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)*

Extremely repetitive motions well suited to mechanization

*Source: unknown*
Textile production in England was first sector to be mechanized and led to major social disruption... home weaving could no longer compete, and rural livelihoods were cut off, forcing migration...
Rapid depopulation of countryside, move to cities

*1696: 1/10\(^{th}\) population urban / 1881: 70\% urban*

Textile production in England was first sector to be mechanized

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

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

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

![Graph showing percent of total employment by age and gender](image)

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

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

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

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

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 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.


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

<table>
<thead>
<tr>
<th>FROM \ TO \ ELECTRO-</th>
<th>KINETIC</th>
<th>HEAT</th>
<th>CHEMICAL</th>
<th>RADIATION</th>
<th>NUCLEAR</th>
<th>GRAV. POT</th>
<th>“ELASTIC”</th>
<th>STORED HEAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRO-</td>
<td>wire, capacitor</td>
<td>electric motor</td>
<td>elect. heater, lightbulb filament</td>
<td>Al smelting, battery charging, electrolysis</td>
<td>fluorescent light, LEDs, lasers, x-ray production</td>
<td>particle generator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KINETIC</td>
<td>generator</td>
<td>water wheel (turbine), belt, windmill, flywheel</td>
<td>brake, refrigerator, AC, heat pump</td>
<td>triboluminescence (light from friction)</td>
<td></td>
<td>pumped hydro / dam release</td>
<td>compressed air storage, springs, hydraulics</td>
<td></td>
</tr>
<tr>
<td>HEAT</td>
<td>thermocouple</td>
<td>heat engine, steam turbine, gas turbine</td>
<td>working fluid</td>
<td>fertilizer (N fixing), metal smelting, chemical synthesis,</td>
<td></td>
<td></td>
<td>swamp cooler, icebox, sweating</td>
<td></td>
</tr>
<tr>
<td>CHEMICAL</td>
<td>battery output</td>
<td>muscles</td>
<td>burning (in furnace, stove, steam boiler, etc.)</td>
<td>eating, lactation, fermentation</td>
<td></td>
<td>bioluminescence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RADIATION</td>
<td>photovoltaics, CCD imaging</td>
<td>solar sails (for spacecraft)</td>
<td>solar thermal, microwave cook, industrial lasers, surgical lasers</td>
<td>photosynthesis, x-ray imaging, film photography, optical fiber, light pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUCLEAR</td>
<td>nuclear decay; beta radiation</td>
<td>nuclear reactor, nuclear bomb, geothermal, sun</td>
<td></td>
<td>nuclear decay; gamma radiation</td>
<td></td>
<td>isotope or element generation (e.g. U -&gt; Pu)</td>
<td></td>
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