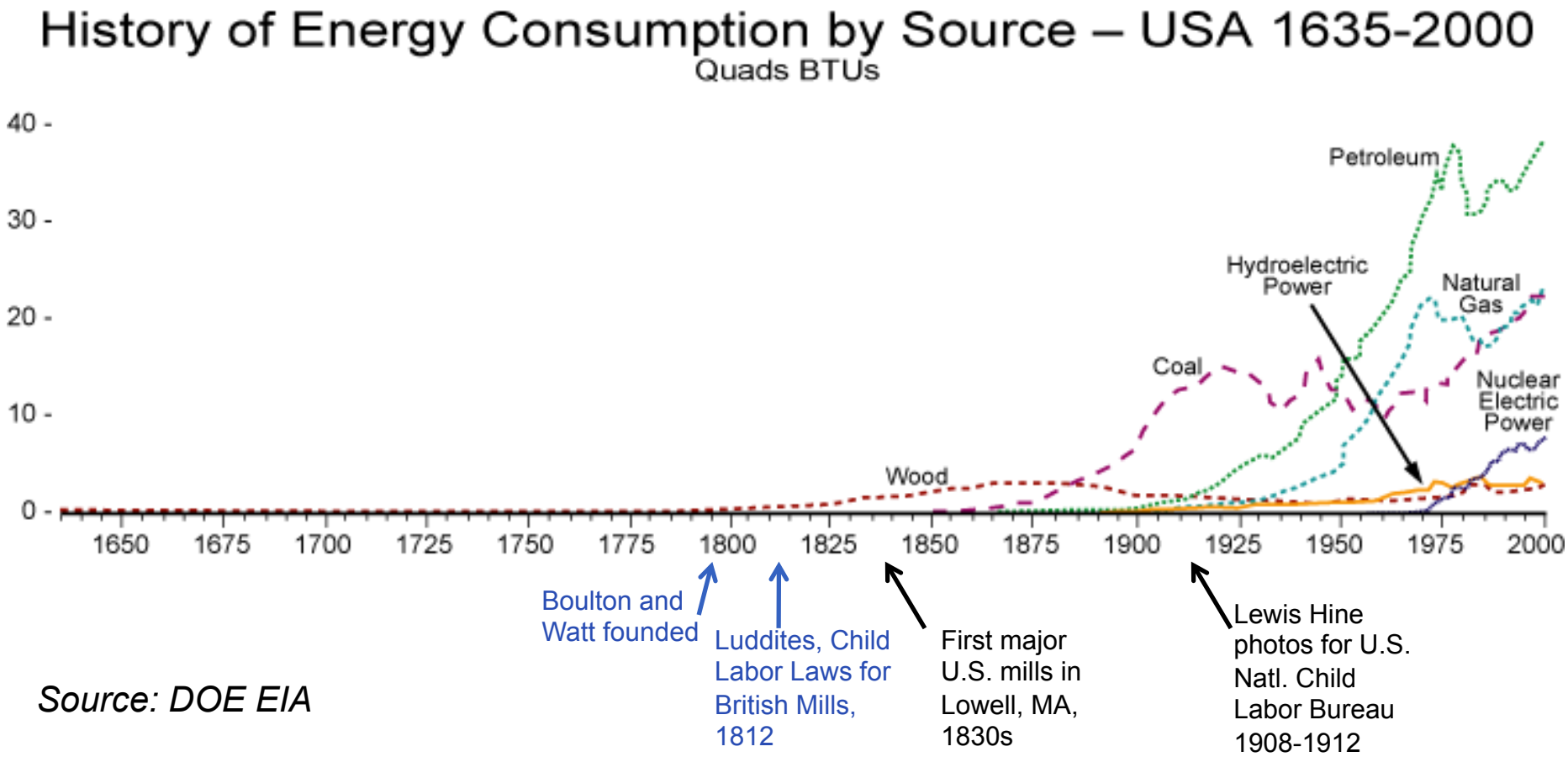


Lewis Hine, 1911, *Breaker boys working in Ewen Breaker of Pennsylvania Coal Co.*

U.S. industrialization came later than for Britain

Why? First was colony of Britain, then independent but little internal capital, no readily available coal, technology IP owned by Britain

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



Source: DOE EIA

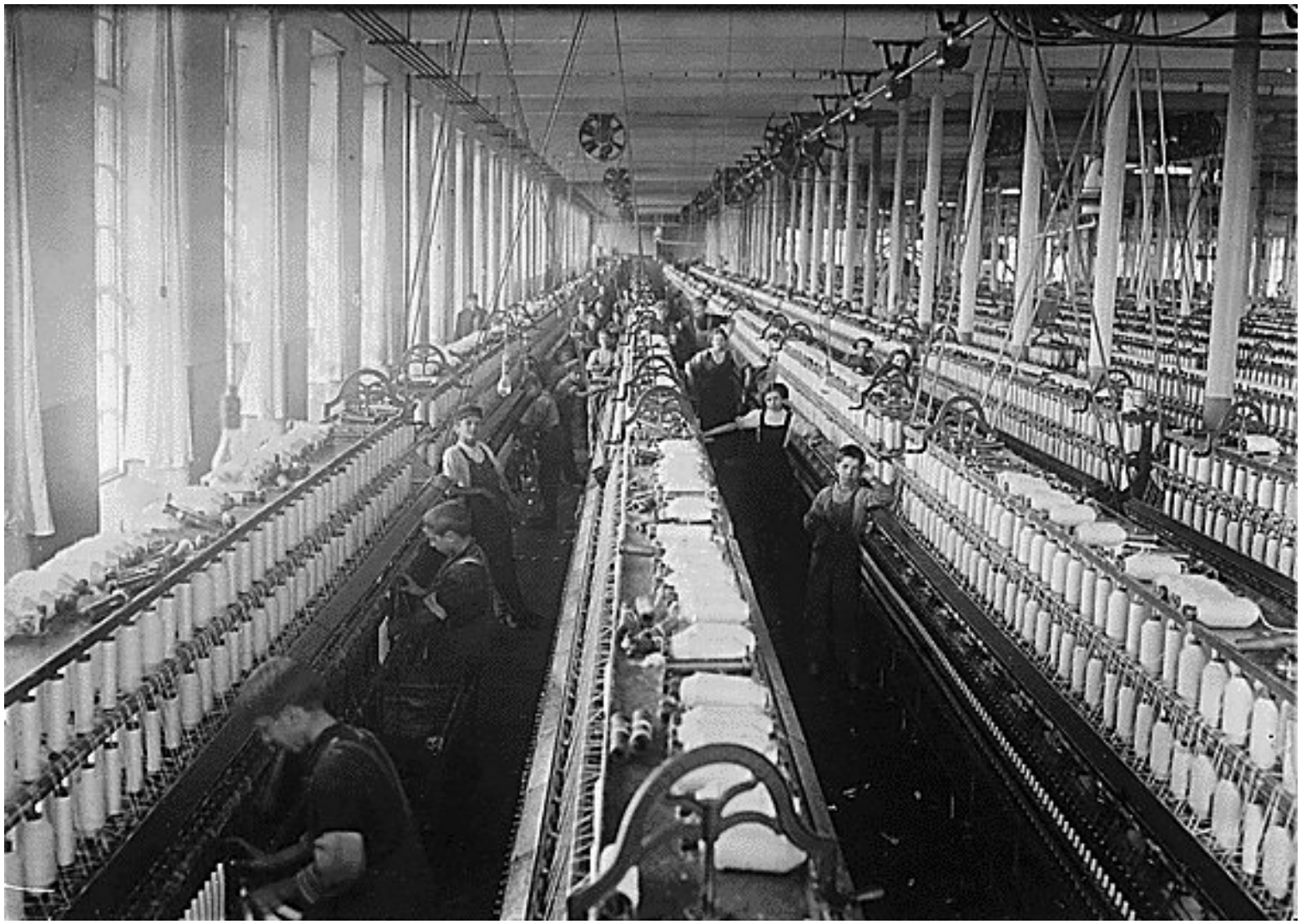
Several things to consider

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?

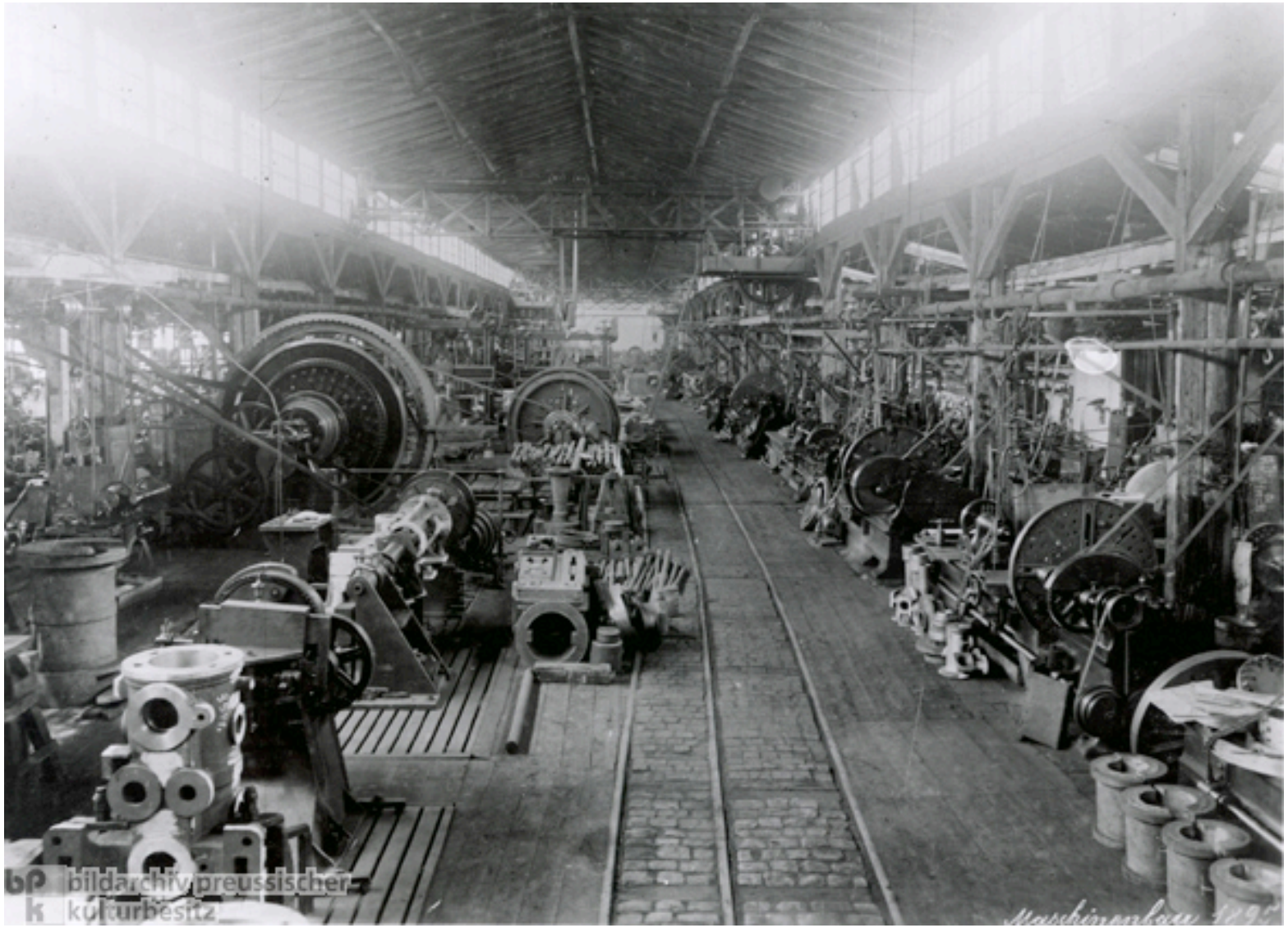
1800s: Mills get larger



Spinning mill, likely mid-late 1800s

(source unknown)

1800s: Mechanization comes to other industries



German machine shop driven by single steam engine

(© Bildarchiv Preußischer Kulturbesitz)

1800s: Mechanization comes to other industries

Machine shop, likely late 1800s

(source unknown)

Several things to consider

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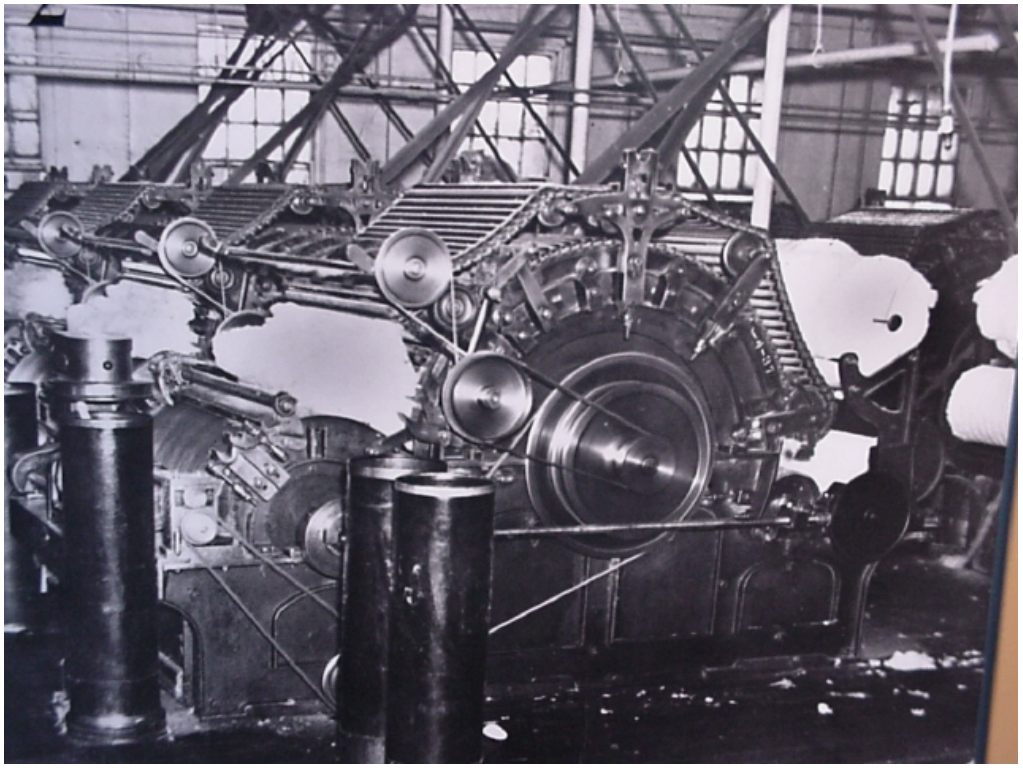
Belts transport rotational motion over long distances



Mills at Lowell, MA, 1850s

Belt and chain drives in modern life

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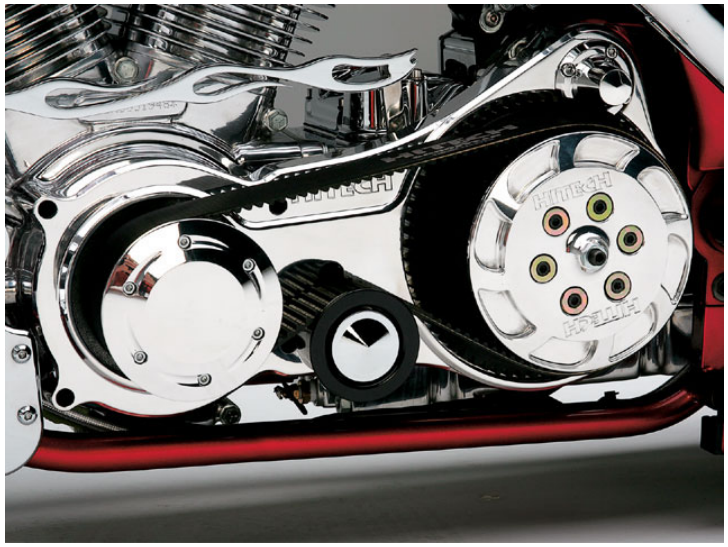
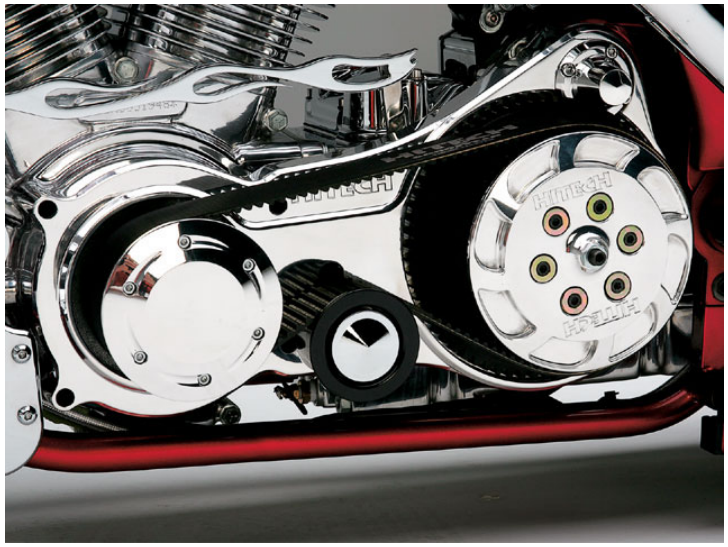
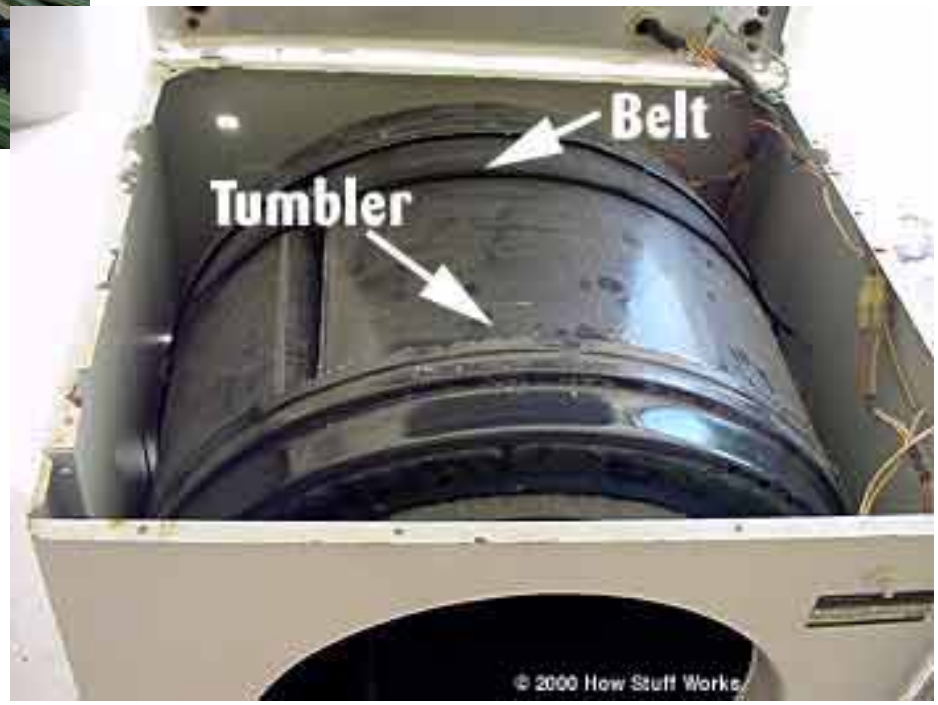


Belt and chain drives in modern life





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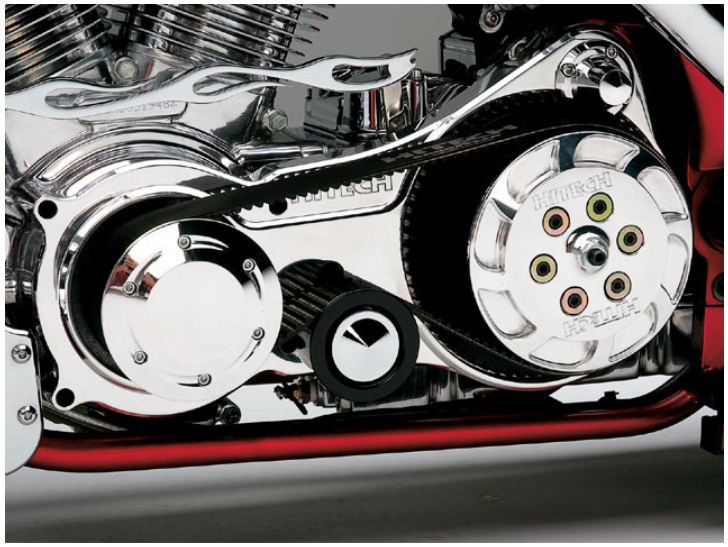

Why do we use fewer belt drives now?

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

Several things to consider

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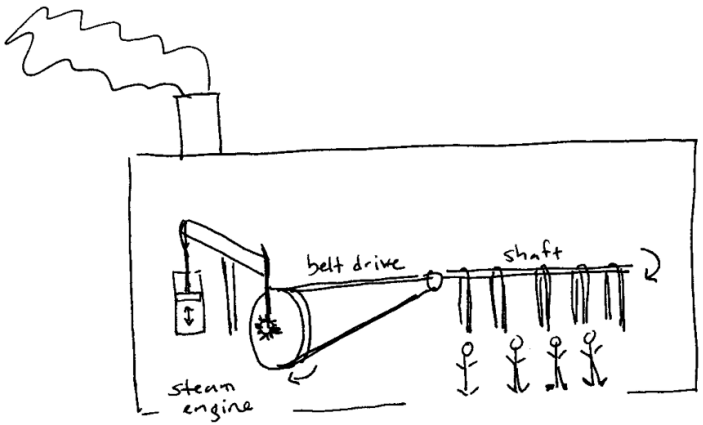
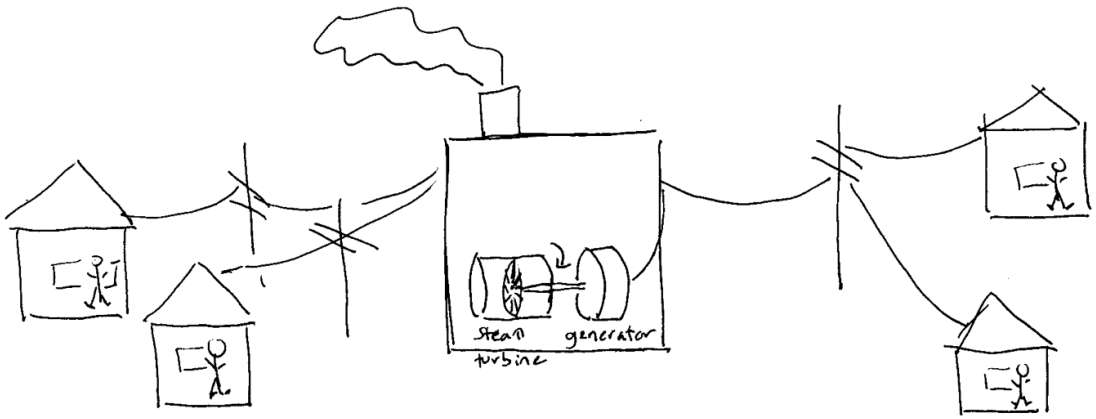
What did the absence of electricity mean for economic organization in the 1800s?

- 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.

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).

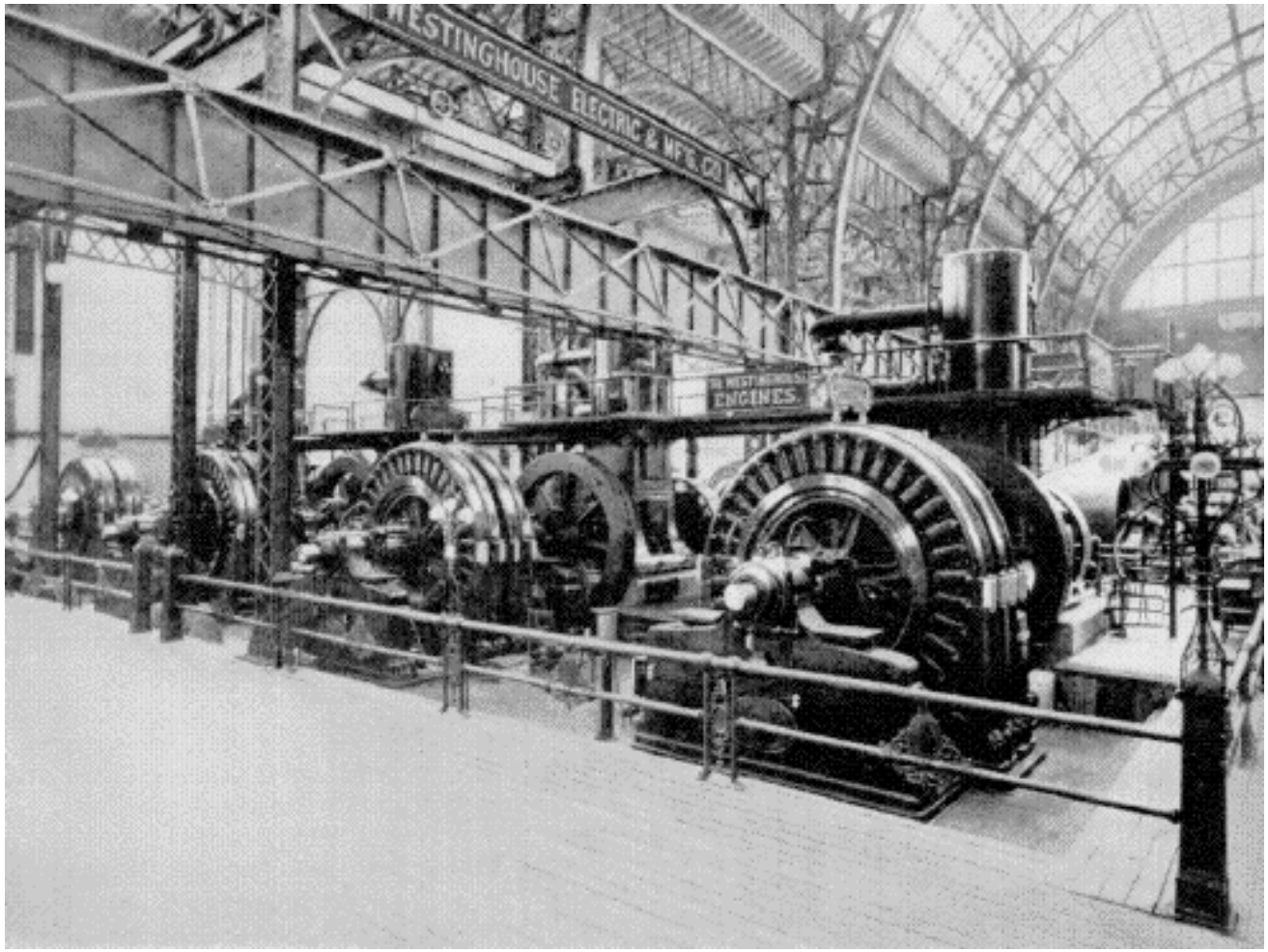
Main use of electricity is take rotational motion in one place and "move" it somewhere else

Early dynamos and generators

Physics principles:

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

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



Westinghouse dynamos exhibited in the Hall of Machinery, Chicago World's Fair of 1893. Similar dynamos also lit the building. *Photographer unknown.*

Early dynamos and generators

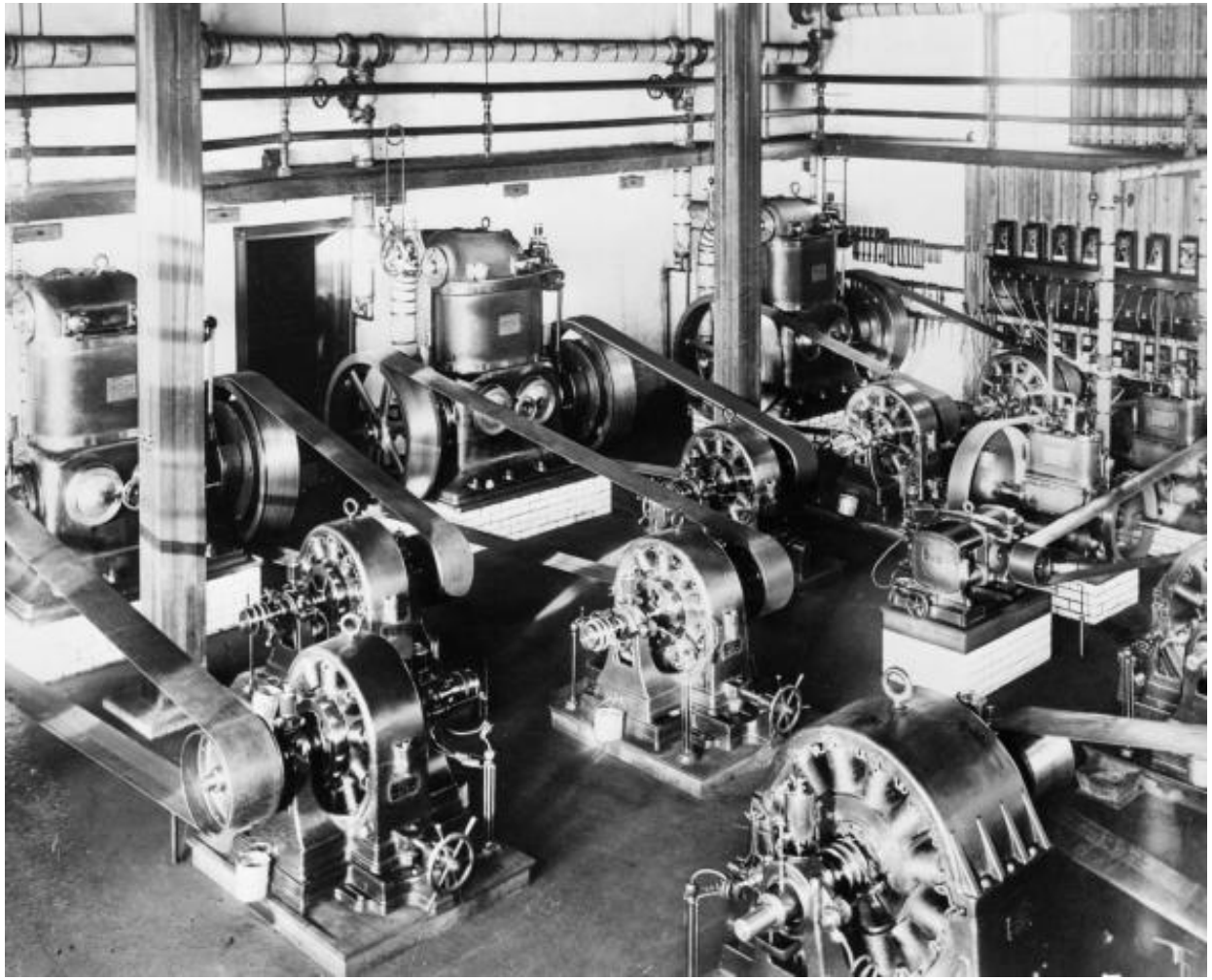
History principles:

1) The inventor is largely forgotten

2) The commercializer gets in the textbooks (Tesla ,Watt)

3) The guy who provides the capital makes all the money (Westinghouse, Boulton)

4) Technology takes decades to go from first commercial use to market dominance



Westinghouse commercial AC generating station, 1888

How to make rotational motion to turn an electrical generator? With a heat engine..

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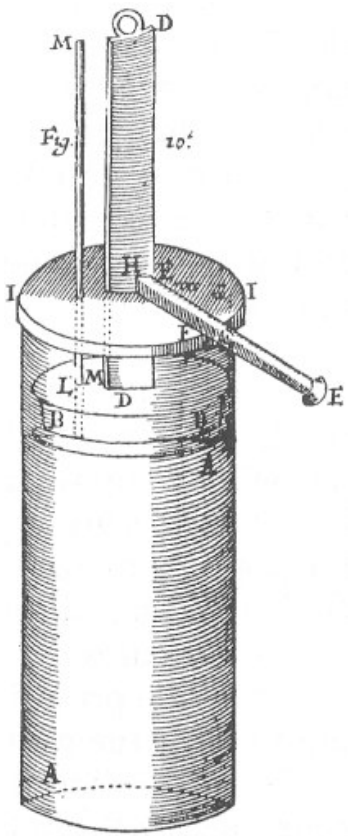
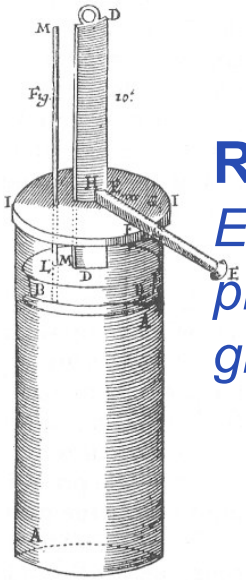


Piston (reciprocating engine)

Impelling rotation by force of steam ejected through a nozzle

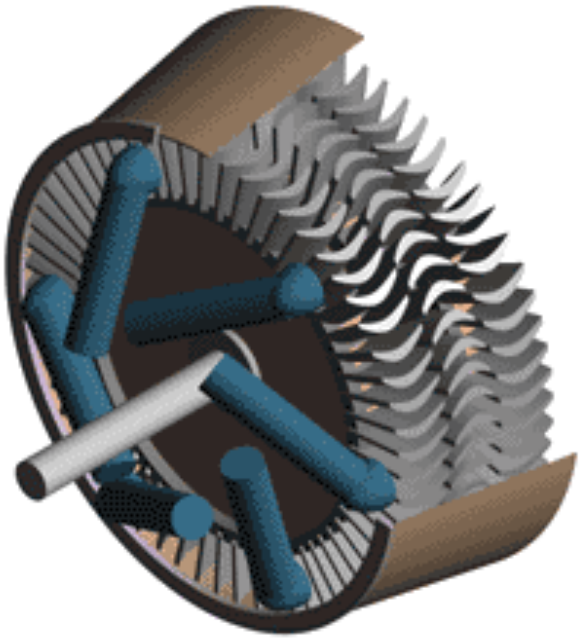
Three major types of engines



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*

The birth of the modern energy system

Pioneers in late 1700's

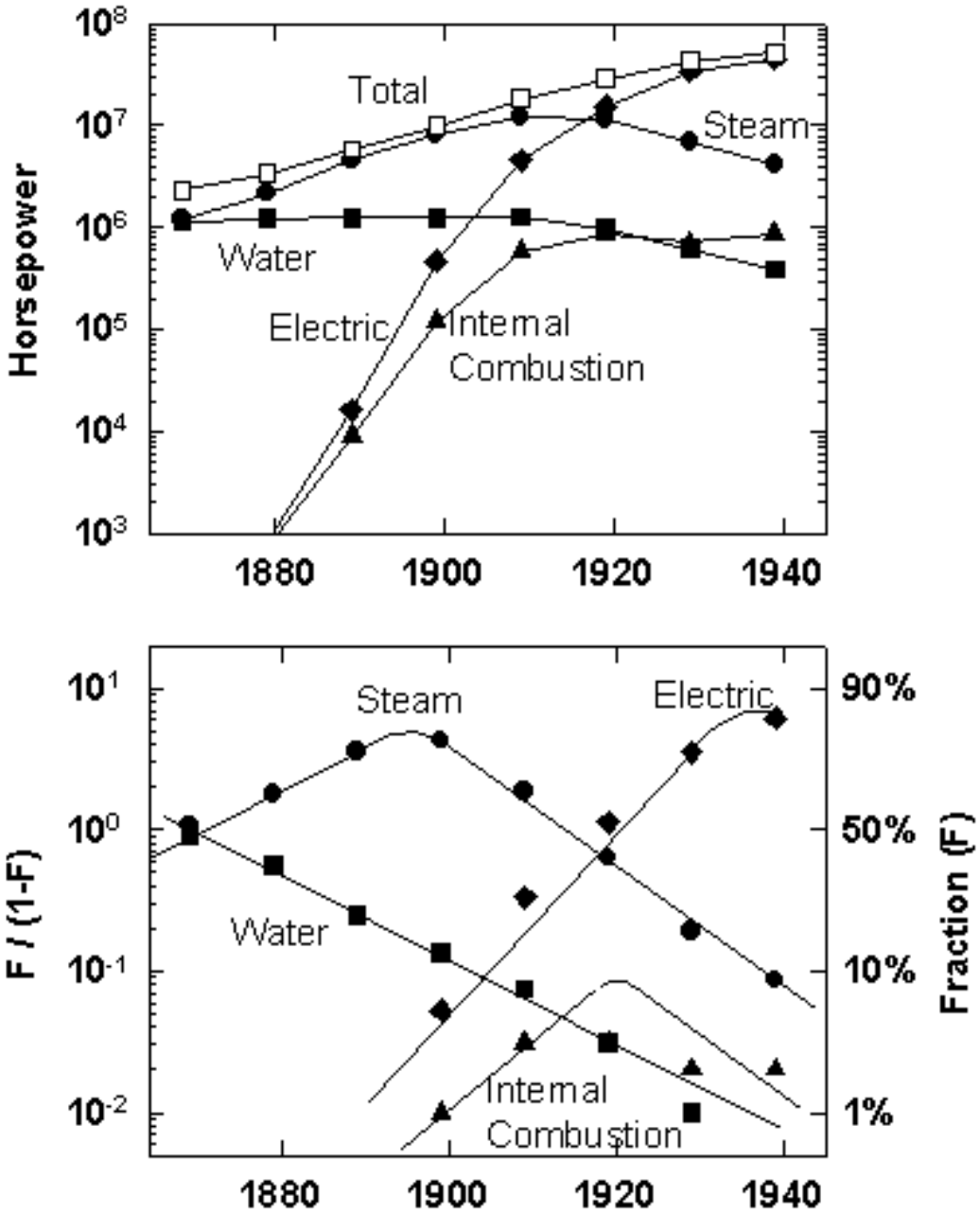
Newcomen's steam engine, 1712
Watt's improvement, 1769
1st gas turbine, 1791
1st internal combustion engine, 1794
1st battery (by Volta), 1800

Foundational inventors in late 1800's

Otto-Daimler-Maybach compression engine, 1876
1st commercial DC generator (Edison), 1870s
Incandescent lightbulb (Swan, Edison), 1878-9
1st commercial AC generator and motor (Tesla), 1880s
First commercial power station (AC), 1883
Parson's steam turbine, 1884
Turbine driven generators, 1890s

Nearly all the modern energy system developed between 1880-1910

Still took ~50 years for electricity to dominate



Sources of Power for Mechanical Drives in the United States.

From:
Ausubel, J., "*Elektron*: Electrical Systems in Retrospect and Prospect", *Daedalus* 125(3): 139-169,1996.

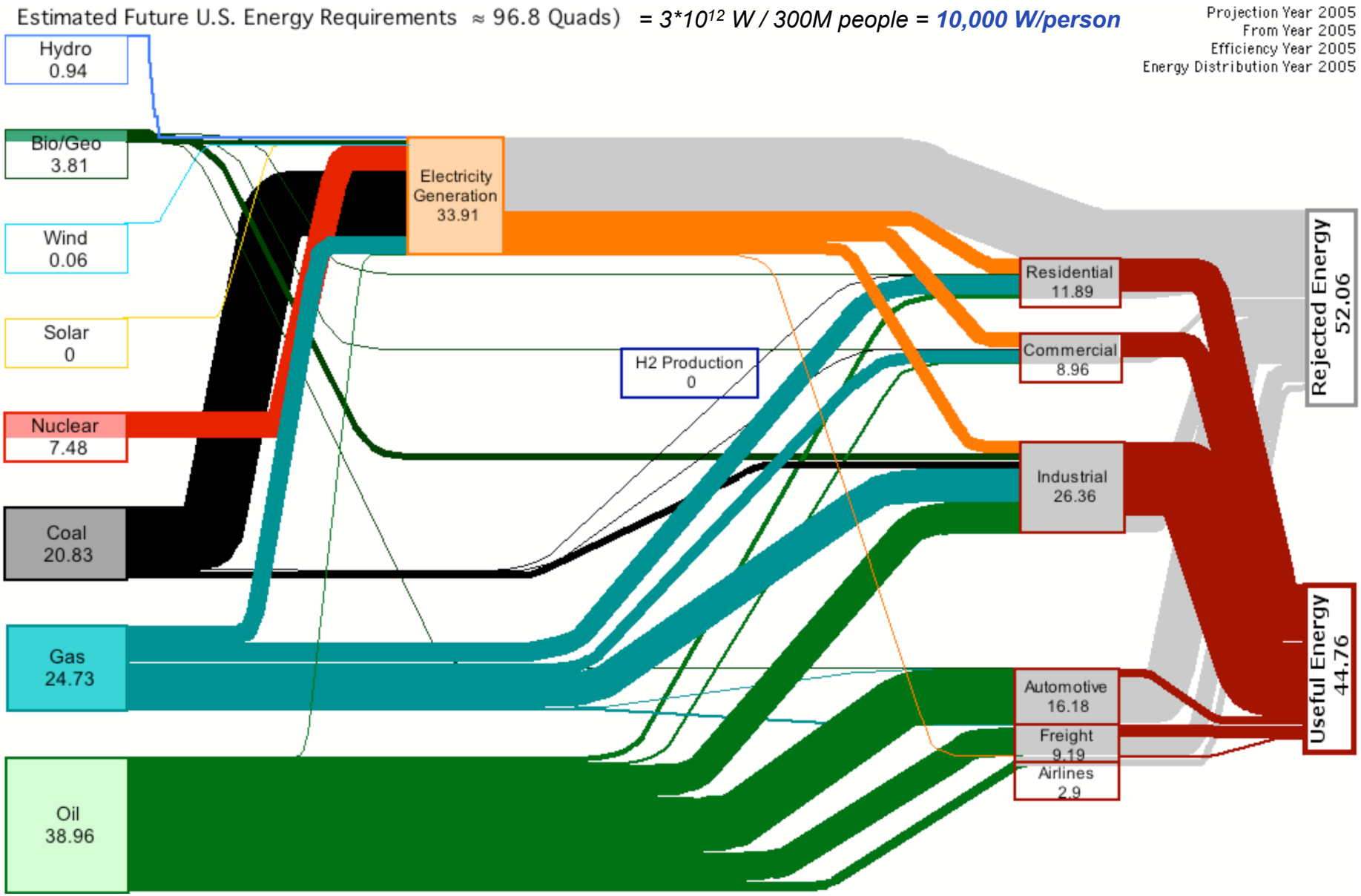
Data Source: Warren D. Devine, Jr., "From Shafts to Wires: Historical Perspective on Electrification," *Journal of Economic History* 43 (1983): 347_372; Table 3, p. 351.

Current energy system?

- Primary sources
- Uses

U.S. energy use, 2005

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



Energy conversion grid

FROM ↓ / TO →	ELECTRO-	KINETIC	HEAT	CHEMICAL	RADIATION	NUCLEAR	Stored Kinetic: GRAV. POT	Stored Kinetic: "ELASTIC"	Stored Heat: LATENT
ELECTRO-	wire, capacitor	electric motor	elect. heater, lightbulb filament	Al smelting, battery charging, electrolosis	fluorescent light, LEDs, lasers, x-ray production	particle generator			
KINETIC	generator	water wheel (turbine), belt, windmill, flywheel	brake, refrigerator, AC, heat pump	butter churning	triboluminescence (light from friction)		pumped hydro / dam release	compressed air storage, springs, hydraulics	
HEAT	thermocouple	heat engine, steam turbine, gas turbine	working fluid	fertilizer (N fixing), metal smelting, cemical synthe-sis,	incandescent lightbulb, candle, gas lamp, sun				swamp cooler, icebox, sweating
CHEMICAL	battery output	muscles	burning (in furnace, stove, steam boiler, etc.)	eating, lactation, fermentation	bioluminescence				
RADIATION	photovoltaics, CCD imaging	solar sails (for spacecraft)	solar thermal, microwave cook, industrial lasers, surgical lasers	photosynthesis, x-ray imaging, film photogra-	optical fiber, light pipe				
NUCLEAR	nuclear decay ; beta radiation		nuclear reactor, nuclear bomb, geothermal, sun		nuclear decay ; gamma radiation	isotope or element generation (e.g. U -> Pu)			