Lecture 5
GEOS24705

Thermodynamics of heat engines

What is a "heat engine"?

A device that generates converts thermal energy to mechanical work by exploiting a temperature gradient

- **Makes something more ordered**: random motions of molecules → ordered motion of entire body

- **Makes something less ordered:** degrades a temperature gradient (transfers heat from hot to cold)

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

First true steam engine:

Thomas Newcomen, 1712, blacksmith

Copy of Papin's engine of design of 1690, with piston falling as steam cooled, drawn down by the low pressure generated

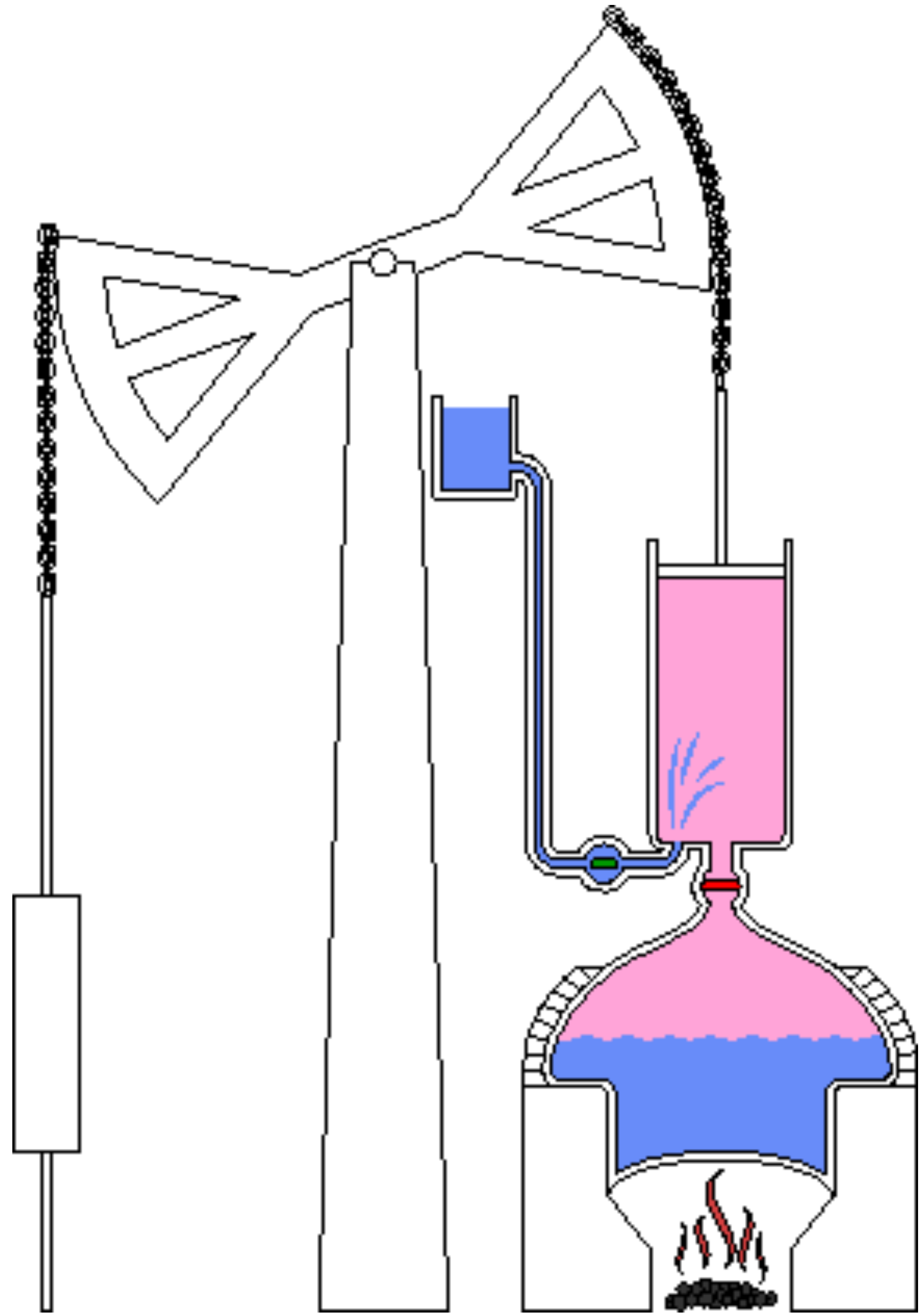
First ***reciprocating engine***: force transmitted by motion of piston

Can pump water to arbitrary height.

Force only on downstroke of piston

Very low efficiency: 0.5%

Intermittent force transmission



Newcomen's design is state of the art for 60+ years

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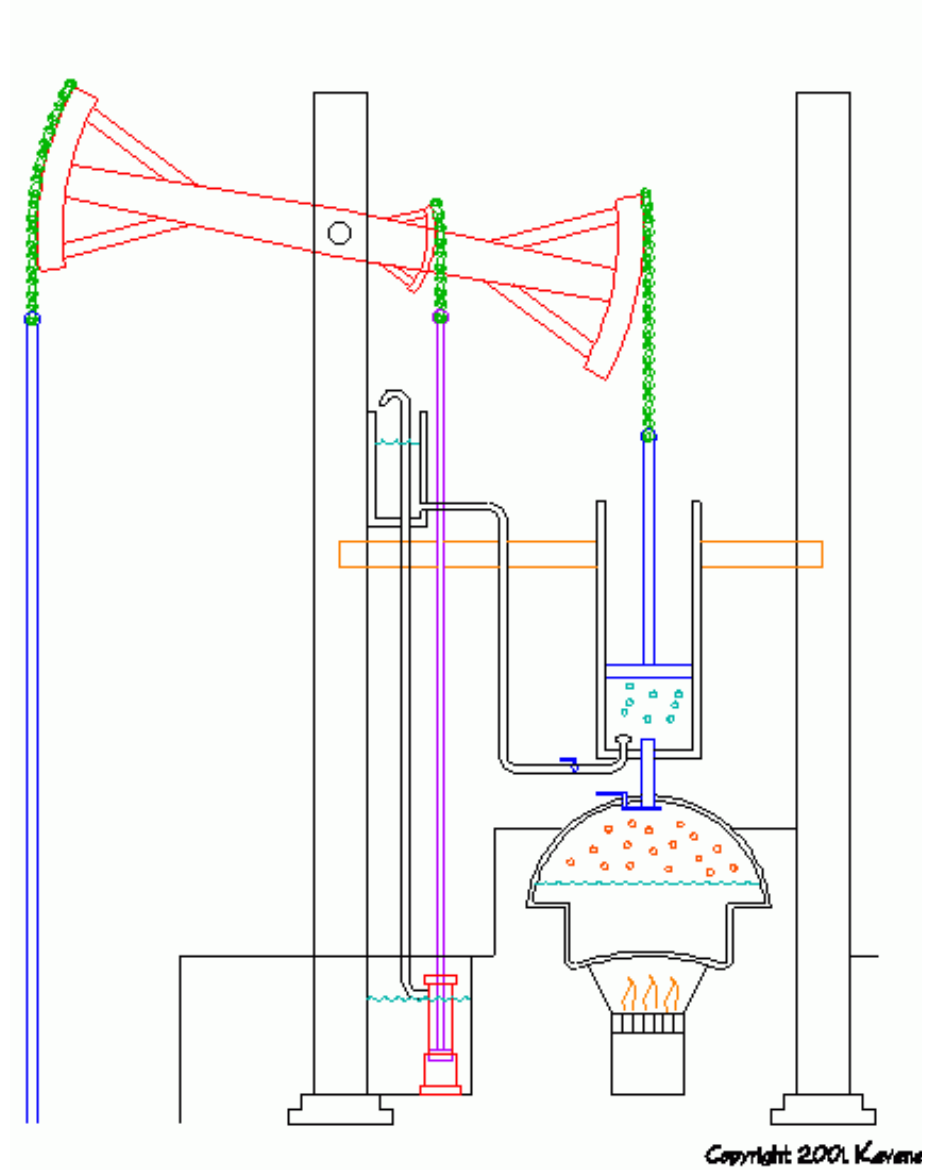
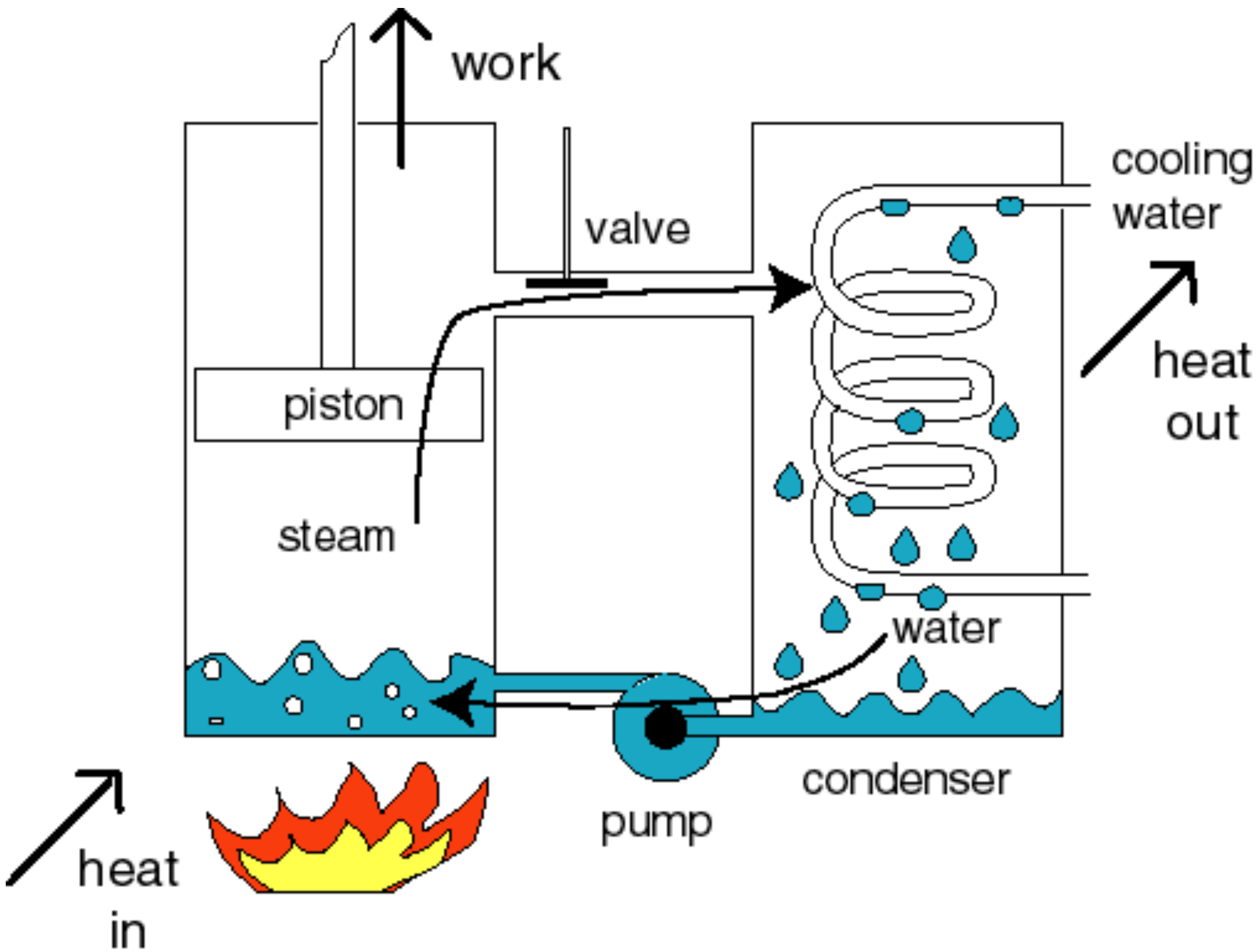
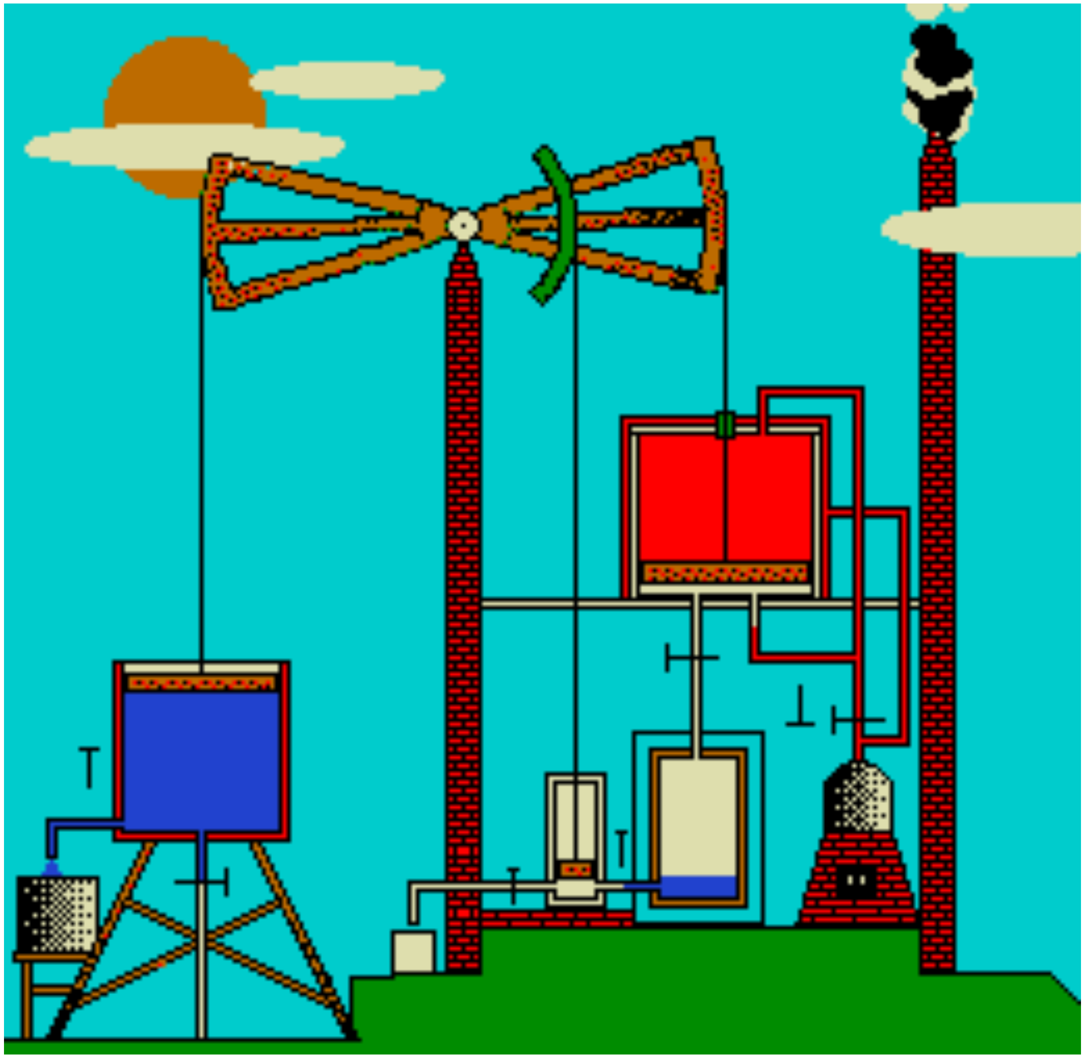


Newcomen's design is state of the art for 60+ years

First modern steam engine:

James Watt, 1769 (patent), 1774 (prod.)
Higher efficiency than Newcomen by introducing separate condense
Reduces wasted heat by not requiring heating and cooling entire cylinder





First modern steam engine:

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Higher efficiency than Newcomen by introducing separate condenser

First modern steam engine:

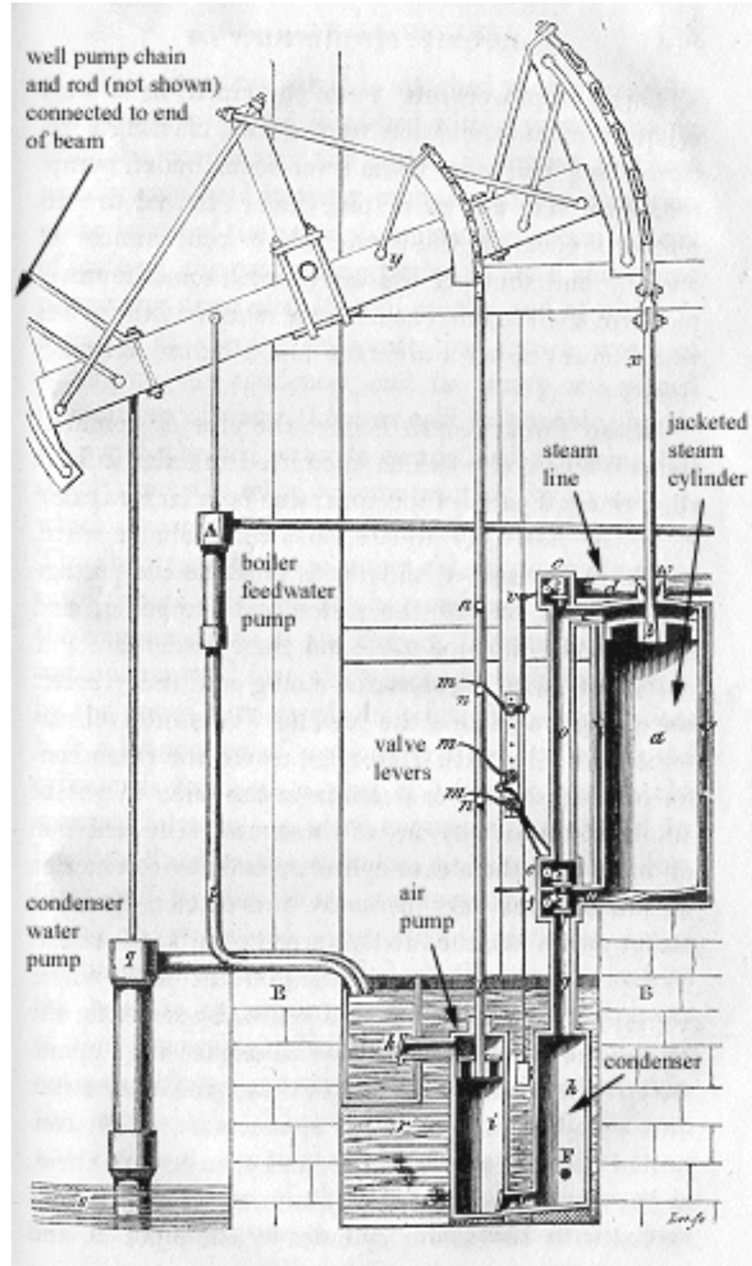
James Watt, 1769 patent
(1774 production model)

Like Newcomen engine only with separate condenser
Higher efficiency: 2%

Force only on downstroke of piston

Intermittent force transmission

No rotational motion



Improved Watt steam engine:

James Watt, 1783 model
Albion Mill, London

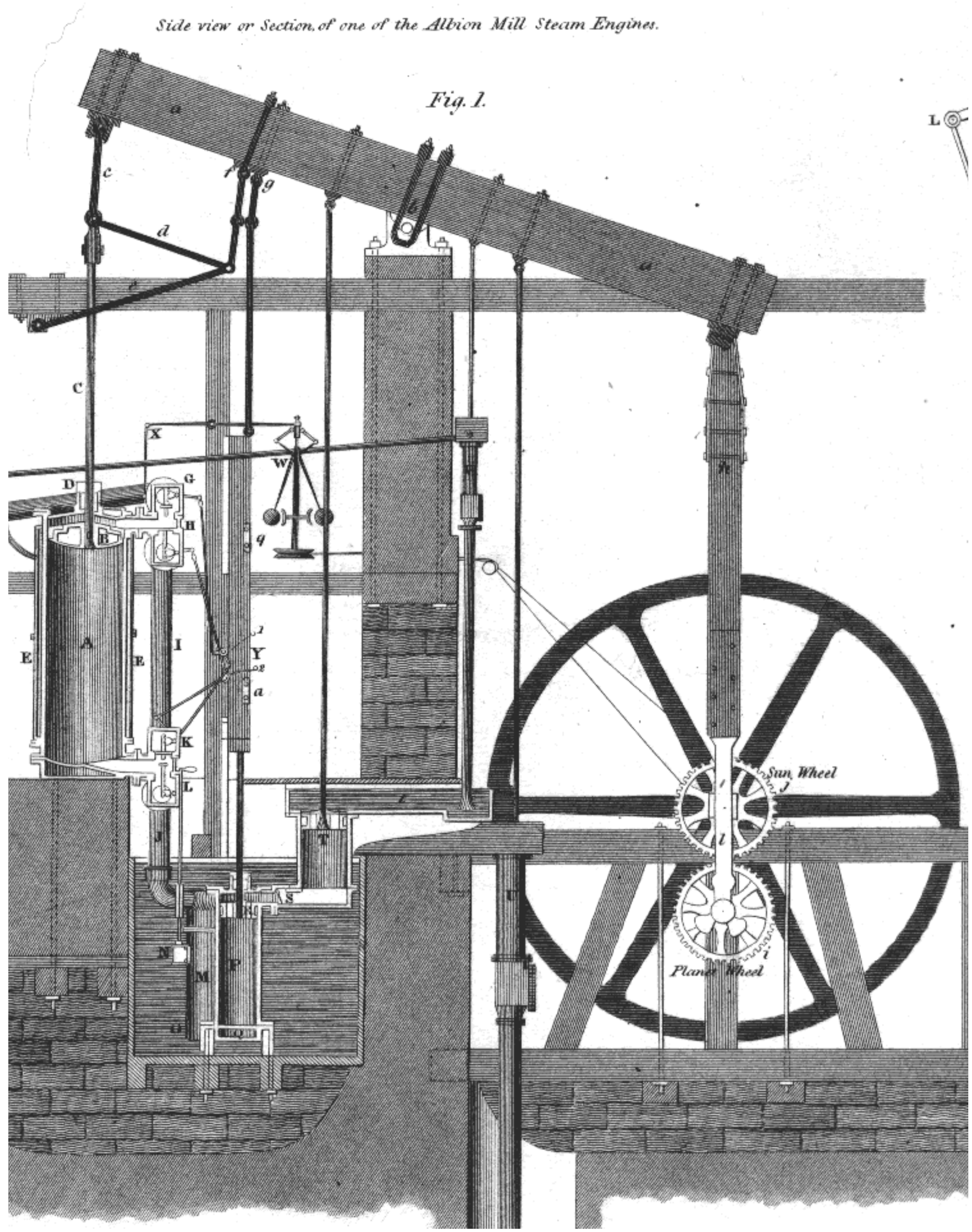
Separate condenser
Higher efficiency: ca. 3%

Force on both up- and downstroke

Continuous force transmission

Rotational motion
(sun and planet gearing)

Engine speed regulator



Steam engines got more powerful AND more efficient over time

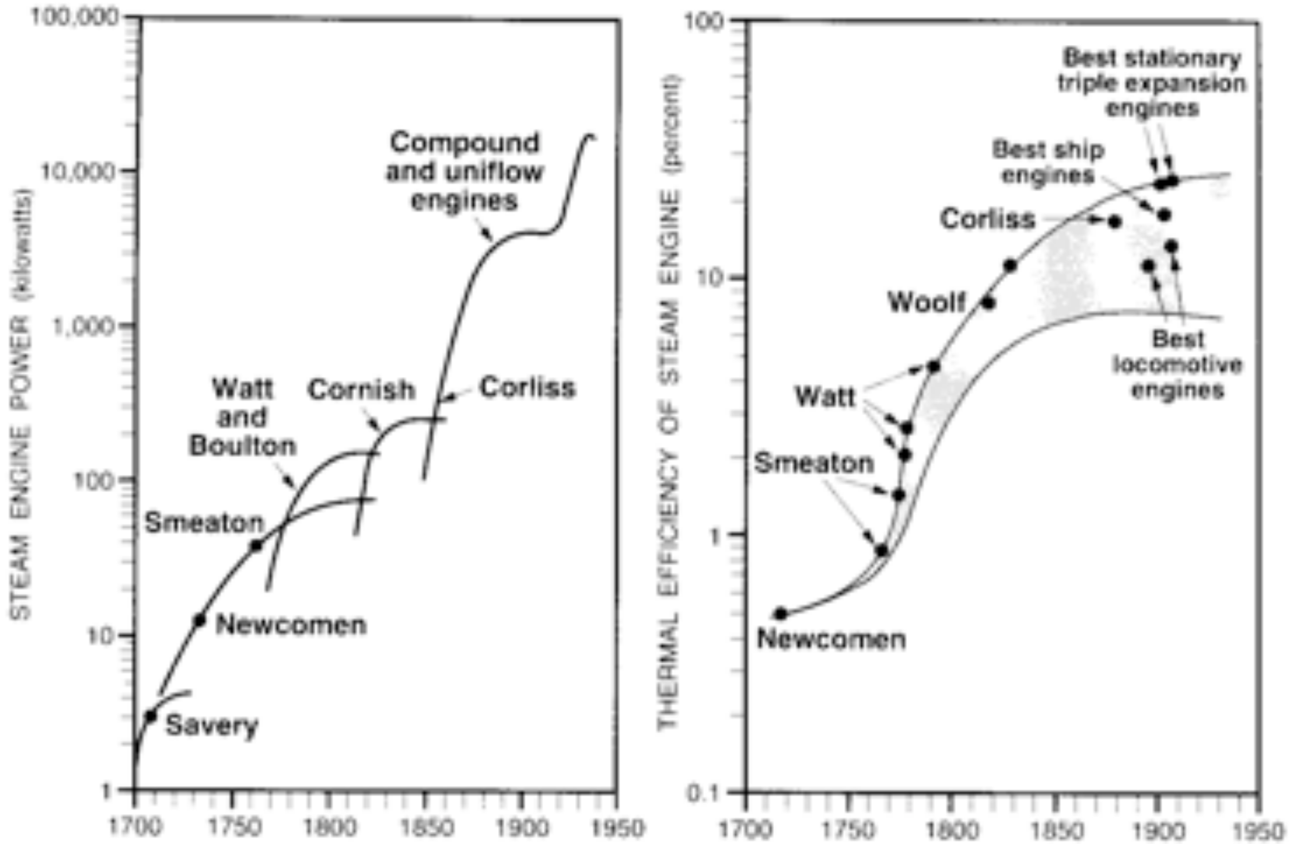


FIGURE 5.3 The rising power and improving efficiency of the best steam engines, 1700–1930. *Sources:* Plotted from data in Dickinson (1939) and von Tunzelmann (1978).

From V. Smil

How were both accomplished?

POWER

- More pressure
- Bigger cylinders
- More cylinders

EFFICIENCY

- Removing obvious losses
- Higher temperatures

Pressure and temperature are related for steam

Prince Consort Beam engine (world's largest steam engine)

Prince Consort Beam engine

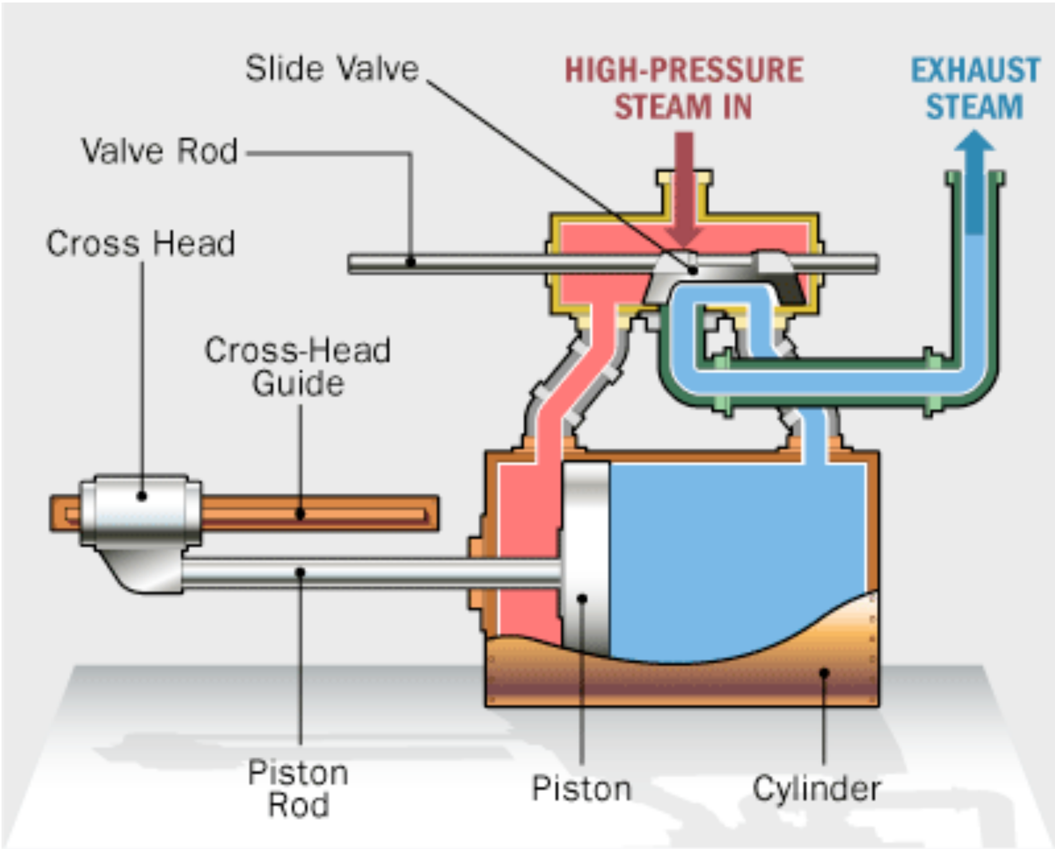
Beam engine train (see 6:20)

Double-action steam engine:

Why use suction to pull the piston down – why not just push it down with another injection of steam?

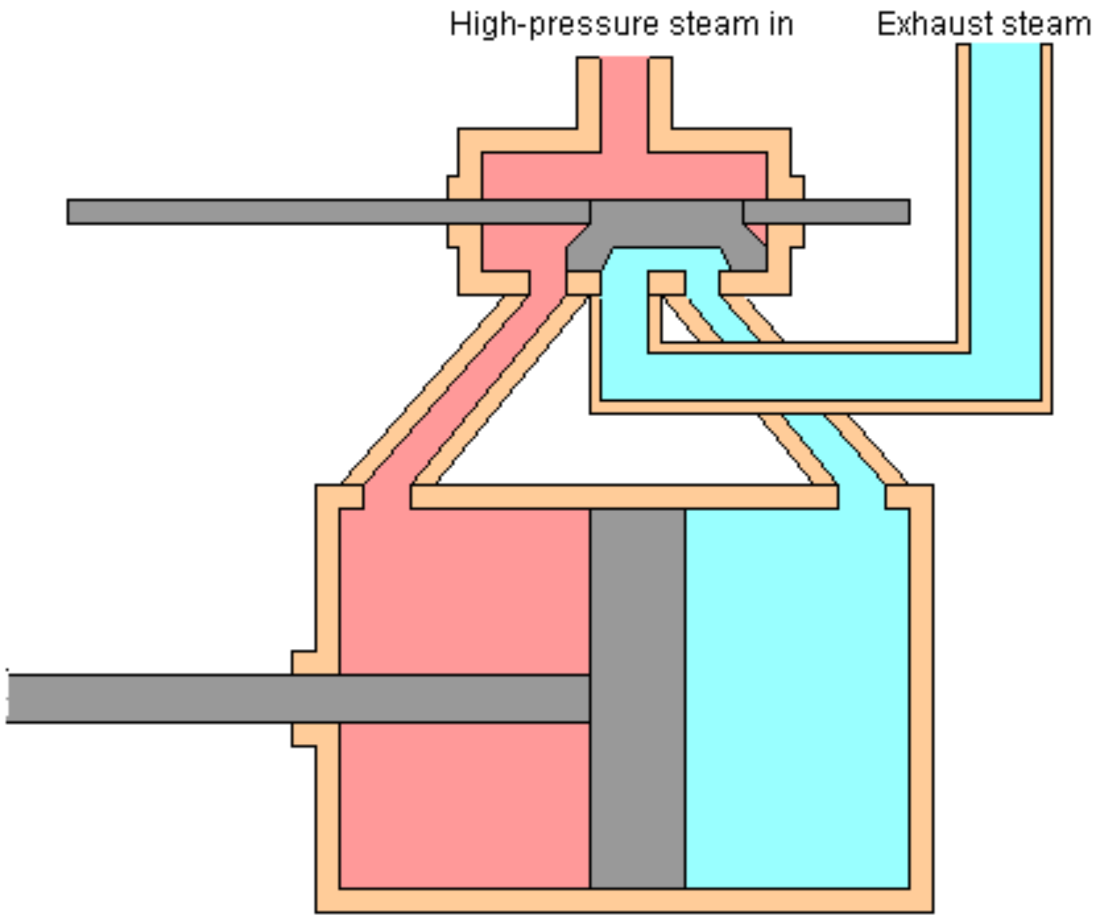
Piston pushed by steam on both up- and down-stroke.

No more need for a condenser. Steam is simply vented at high temperature



slide valve alternates input & exhaust

Double-action steam engine:



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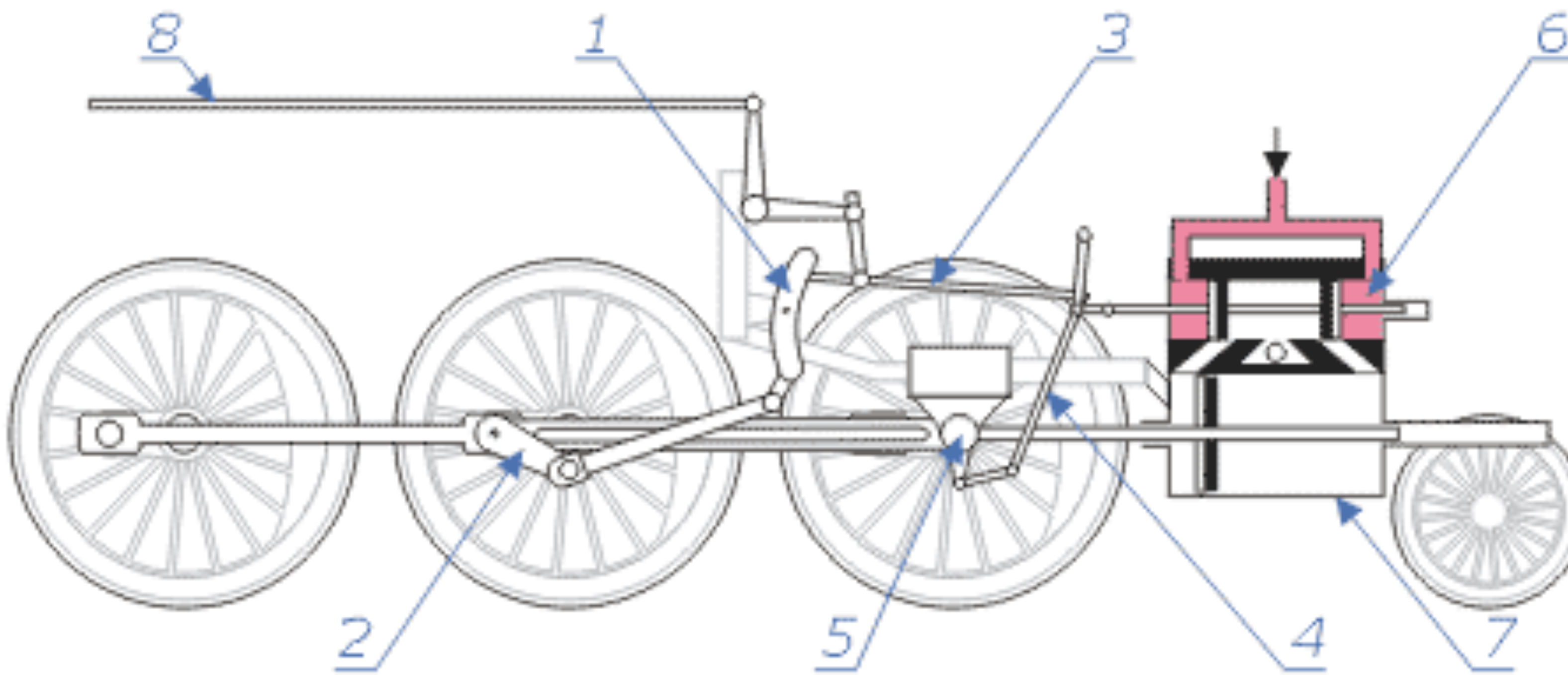

primary use: *transportation*

Indicator diagrams told engineers how much work a cylinder put out on each stroke