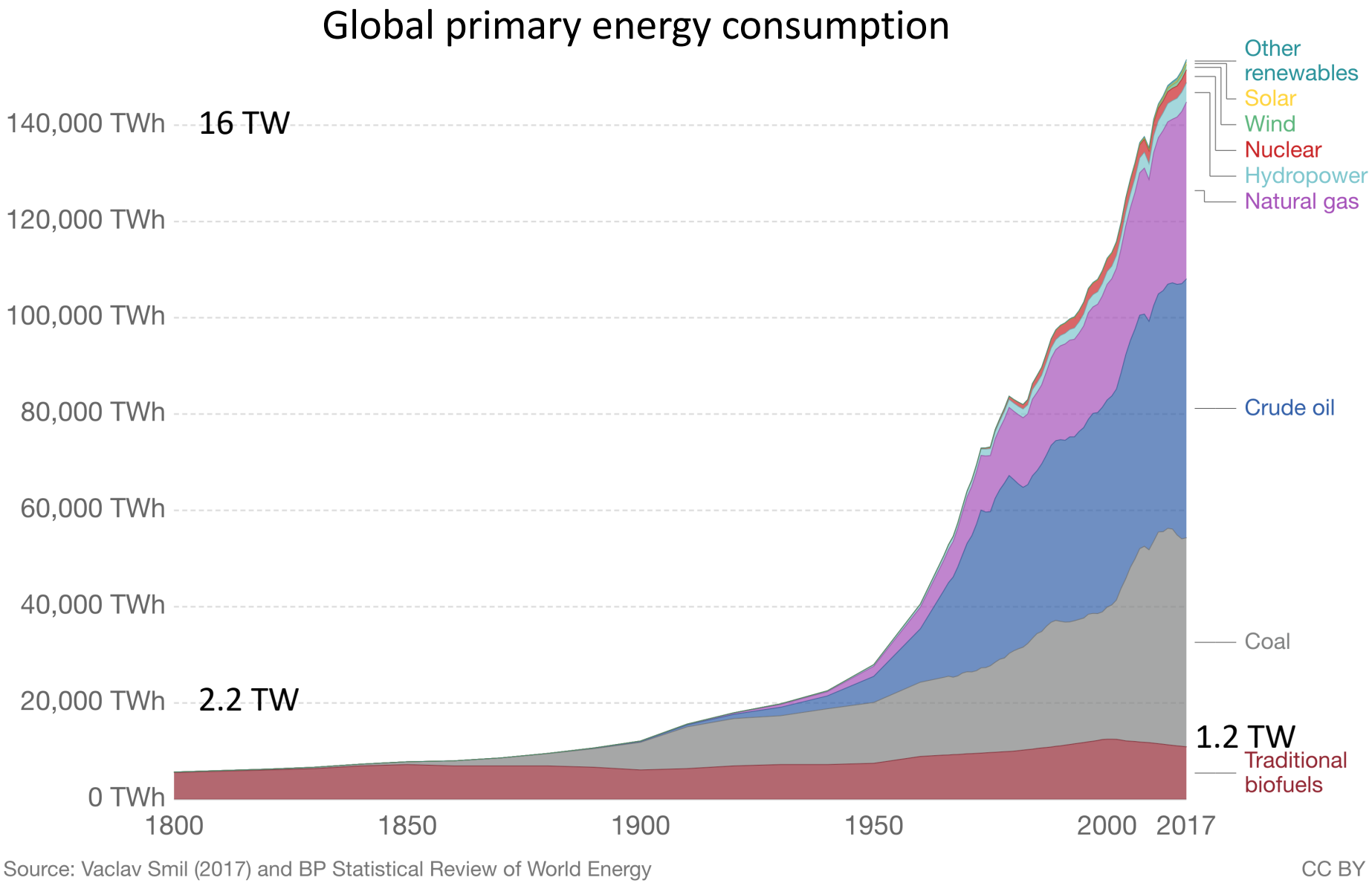
GEOS 24750
Humans in the Earth System

2019

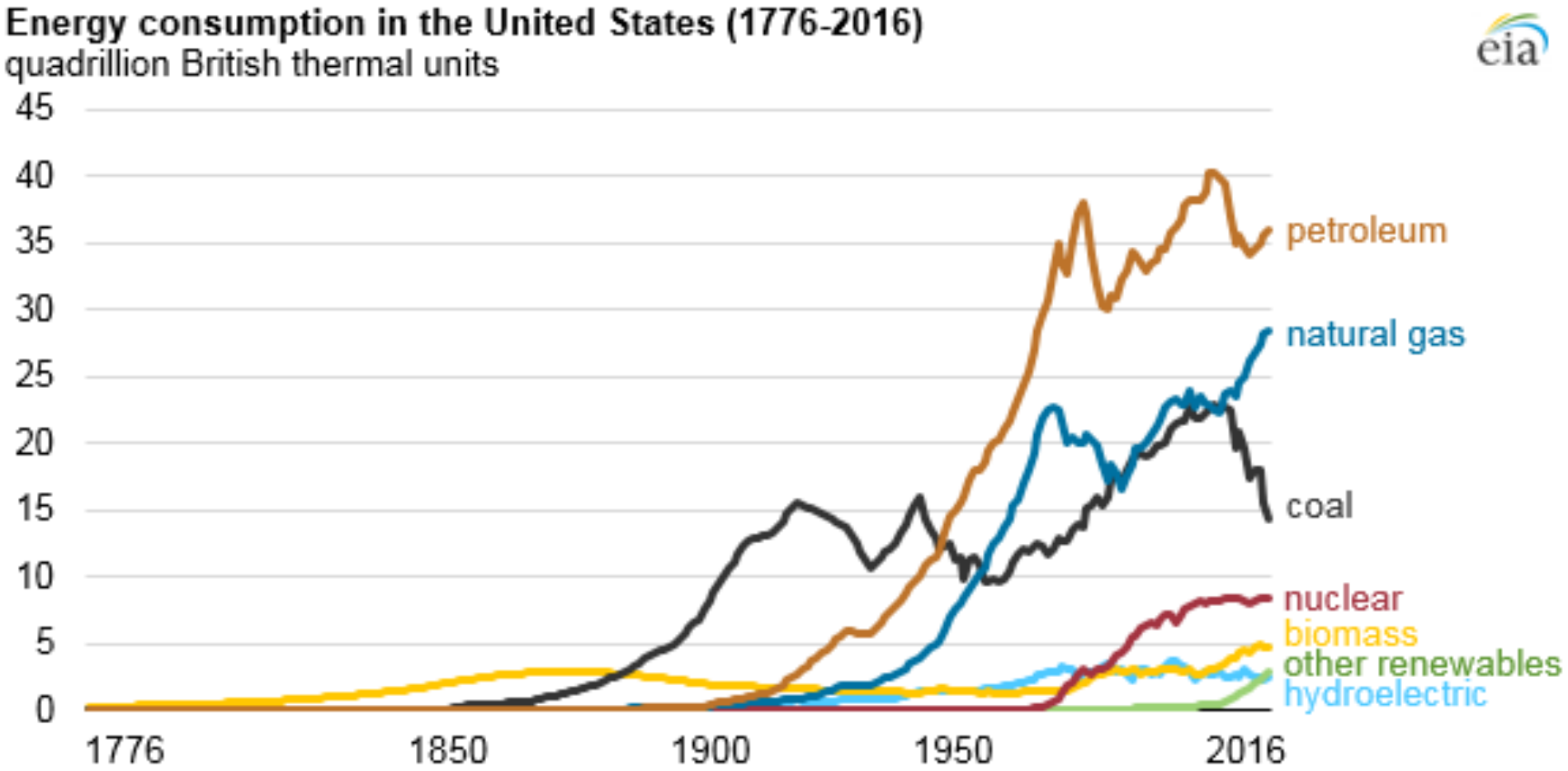
Liz Moyer

Lecture 10

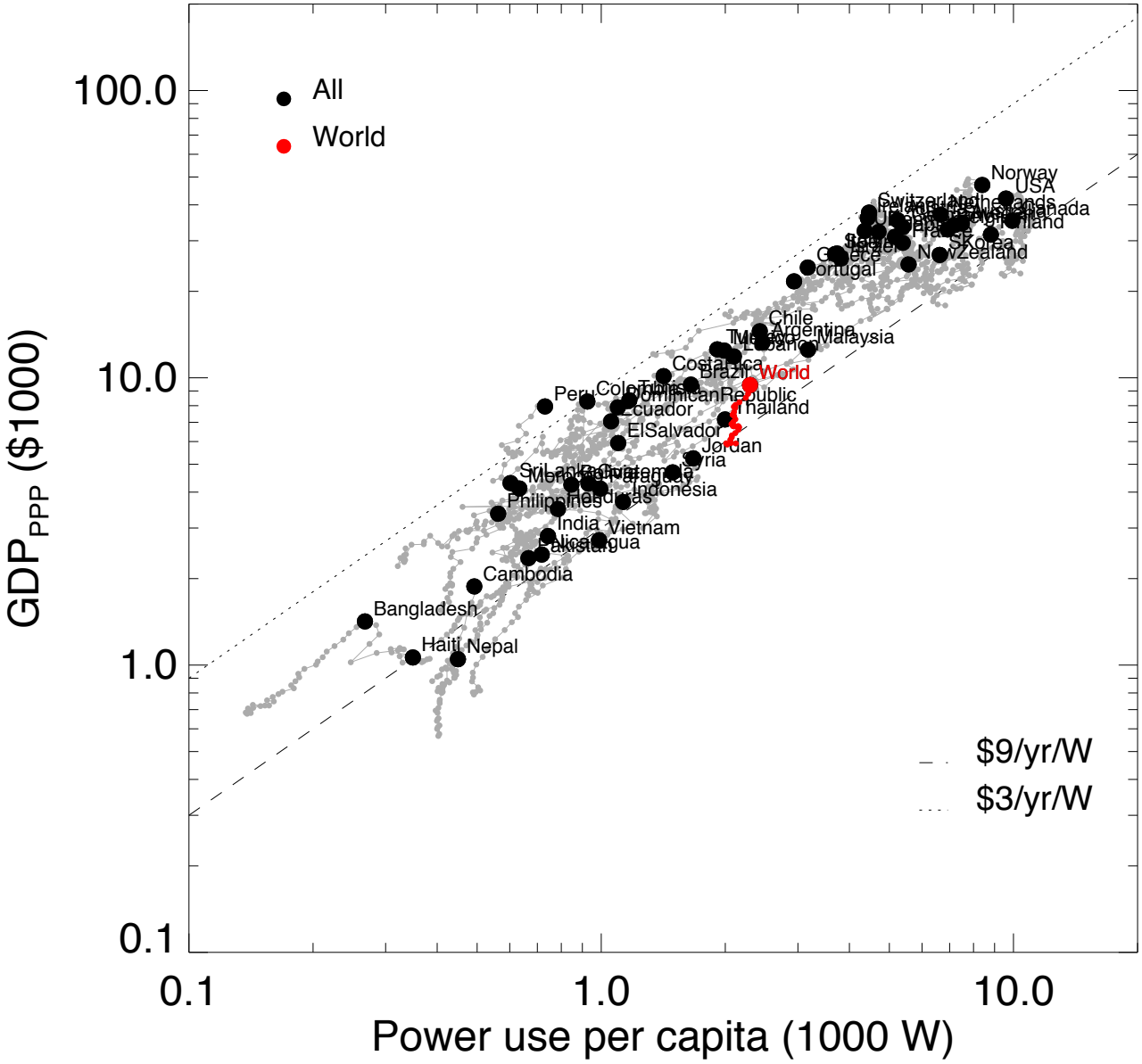
Change in energy use from Braudel's time to present



Change in energy use for U.S.



Wealth is strongly predicted by energy use



Sample shown: all countries other than

- < 4M pop.
- major oil producers
- former Soviet Union or East bloc or China
- sub-Saharan Africa

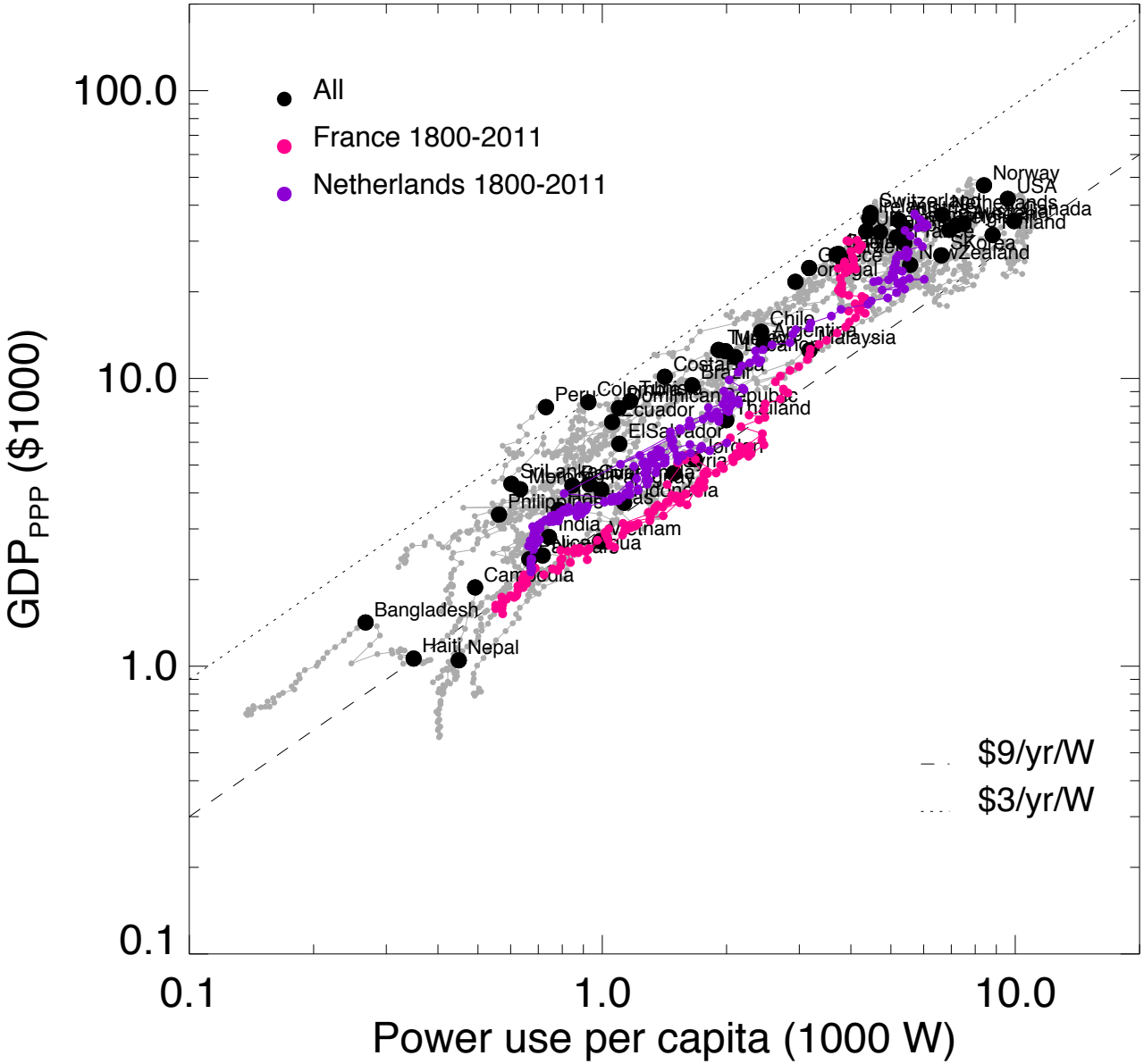
Energy use is ***total primary energy usage*** (not just electricity), in common units of Watts per person.

For these "normal" countries, energy use predicts GDP to x3 *lines $3-9/yr GDP / Watt*

Relationship holds across countries and across time for a given country, over x 100

Data: World Bank, ~1960-2011, 2005 USD

Relationship extends to Industrial Revolution



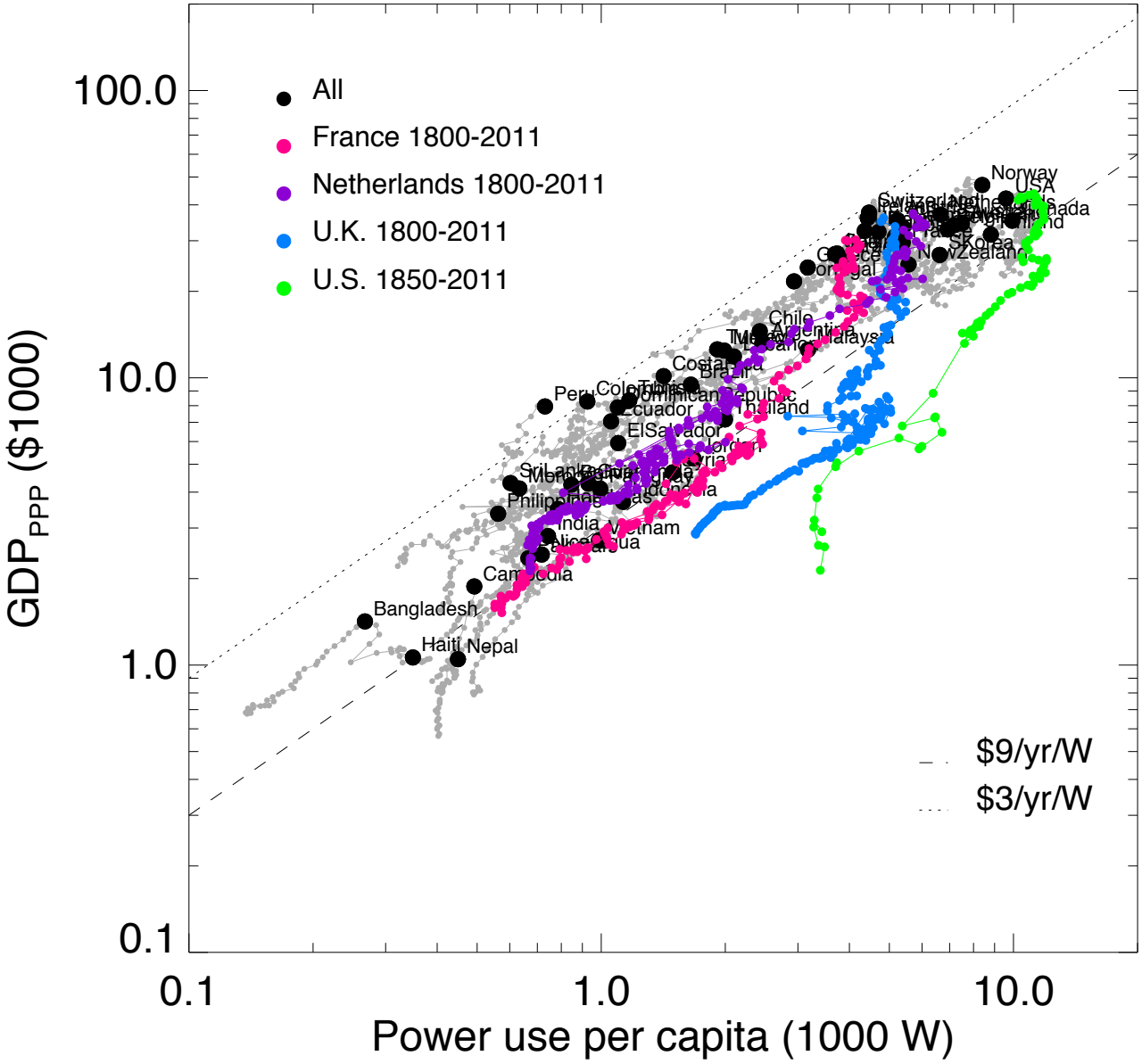
France and the Netherlands grew by x 10 from 1800-1900 and energy usage increased correspondingly.

In last few decades wealth has risen without much change in energy use. (This is common in high-income countries.)

Data:
World Bank, ~1960-2011 2005 USD

www.energyhistory.org, converted to 2005 USD

U.S. initially “wasteful”



1800-1900 Britain: doubling energy = doubling wealth.

Both Britain (and U.S.) historically were “wasteful” energy users – excess energy used per GDP – and are more “normal” now.

U.S. note: one datapoint per 10 years til 1949

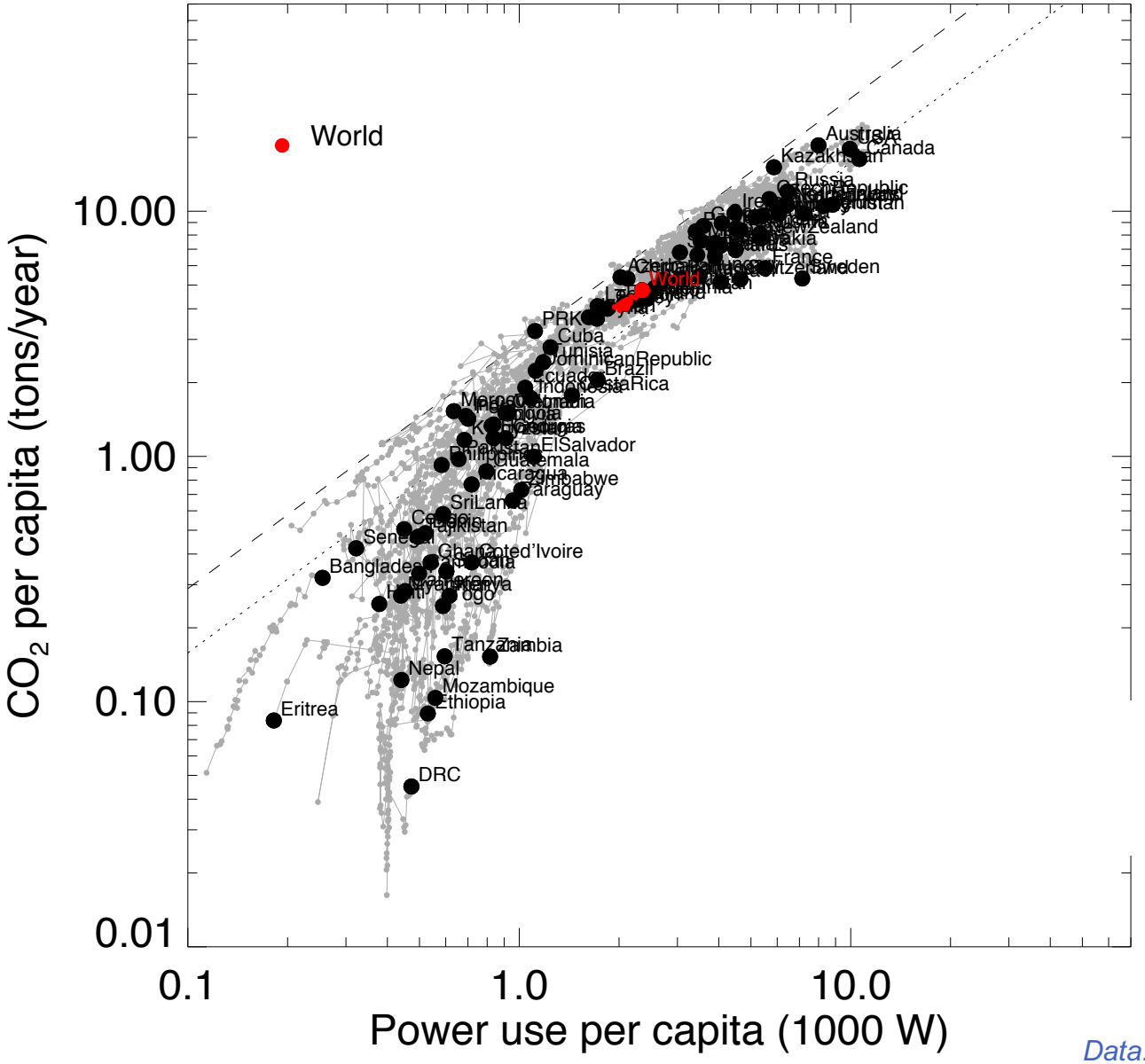
Data:
World Bank, ~1960-2011 2005 USD

www.energyhistory.org, converted to 2005 USD

U.S. data from EIA

All developed countries are fossil-fuel dependent

CO_2 to energy relationship is tightly constrained

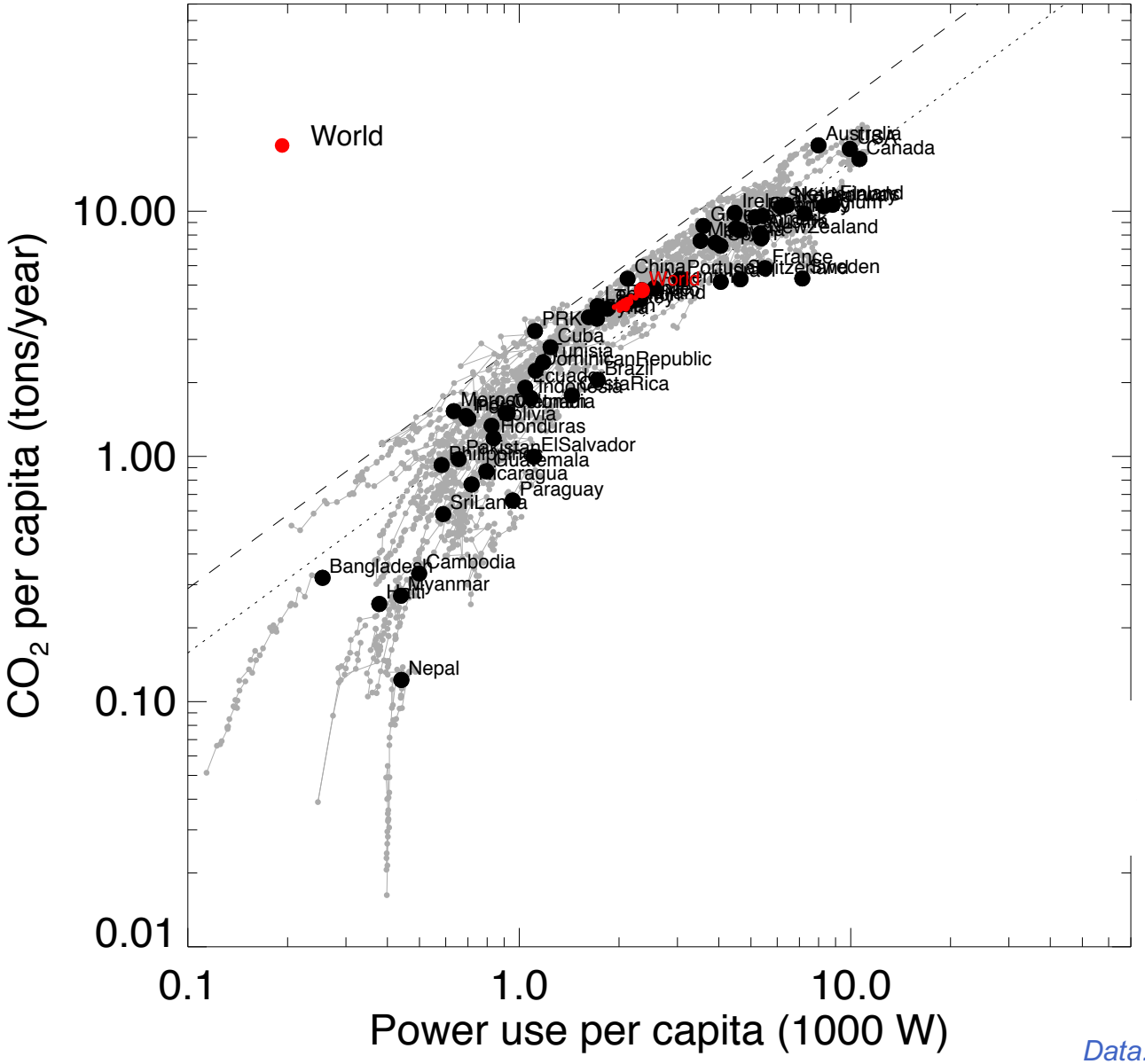


Data here includes all countries, not restricted set from before.

Data: World Bank, ~1960-2011 2005 USD

All developed countries are fossil-fuel dependent

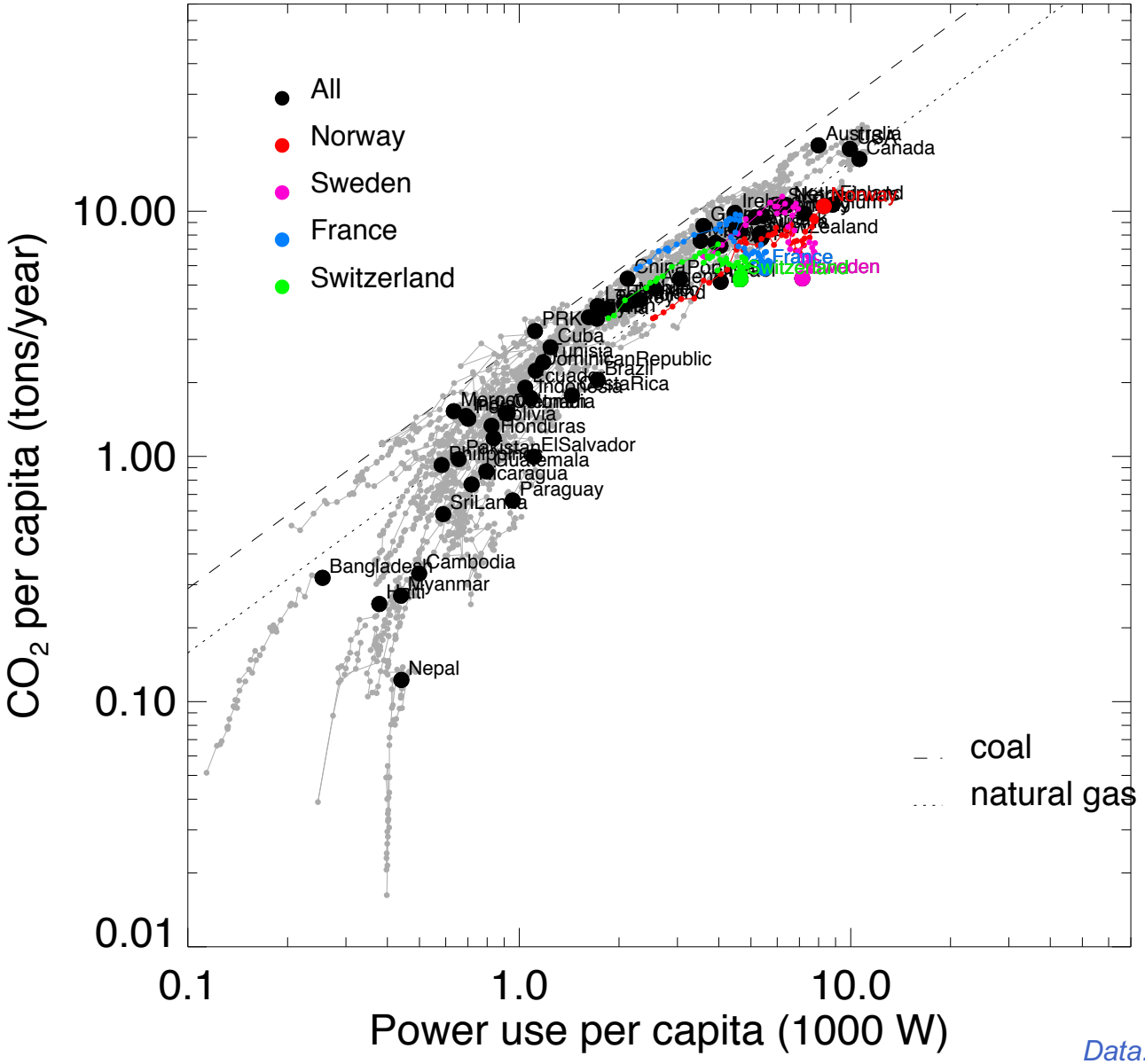
CO_2 to energy relationship is tightly constrained



Data is now (here and in future plots) restricted to same sample as in previous plots of GDP vs energy use.

Data: World Bank, ~1960-2011 2005 USD

Only a few wealth countries have low CO_2/energy



Data: World Bank, ~1960-2011 2005 USD

The 18th century European energy crisis has 3 parts

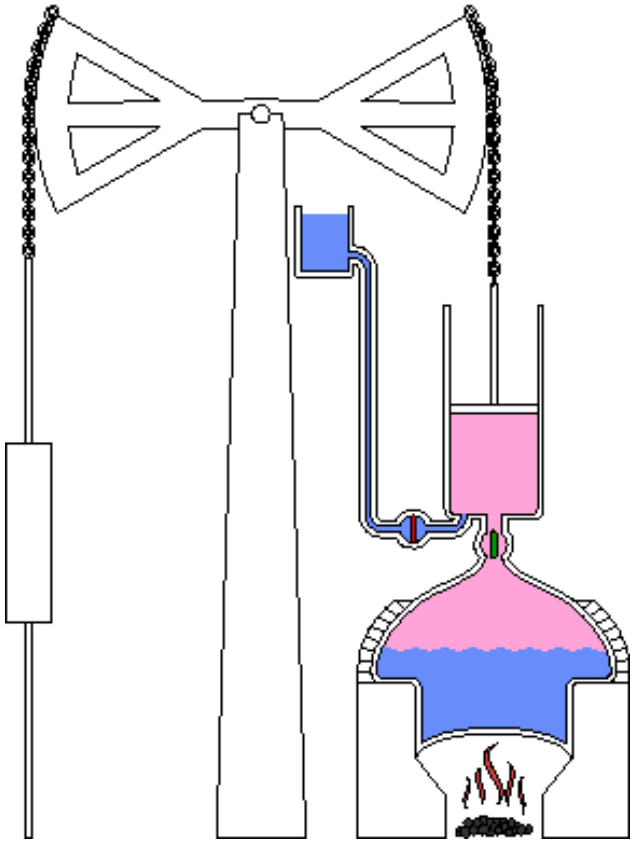
1. **Fuel became scarce even when only used for heat**
   Wood was insufficient, & coal was getting hard to extract
   Surface "sea coal" → deep-shaft mining below the water table

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.

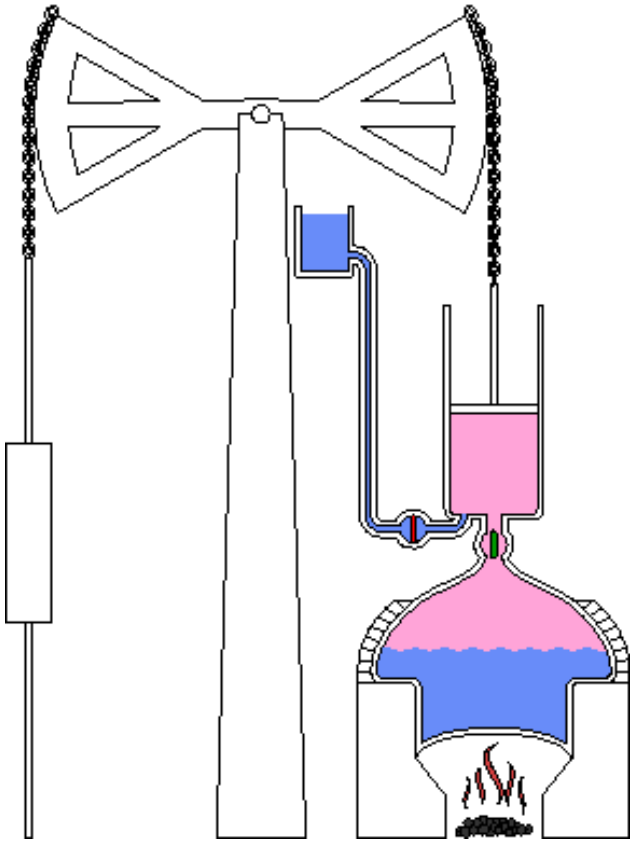
The revolutionary solution = break the heat → work barrier



the invention of the heat engine allows today's fossil-fuel-powered society

The revolutionary solution = break the heat → work barrier

use heat to make ordered motion



Newcomen "Atmospheric Engine", 1712

(Note that widespread use & Industrial Revolution followed invention by ~100 years – typical for energy technology)

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)

Process is necessarily inefficient, by 2nd law of thermodynamics

First true steam engine:

Thomas Newcomen, 1712, blacksmith

First ***reciprocating engine***: linear motion of piston that transmits force

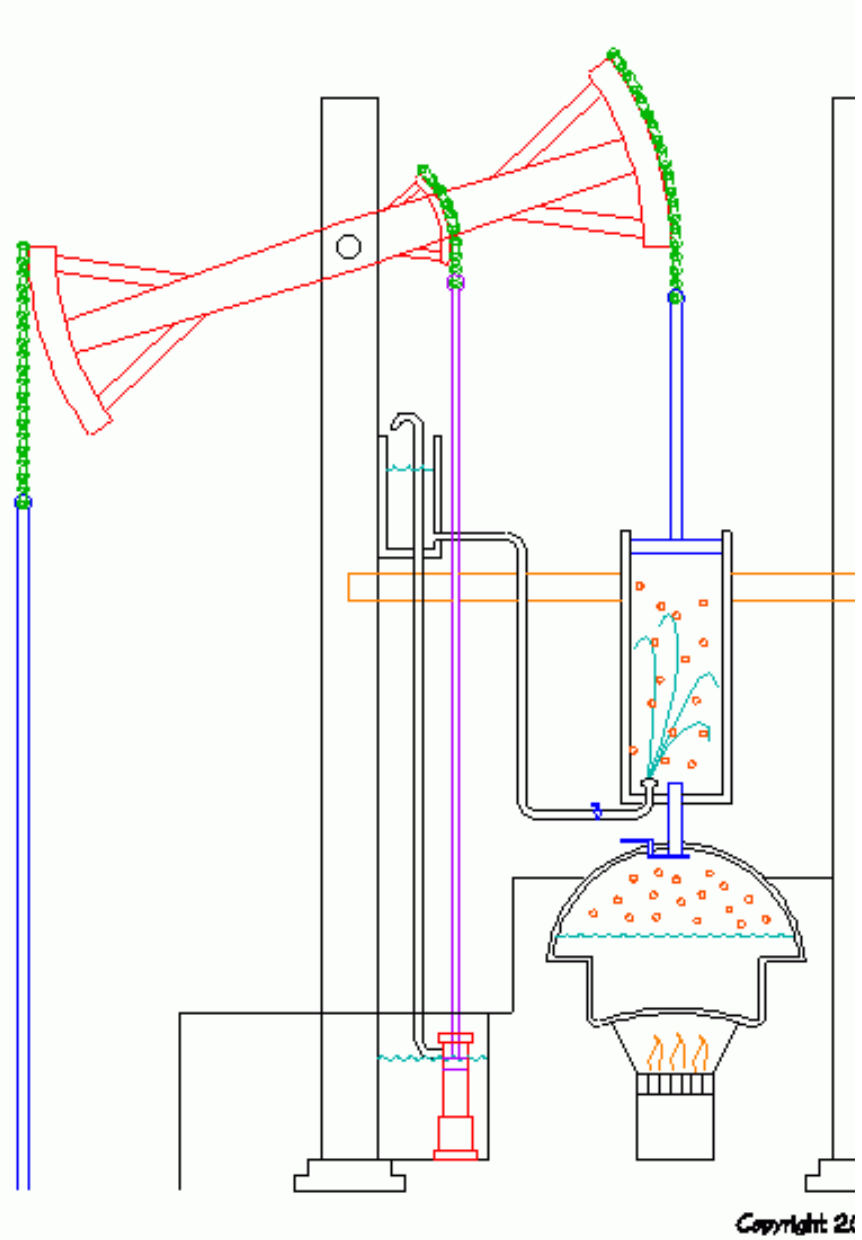
Steps

1 Fill chamber with steam
2 Cool the chamber to condense steam
3 Low chamber pressure pulls piston down
4 Open valve at bottom of piston, let gravity pull pump side down again
..... Steam fills chamber as piston rises

Issues:

Very low efficiency: 0.5%

Intermittent force transmission



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

Newcomen engines wasteful but built for 100 years

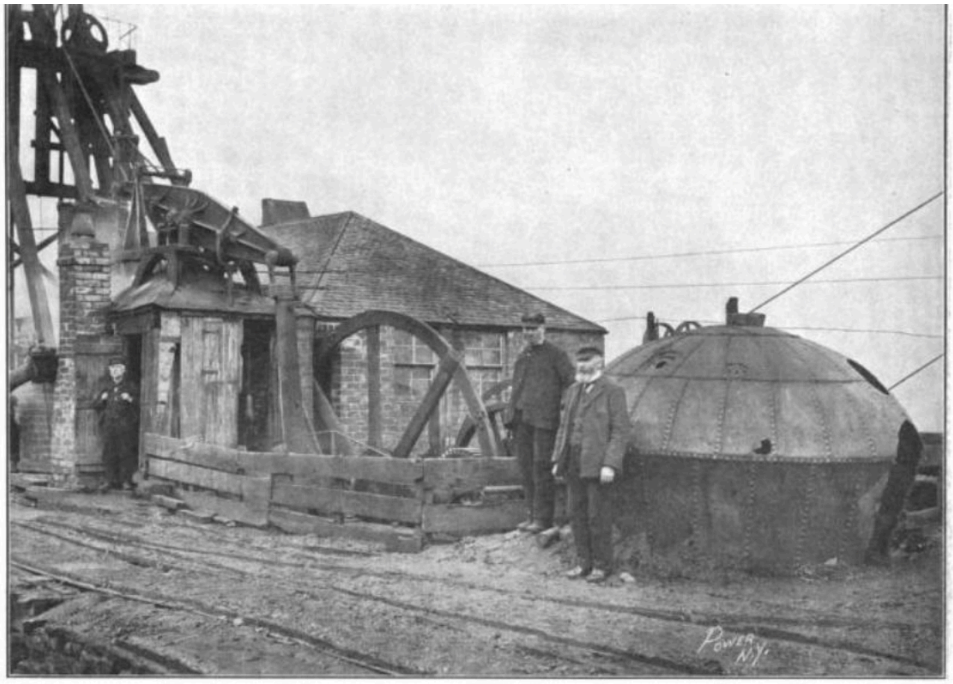
First Newcomen engine
(1712, Dudley Castle)

(reproduction)

video: https://www.youtube.com/watch?v=HC6LUWSBXjk

video: https://www.youtube.com/watch?v=QltRwiu4U2Q

Last Newcomen engine
(1810 – 1923, Farme Colliery)



manually operated valves
used for lifting coal, not pumping

Fig. 4. *Newcomen Engine at Ashton Vale Iron Works, Bristol.*

From a Sketch made in September, 1895. Erected about 1746-60. Dismounted 1900.

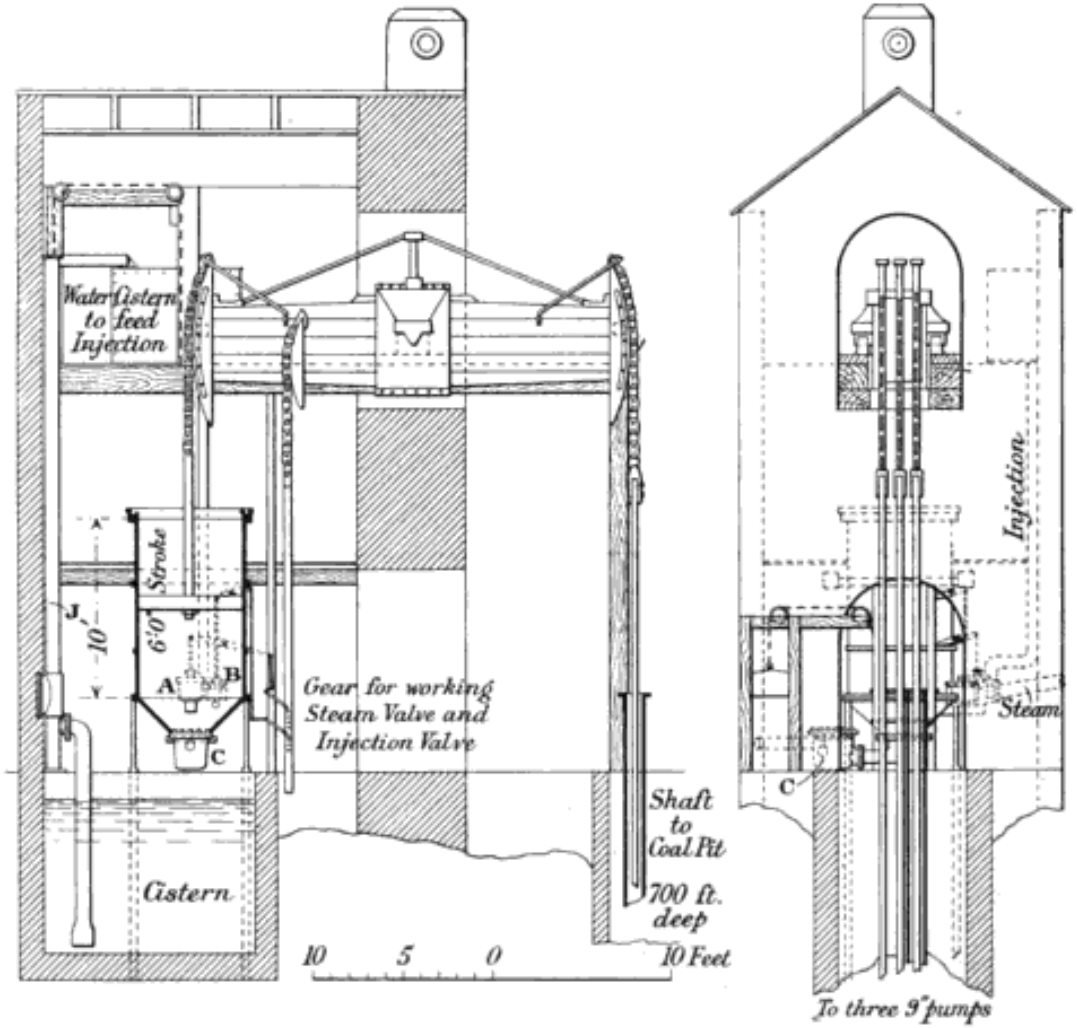


Fig. 5. *Indicator Diagram taken from above Engine, 27th May, 1895.*

Dia. of Cyl. 5' 6"
Stroke 6' 0" about
No. of Strokes per min. 10.

Boiler Pressure 2·3 lbs.
Vacuum Gauge, none fixed.
Time 3 p.m.

Use Newcomen engine to begin to understand heat engine physics

Work = force x distance

= pressure x volume

from *Mechanical Engineers,* 1903

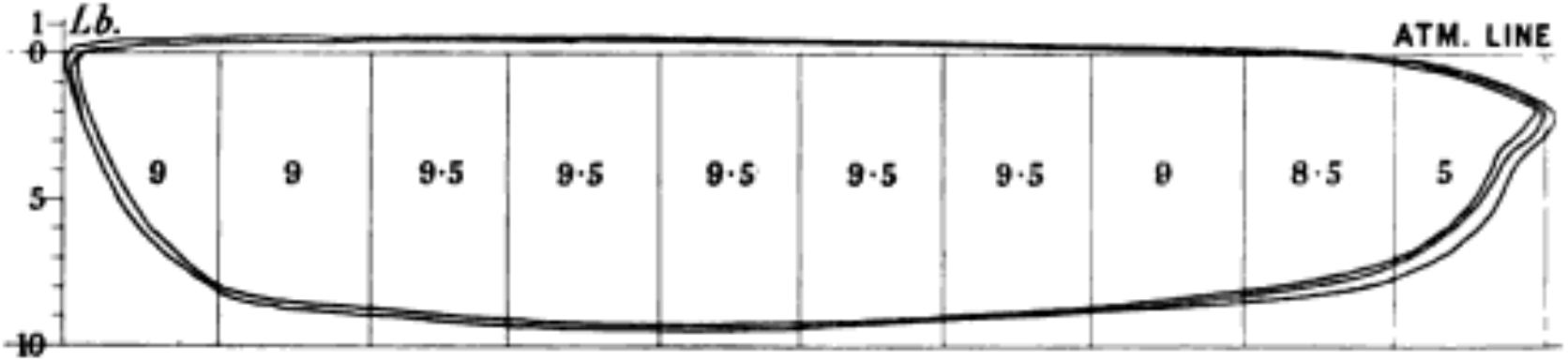
Indicator diagram tells you engine performance: *work done per stroke*

Aston Vale Newcomen engine, built 1746-60, measured 1895

Fig. 5. *Indicator Diagram taken from above Engine, 27th May, 1895.*

Dia. of Cyl. 5' 6"
Stroke 6' 0" about
No. of Strokes per min. 10.

Boiler Pressure 2·3 lbs.
Vacuum Gauge, none fixed.
Time 3 p.m.



from *Mechanical Engineers,* 1903

Gradual improvements in engine efficiency

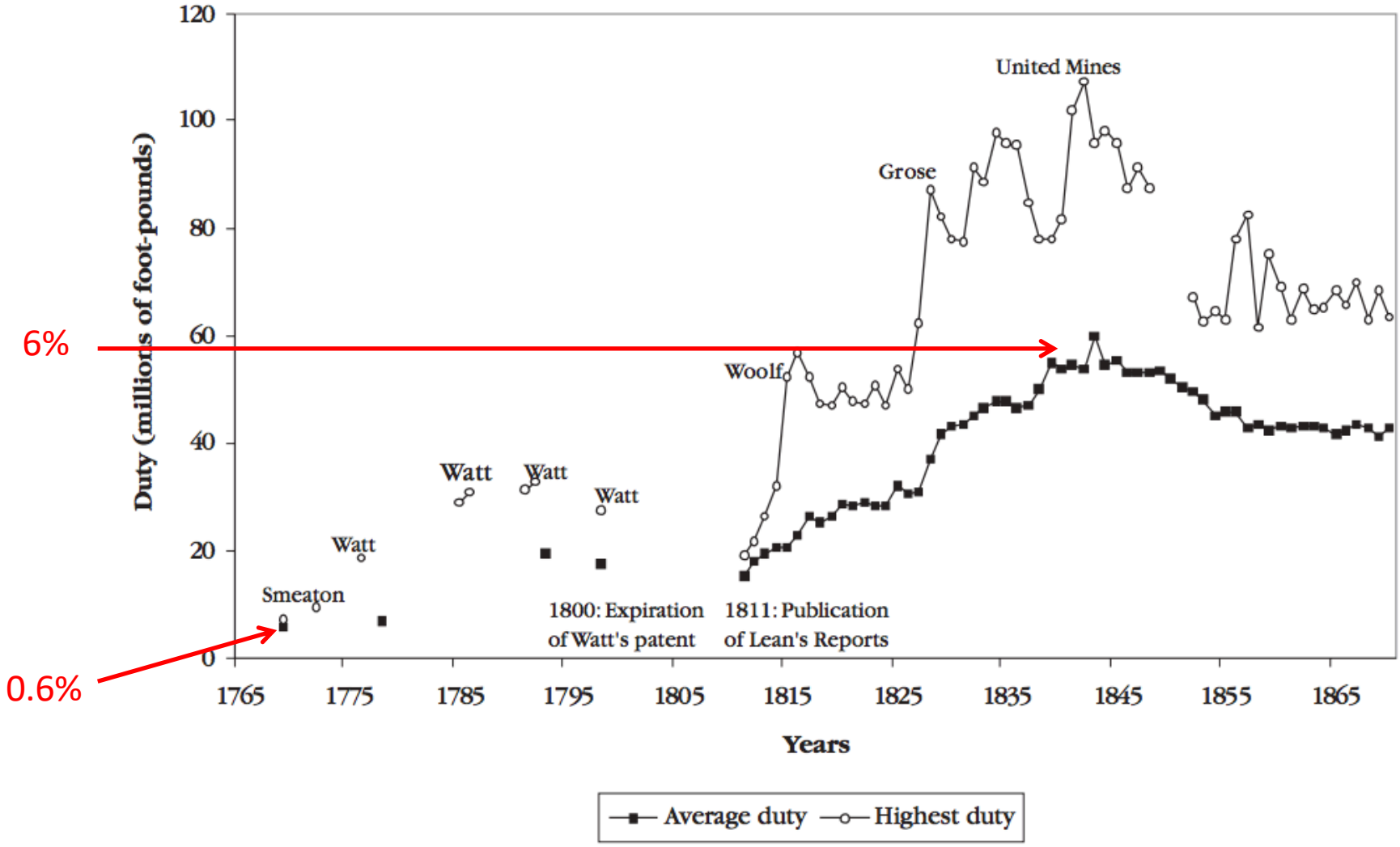
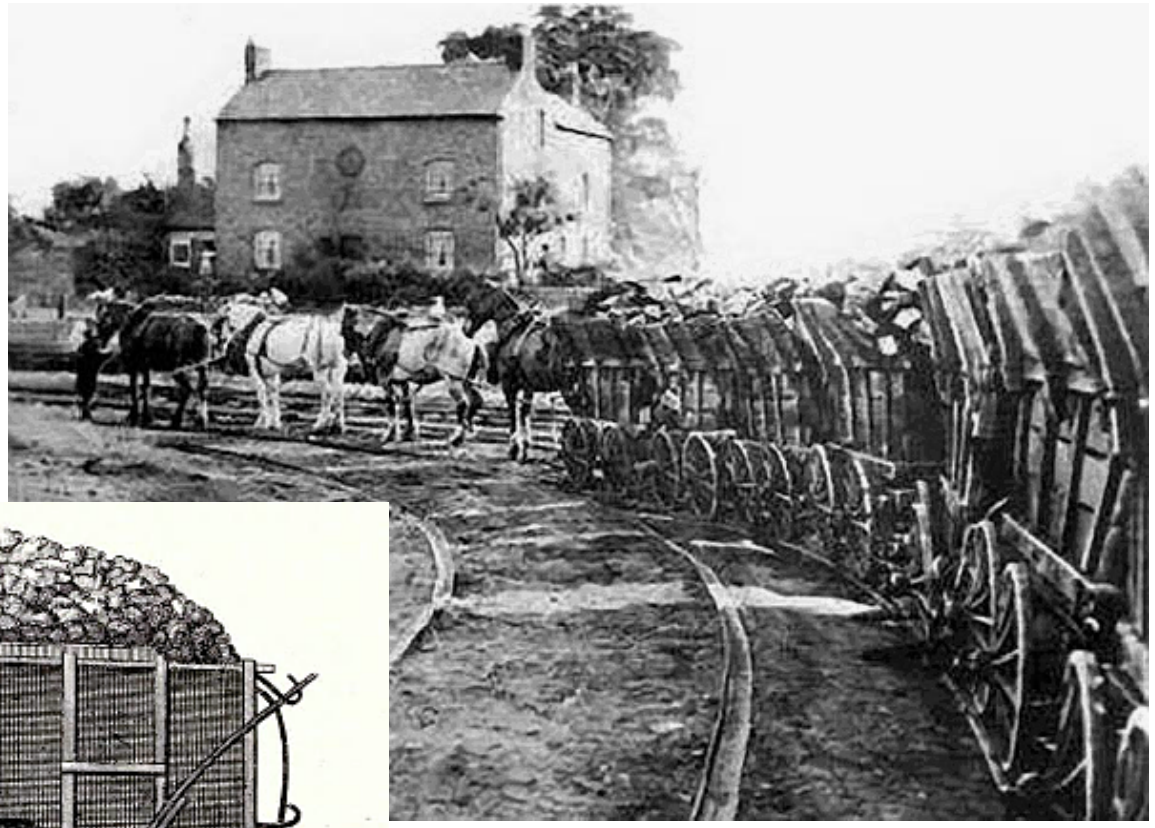
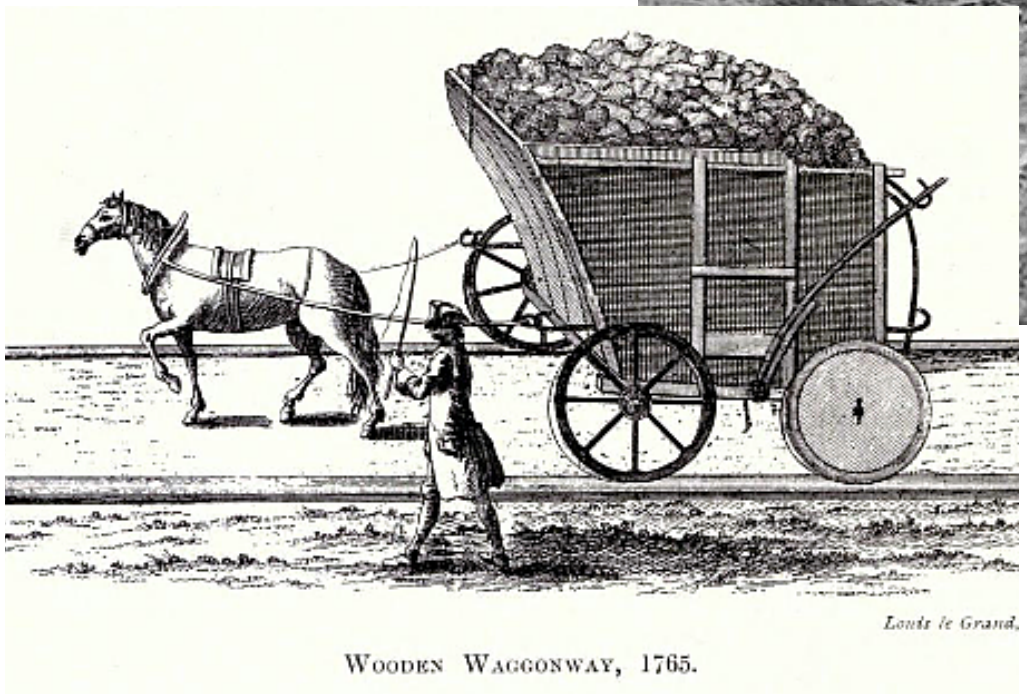


Fig. 1. Duty of Cornish engines.

Sources: Lean (1839), Pole (1844), Dickinson and Jenkins (1927), Barton (1965).

Once you have an engine to pump the mines, you envision other uses...





Louis le Grand.

Wooden Waggonway, 1765.

Little Eaton Gangway, Derbyshire, working til 1908

Coal and ore from mines have been carried by “tramways” since the 1500’s

First locomotive, 1804 – conversion of stationary steam engines

built by Richard Trevithick, mining engineer
Experimented with “high-pressure” steam (50 psi), double-acting cylinders.
1804 Pen-y-Darren locomotive, carrying iron in Wales, replacing horse-drawn tramway. Ran ~10 miles at ~2 mph but destroyed track.

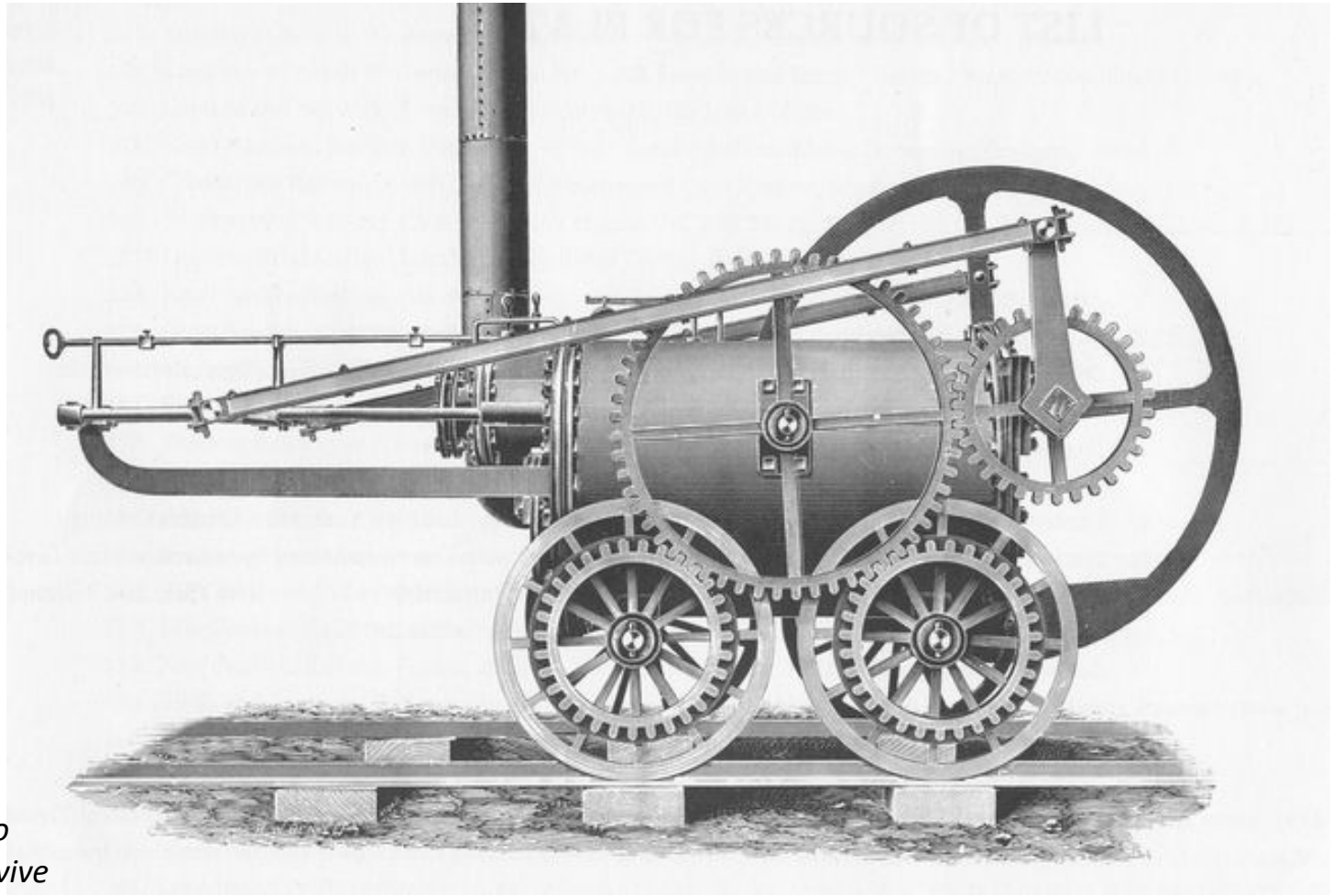


Image: 1804 Coalbrookdale locomotive, which failed. No images of Pen-y-Darren survive

First practical locomotives begin 1814

"Puffing Billy", designed by William Hedley, (mine manager),
built by the mine's blacksmith and enginewright
Coal hauler, 9" x 36" cylinders

Still basically a stationary steam engine placed on wheels

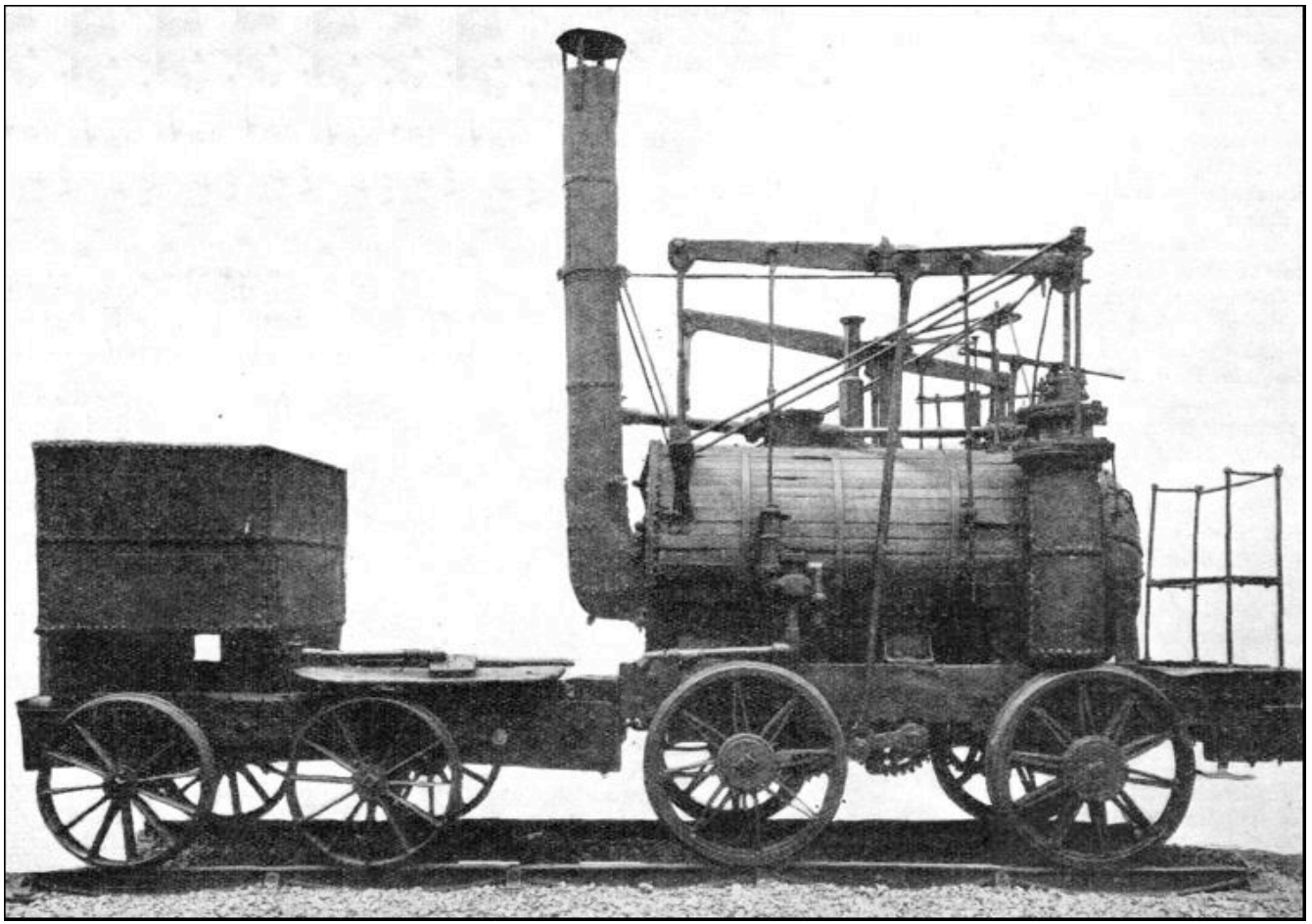
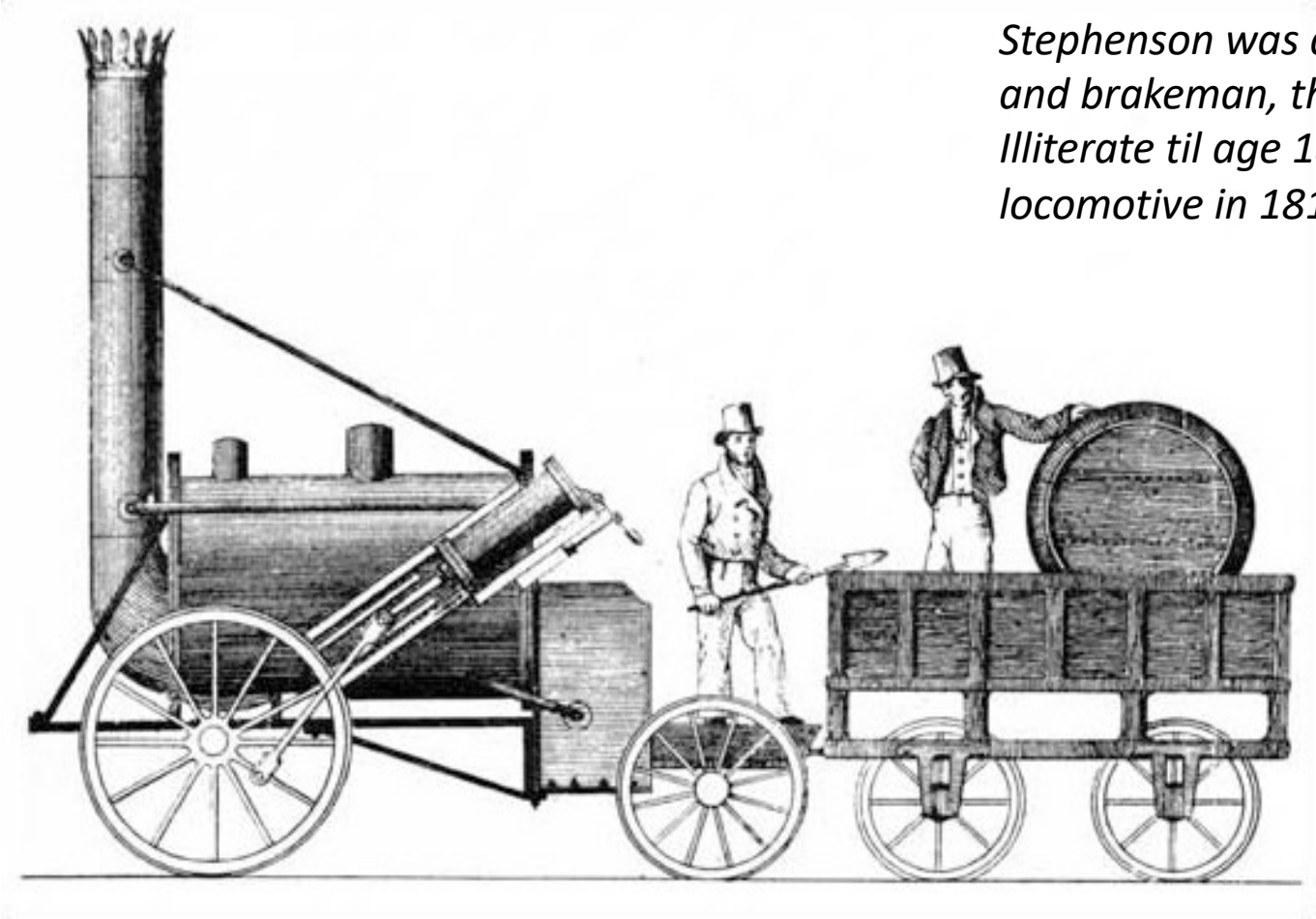


Image: source unknown

First passenger locomotive, 1829

George Stephenson's "Rocket", built for Liverpool and Manchester Railway
won the Rainhill trials at 29 mph (unloaded), 14 mph loaded
first example of single pair of drive wheels



Stephenson was a mine engineman and brakeman, then enginewright. Illiterate til age 18. Built first locomotive in 1814.

Image: source unknown