Energy

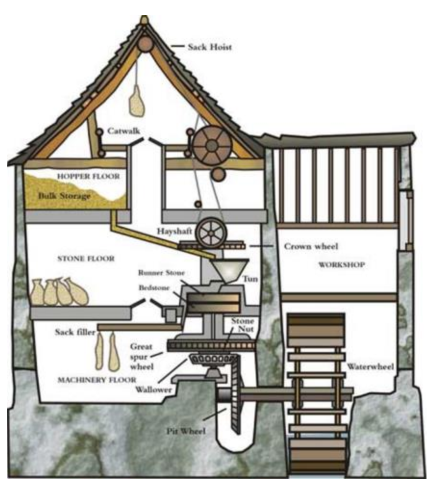
The Mill, 1648
Rembrandt
Harmenszoon
van Rijn

Work is what is done when things are moved. Energy is needed to do work. Energy comes in various forms: mechanical, chemical, radiation, etc. The unit of energy/work is the joule named after James Prescott Joule. Power is the term used to describe the amount of work done per unit time. Its unit is the watt named after James Watt. In the days before the industrial revolution work was done by animals, by wind and by water.

The possibility of windmills was considered in Greece but the first practical windmills were used in Persia in the 9th century. These used horizontally rotating blades, and were used for grinding grain and irrigation. The classic windmill such as that in Rembrandt's painting dates to the 12th Century in Northern Europe.

Watermills

The first watermills were made in the Middle East in the 3rd Century BCE. In the Middle Ages they became abundant – the Domesday Book (1086) lists over 5000 mills in England. They were essential for the grinding of wheat and cereals. Each mill was a small factory: the power of the running water was harnessed to operate the rotating grindstones and to lift the wheat up to the hopper.



Running water provided a more consistent source of power than the wind and was less expensive than maintaining oxen to operate the grindstones.

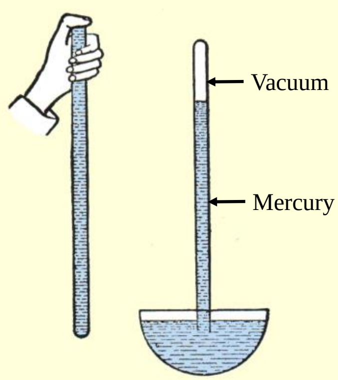
Diagram of Watermill is by Colin Brown
https://www.hampshiremills.org/Snippets%20Mill%20diagrams.htm

The inner workings of a windmill would be much the same as those of the watermill. The windmill was driven by wind. Winds are caused mainly by differences in atmospheric pressure. The main reason atmospheric pressure changes is because of temperature. Another factor is the inertia of the air particles which makes them move relative to the Earth's rotation. These tidal forces cause the winds to move in particular directions over wide ranges of latitude, e.g. the Easterly winds on either sides of the equator and the Westerly winds in the temperate regions.

The first idea that the atmosphere exerted pressure came the findings of Torricelli:

The Weight of Air

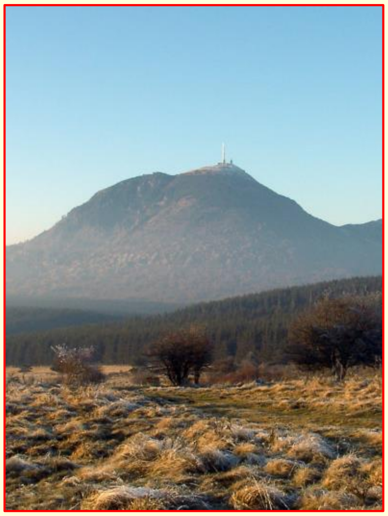
In 1643 the Italian physicist Evangelista Torricelli created a glass tube about a meter long and closed at one end. He filled the tube with mercury and inverted it in a bowl of mercury. The mercury fell to a height of about 760 mm, leaving a vacuum in the tube above it. A similar experiment with water left no vacuum. The Aristotelian explanation would be that nature abhors a vacuum but there was no reason why mercury should abhor a vacuum less than water.



This finding suggested that the air exerted a force upon the mercury in the dish that kept the mercury in the column at a particular height. This force would be equal to the weight of the mercury in the column. Since mercury weighs 13.6 times as much as water, a water barometer would have to be taller than 10 meters to show the vacuum. This was not measured. However, the idea fit with the knowledge that a suction pump could not raise water more than 10 meters.

So we have one explanation – the weight of air – instead of the complicated idea that nature abhors a vacuum.

But if this explanation was correct, it could be tested by taking the barometer to a higher altitude – where there would be less air to weigh down upon the mercury in the dish. This would be a true scientific experiment.



Pascal's Experiment

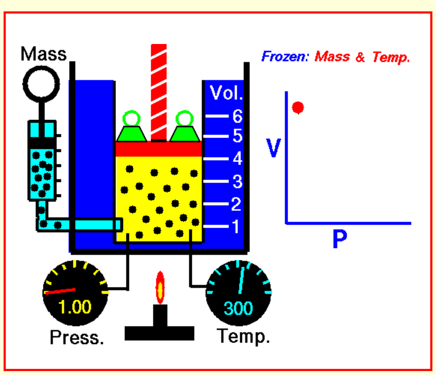
In September 1648, Blaise Pascal (1623-1662) asked his brother in law Florin Périer to take one of Torricelli's barometers up to the summit of the Puy de Dôme, a volcanic mountain near their home in Clermont-Ferrand. The summit is about 1000 meters higher than the city. The level of the mercury in the barometer was about 81 mm lower at the summit than in a control barometer in the city. This could only be caused by the decreased atmospheric pressure. Robert Boyle considered this the *experimentum crucis* of the new physics.

Pascal's measurements were in *pouces* which were about 27 mm – a little longer than modern inches. I have converted these to mm Hg. Pascal entrusted the experiment to his brother in law because he was not well enough to make the climb himself.

Pascal also contributed to the mathematical analysis of probability, constructed a mechanical calculating instrument and wrote extensively on philosophy and theology. Pascal's wager is the idea that a rational person should believe in God since the cost of not believing (eternal damnation) is far worse than the cost of believing (rejection of some sensual pleasures) and the benefits are far worse (some transient sensual pleasures vs the eternal joy of heaven). The logic of the wager however depends on the truth of the Christian theology. The actual state of affairs may be as easily be that God punishes those foolish to believe in something for which there is no evidence.

Boyle's Law

$$P \propto 1/V$$

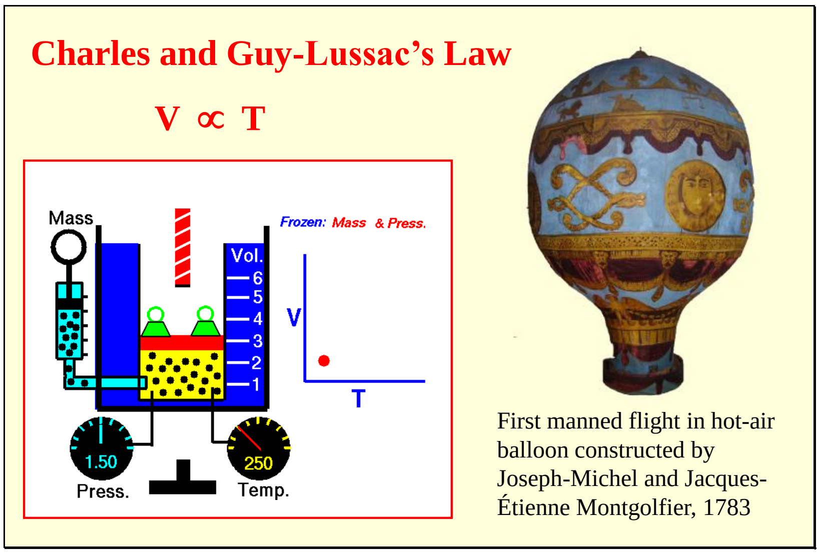


Robert Boyle (1627-1691)

We have already met Robert Boyle in the presentation on chemistry. He wrote *The Skeptical Chemist* questioning the ideas of alchemy. He was far more famous as a physicist. He conducted many experiments on the pressure of gases. He is remembered for the law governing the relationship of pressure to volume:

The absolute pressure exerted by a given mass of a gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged.

The animation is from NASA;
http://www.grc.nasa.gov/WWW/K-12/airplane/aboyle.html



First manned flight in hot-air balloon constructed by Joseph-Michel and Jacques-Étienne Montgolfier, 1783

Another law related the volume of a gas to the temperature when the pressure was maintained constant. This law was first published in 1802 by Joseph Louis Guy-Lussac. He credited the idea to much earlier work by Jacques Charles. The English scientist John Dalton also published similar results at about the same time.

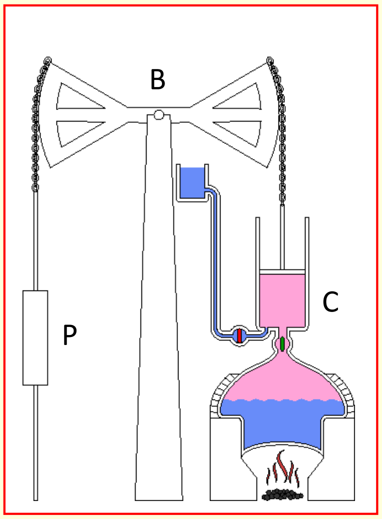
When the pressure of a sample of gas is held constant, the volume will vary directly with the temperature.

The animation is from NASA.
http://www.grc.nasa.gov/WWW/K-12/airplane/aglussac.html

Both Charles and Guy-Lussac were involved in early balloon flights, Charles in a hydrogen balloon and Guy-Lussac in a hot-air balloon.
When the temperature of the air increases the volume increases. The density of the air in the balloon therefore decreases, making it lighter than the outside air. The balloon floats upward.

Newcomen Atmospheric Engine (1712)

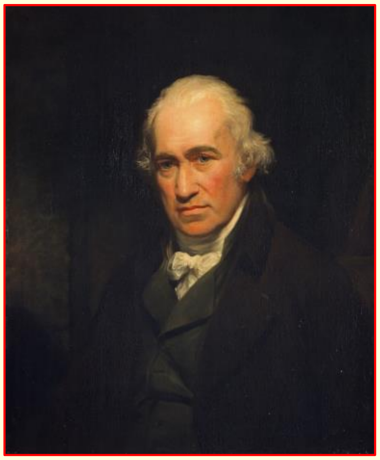
Thomas Newcomen (1664-1729) was an ironmonger and lay preacher. He invented a machine based on gas pressures to pump water out of mines. A boiler supplied low pressure steam (pink) into a cylinder (C) connected to a rocking beam (B) that drove the pump (P) up and down. The steam was rapidly condensed by spraying cold water into the cylinder, lowering the pressure. Atmospheric then forced the piston in the cylinder down and raised the pump.



The main force was not exerted by the steam. The piston in the cylinder was raised by gravity pulling down the pump (P). Thus low pressure steam was sucked into the cylinder (C). High pressure steam was not used since there was a danger of exploding the cylinder. The main force in the machine was exerted by the atmosphere against the low pressure in the cylinder caused by the steam's condensation.

James Watt (1736-1813)

Born in Greenoch near Glasgow, Watt studied instrument-making in London and then worked as a technician at the University of Glasgow. In 1763 he was asked to repair a working model of a Newcomen steam engine. He invented several changes to improve the efficiency of the engine. However his improvements were difficult to instantiate, and it was only in 1776 that he was able to manufacture his improved engine in partnership with Matthew Boulton (1728-1809) in Birmingham.



Portrait by John Partridge, 1806

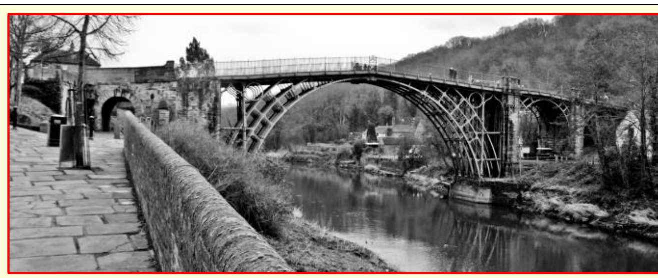
The main changes that Watt made in the Newcomen engine were

- making condensation occur separately from the piston. In the Newcomen engine the temperature of the piston continually changes from hot steam to cold water. This expands and contracts the piston making it less effective.

- letting the steam pass alternately though valves to each side of the piston – this was perhaps the most important change. Power was applied throughout the piston's cycle. If the piston was well built, higher pressure steam could be used.
- Sun and planet gears allowed the engine to operate a flywheel. This provided a continuous source of rotational energy that could power machines.

Watt's Steam Engine

video is from
https://www.youtube.com/watch?v=6mNsPjHqxz4



The Iron Bridge, Shropshire, 1781

Industrial Revolution

From 1750 to 1850 important innovations changed hand crafting to machine production. First was the invention of **machines** such as the cotton jenny and the flying shuttle. Second was the **steam engine** which produced the power to operate large machines. Third was the improved production of **iron and steel**, particularly the use of coke rather than coal to make cast iron. Fourth was the building of **factories** specifically designed for particular products.

The word "manufacturing," which originally meant making things by hand, soon began to mean machine production.

The Industrial Revolution began most prominently in the textile industry in Northern England, where coal was easily available.

Historical periods:
Renaissance 1400-1550
Scientific Revolution 1543 (Copernicus)-1700 (Newton)
Enlightenment 1700-1789 (French Revolution)
Industrial revolution 1750-1850

Eric Hobsbawm characterized modern political history as
age of revolution 1789-1848
age of capital 1848-1875
age of empire 1875-1914
age of extremes 1914-1991

Klaus Schwab and the World Economic Forum have suggested that there are 4 different industrial revolutions, the first associated with the steam engine, the second with the internal combustion engine, the third with digital control mechanisms and the fourth with interactive connectivity (internet, cloud storage, artificial intelligence, etc.)

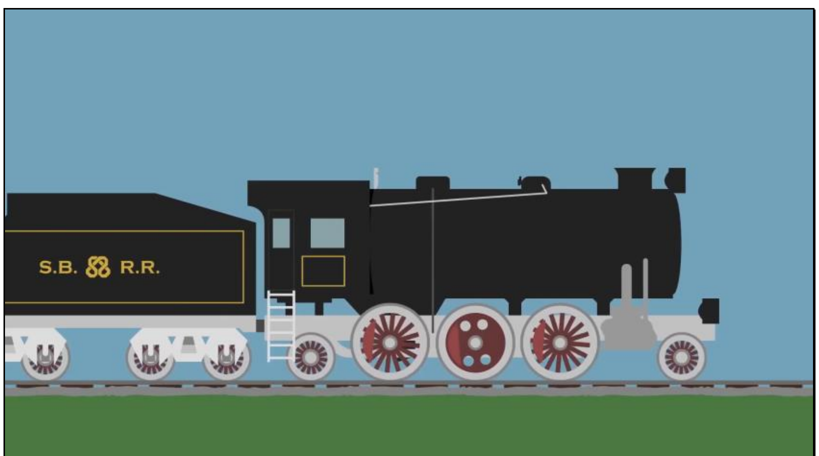
South Wales Industrial Landscape, Penry Williams, 1825

Watt's steam engine transformed the world. The landscape changed as agriculture gave way to industry. Society changed as human beings learned to work in factories.

George Stephenson (1781-1848)

Although he was unschooled and illiterate until the age of 18 years, Stephenson attended night school and learned to read and write. Several people had used steam engines to pull coal carts from the mines. Stephenson's new steam locomotive was used on the Stockton and Darlington Railroad connecting several collieries to the River Tees in 1821, and Stephenson's *Rocket* was the first locomotive to transport passengers on the Liverpool and Manchester railway opened in 1830.

As well as providing power to industry, the steam engine completely changed transportation.



How Do Steam Locomotives Work, Seb van den Brink

Video by Seb van den Brink at
https://www.youtube.com/watch?v=nd2Ii4OGQ4k

Other videos are
https://www.youtube.com/user/Sebasvandenbrink

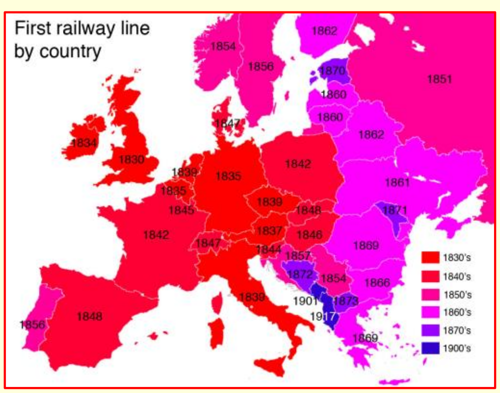
One way in which the steam locomotive differs from the original Watt steam engine is that there is no longer any condenser. The steam is just left to escape with the smoke after it has done its work in the piston chamber.

Rain Steam and Speed – The Great Western Railway, Joseph Mallord William Turner, 1844.

The Great western Railway – from Bristol to London was constructed by Isambard Kingdom Brunel, and opened in 1838.

Turner's picture shows the Maidenhead railway bridge across the Thames.

There is a suggestion of a hare racing before the train – nature vs industry.
https://artguideturner.wordpress.com/2014/10/13/i-spy-with-my-little-eye/



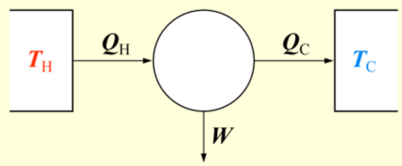
Expansion of the Railways

Railways rapidly expanded throughout Europe. The USA built its first railway in 1830. Railways were also constructed in various regions of the British Empire: Canada beginning in 1836, India in 1845, and Australia in 1854. The first transcontinental railways opened in 1869 in the USA and in 1885 in Canada

The Nature of Heat

Steam Engines operate by means of heat. Heat expands a gas which then does work. At the time of Watt's engine, however, no one was sure what heat was. Lavoisier (1743-1794) proposed that heat was a subtle fluid that is self-repelling. It therefore flows from hot regions (dense in caloric) to cold (low concentration of caloric).

The French engineer Nicolas Léonard Sadi Carnot (1796-1832) discussed the efficiency of heat engines. He showed that not all of the heat energy could be converted to work. Some must be "lost." This idea was the basis of the second law of thermo-dynamics.



The efficiency of a gasoline or steam engine is about 30%. Most of the energy is transformed into heat.
Turbines generating electricity have an efficiency of about 50%.
A car operated by a battery has an efficiency is around 70% and there is no loss of energy during idling.
Thus it is usually more efficient to use fuel to generate electricity, which is then stored in batteries for later use, than to use the fuel to generate work directly.

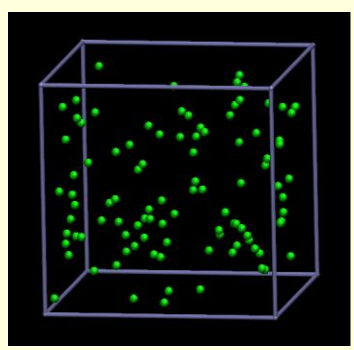
Ideal Gases

1. In 1811 Amedeo Avogadro proposed the idea of "molecules." He further stated that equal volumes of gases under the same conditions of temperature and pressure will contain equal numbers of molecules.

2. This could be combined with Boyle's Law and Charles's Law to give the ideal gas law, first stated by the French physicist Benoît Paul Émile Clapeyron in 1834:

$$PV=nRT$$

where **P** is pressure, **V** volume, **n** the number of molecules **R** the ideal gas constant and **T** the temperature.

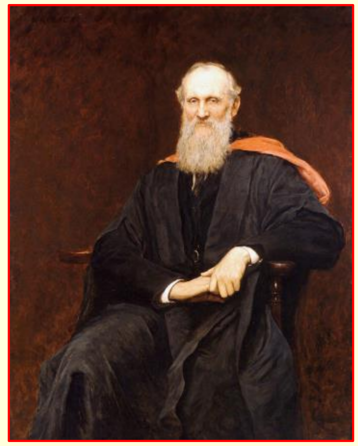


3. Following the work of several other scientists, Rudolf Clausius proposed the kinetic theory of gases in 1857.

In the kinetic theory, a large number of molecules of the gas are in constant random motion, bumping into each other and into the sides of the container. Temperature depends on the average kinetic energy of the molecules, and pressure depends on the average force they exert upon the walls of the container.

Absolute Zero

William Thomson, a Scottish physicist later known as Lord Kelvin, derived a value for absolute zero – the minimum possible temperature – from the linear relationship between temperature and pressure in gases. This can be extrapolated down to a hypothetical temperature at which the pressure is zero. At this point the gas molecules would have no kinetic energy. He estimated absolute zero as 273 degrees below the melting point of water, using degrees as defined by the Celsius scale (100 degrees between melting and boiling points of water). The Kelvin scale measures the temperature in degrees relative to absolute zero.



Lord Kelvin (1824-1907), by Herbert von Herkomer, ~1900

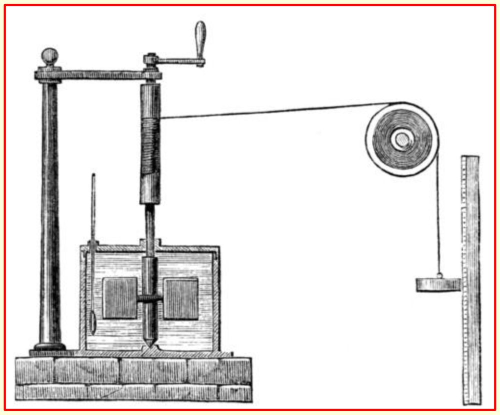
Gases liquefy before they can be cooled down to absolute zero.
melting points
hydrogen – 20K
helium – 4K
oxygen – 90K
nitrogen – 77K
natural gas (methane, ethane and propane) – 110K

Experimental results estimating absolute zero are provided in https://www.carolina.com/teacher-resources/Interactive/gay-lussacs-law-temperature-pressure-relationship-in-gases-determination-absolute-zero/tr10730.tr

The third law of thermodynamics states that the entropy of a system approaches a constant value as its temperature approaches absolute zero. Entropy is not easy to define. In the physics of gases it is the logarithm of the number of different microstates (configurations of molecules). It is thus related to the amount of information necessary to specify the system. The more ordered the system the less entropy.

James Prescott Joule (1818-1889)

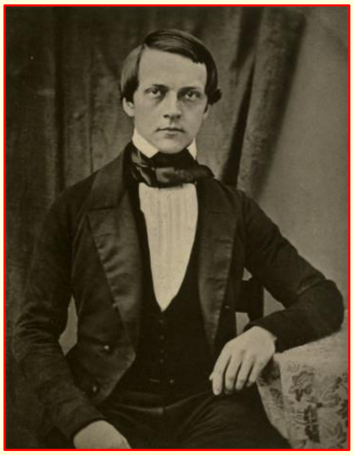
Joule operated the family brewery near Manchester and did science in his spare time. His most important experiment was to measure the mechanical equivalent of heat. A weight dropping over a distance rotated paddles in a bath of water thereby increasing the temperature of the water. Though reported in 1843 his findings were ignored.



Joule's Brewery is the only commercial enterprise allowed to use the red cross logo.It still exists: http://www.joulesbrewery.co.uk/our-story

Joule's result is expressed:
Wherever mechanical force is expended, an exact equivalent of heat is always obtained.

Joule also did electrical research and is remembered for Joule's law which states that the energy emitted per unit time (power) by the passage of a current through a conductor depends upon the amount of current and resistance of that conductor.
$P \propto I^2 R$



Portrait, 1848

Hermann von Helmholtz (1821-1894)

In 1847 Helmholtz published *Über die Erhaltung der Kraft* (On the Conservation of Force). This stated that energy could not becreated or destroyed. Rather it can only be changed from one form to another. This principle became the First Law of Thermodynamics. He came upoon this statement not from the study of physics but from his work in physiology. Muscles were moved by the energy derived from metabolism not from hypothetical vital forces..

Helmholtz contributed immensely to our understanding of the nervous system. He showed that the velocity of nerve conduction is finite rather than infinite. In audition he proposed that the cochlea acted to analyze sounds in terms of their frequency. In vision he invented the ophthalmoscope.

Donald Swann & Michael Flanders

The Second Law of Thermodynamics

In a closed system, entropy cannot decrease.

Heat cannot flow from a material at lower temperature to a material at higher temperature.

It is impossible to convert heat completely into work.

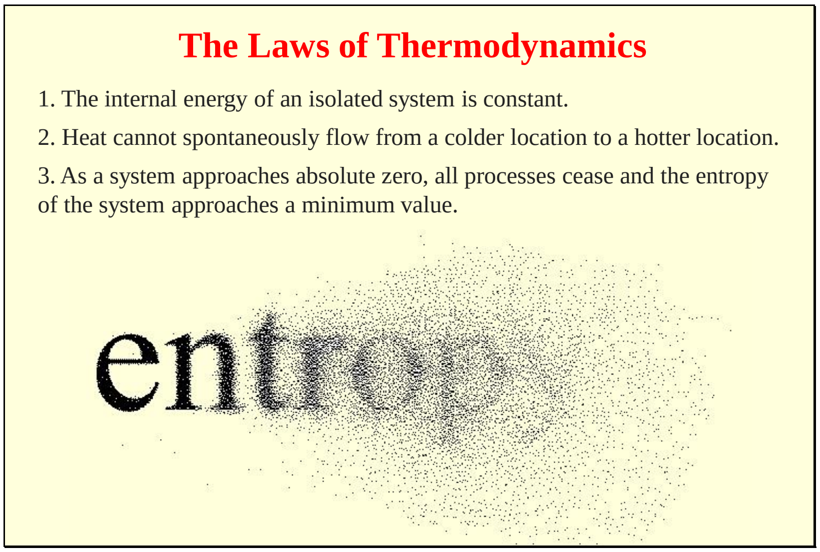
> That you can't pass heat from a cooler to a hotter
> Try it if you like but you'd far better not-a
> 'Cos the cold in the cooler will get hotter as a rule-a
> 'Cos the hotter body's heat will pass to the cooler

"Why don't you call it entropy … no one understands entropy very well so in any discussion you will be in a position of advantage" (Von Neumann to Shannon about "missing information")

Full text of the Flanders and Swann song:

> The First law of Thermodynamics.
> Heat is work and work is heat
> Heat is work and work is heat
> *Very Good.*
> The Second law of thermodynamics.
> Heat cannot of itself pass from one body to a hotter body
> Heat cannot of itself pass from one body to a hotter body
> Heat won't pass from a cooler to a hotter
> Heat won't pass from a cooler to a hotter
> You can try it if you like but you'd far better not-a
> You can try it if you like but you'd far better not-a
> 'Cos the cold in the cooler will get hotter as a rule-a
> 'Cos the cold in the cooler will get hotter as a rule-a
> 'Cos the hotter body's heat will pass to the cooler
> 'Cos the hotter body's heat will pass to the cooler
> Heat is work and work is heat and work is heat and heat is work
> Heat will pass by conduction and
> Heat will pass by conduction and
> Heat will pass by convection and
> Heat will pass by convection and
> Heat will pass by radiation
> Heat will pass by radiation
> And that's a physical law

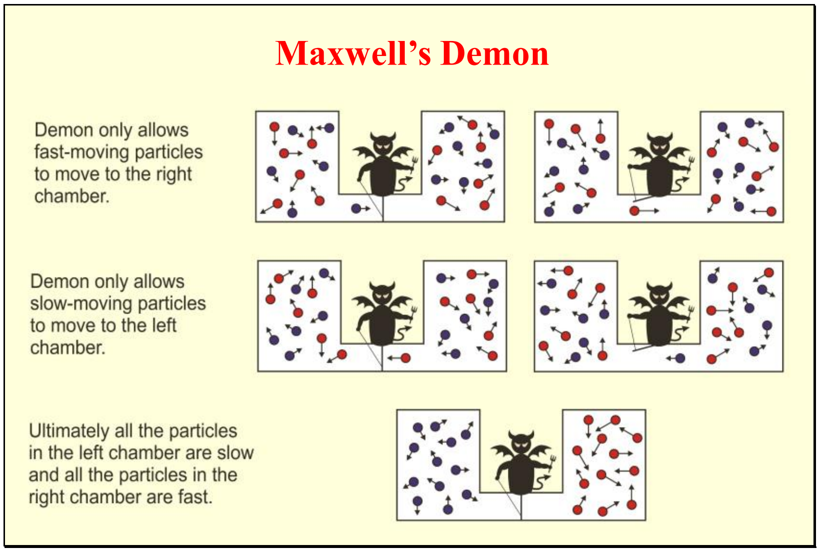
Heat is work and work's a curse
And all the heat in the universe
Is gonna cool down,
'Cos it can't increase
Then there'll be no more work



There is also a zeroth law: If two systems are each in thermal equilibrium with a third, they are also in thermal equilibrium with each other.

Entropy is the opposite of order. Entropy is evident in the decay of things.

Some scientists have wondered whether intelligence might operate to counter the increasing entropy in the universe. Intelligence can certainly bring order to disordered things. Examples are the physical construction of buildings from randomly organized matter and the creation of scientific laws to explain experience. However, such intelligent work requires the transfer of energy. This willy-nilly leads to the release of some energy in random kinetic form (heat). Thus, whatever entropy is decreased locally (in making the building or defining the laws) is more than balanced by the global increase in entropy caused by the physical work of construction or the physiology of thought.

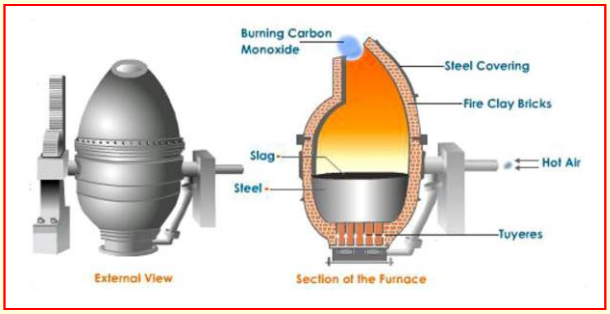


The ideas of entropy, information and intelligence can be considered in a thought-experiment proposed by James Clerk Maxwell (1831-1879) in 1867, and now called Maxwell's Demon:

A space containing particles moving at various rates and in various directions is divided into two sections. A "demon" (in the sense of an intelligent rather than malignant agent) perceives the velocities of all the particles, and closes the gate between the two spaces when a particle moving more slowly than the rest (blue circle) approaches from the left side, or when a fast particle (red circle) approaches from the right (left side of figure). The demon opens the gate whenever a fast particle from the left side or a slow particle from the right side approaches (right side of figure). In this way, the demon can increase the number of fast particles in the right section and the number of slow particle in the left. Order has been imposed. The entropy of the system decreases. Maxwell's Demon thus counteracts the law that entropy must always increase. Furthermore, the difference in kinetic energy between the sections could perform work. Intelligence has apparently created useful energy.

The problem is that work must be done (and heat released) to perceive the velocities of the particles, to maintain an up-to-date memory of their velocities and directions, and to open and close the gate. The increase in entropy resulting from this work more than balances the decrease caused by the separation of the particles. We cannot generate useful energy without wasting energy. We cannot create a perpetual motion machine.

Bessemer Process



Henry Bessemer (1813-1898) patented a process to make large amounts of high-quality steel in 1856. Pig iron (iron smelted with a high carbon content) was melted in a coke-fired furnace able to withstand high temperatures (because of the brick lining). This was then submitted to a blast of hot air through the *tuyeres* (nozzles). The air burned off the carbon and other impurities. These either escaped as gases or formed "slag" which floated on top of the melted iron and could be separated from it during the pour.

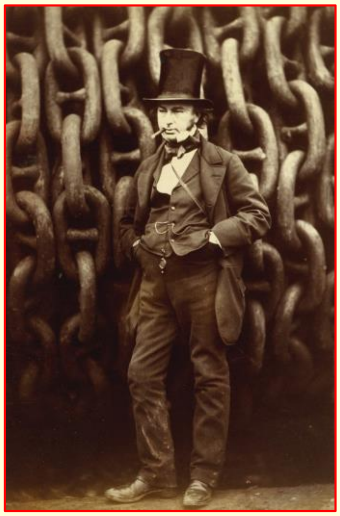
The industrial revolution needed steel in great quantities – to make the steam engines that operated the machinery and the locomotives, to construct the factories that housed the machinery, to lay the rails on which the locomotives ran.

The removal of impurities in the metal could also be facilitated by adding quicklime to the mix.

Before the Bessemer process, steel was made by hammering heated pig iron (wrought iron). This was very labor-intensive and suited only to making small objects.

Captains of Industry

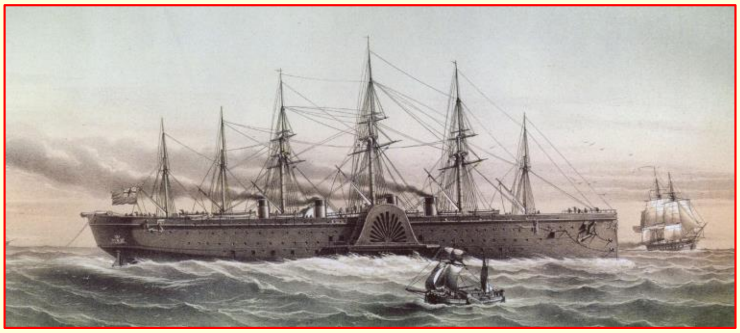
In the 19th Century, men of vision were able to raise capital and complete large projects. The most notable of these was Brunel. He constructed the Great Western Railway from Bristol to London. He later built the first steamship *The Great Eastern*. Huge steel works were established in Germany by Friedrich Krupp and in the USA by Andrew Carnegie.



Isambard Kingdom Brunel Standing Before the Launching Chains of the Great Eastern, photograph by Robert Howlett, 1857

The captains of industry became very rich. Much of their wealth was accumulated on the backs of poor workers. Late in life, they often became very philanthropic. However, there is always some dispute about whether the better term to describe these industrialists should not be "robber barons."

The Great Eastern Steamship



Steamships began in the early 1800s and the first iron steam ship was built in 1821. Brunel's *The Great Western,* a paddle steamer, was launched in 1838. His greatest achievement, however was The Great Eastern, launched in 1858. This was a combination paddle and propeller ("screw") steamer.

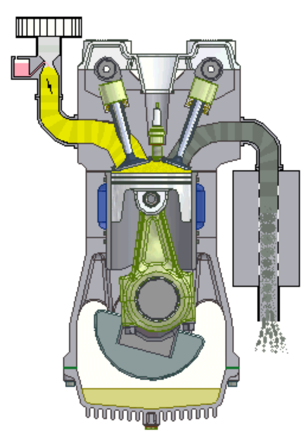
The designation SS actually means "screw steamer" as opposed to PS meaning paddle steamer. The Great Eastern was designed for the routes between Britain and Asia. However, these routes became less profitable with the Suez Canal (1869) and the steamer ended up being used for Atlantic crossings. The ship was huge – five funnels and 4000 passengers.

The Great Eastern was the only steamer capable of carrying and laying the transatlantic cable in 1866. The ship was too big to be commercially successful. It ended its life as a floating music hall in Liverpool.

Internal Combustion Engine

In 1876 Nikolaus Otto and Gottlieb Daimler patented the four-stroke internal combustion engine. The four strokes are

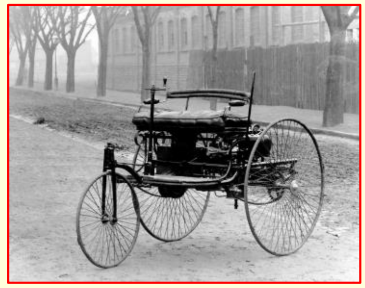
1. Intake – the piston move down sucking in air and fuel
2. Compression – the piston moves up and compresses this mixture
3. Power stroke – the fuel and air are ignited and the resultant explosion drives the piston down.
4. Exhaust – the piston moves up to expel the combustion gases.



The diesel engine was invented by Rudolf Diesel in 1892. In this two-stroke engine ignition results from the increase in temperature during the compression stroke.

Automobiles

The first practical automobile was the Benz Patent Motorwagen produced by Karl Benz and his associates in 1885 in Mannheim, Germany.



The first mass produced automobile was Henry Ford's Model T which began in 1908. It was manufactured on a moving assembly line in Detroit, Michigan.

The "T" in model T just signified its position in Ford's designs which began with the Model A.

Flyer 1, Kitty Hawk, North Carolina, December 17, 1903

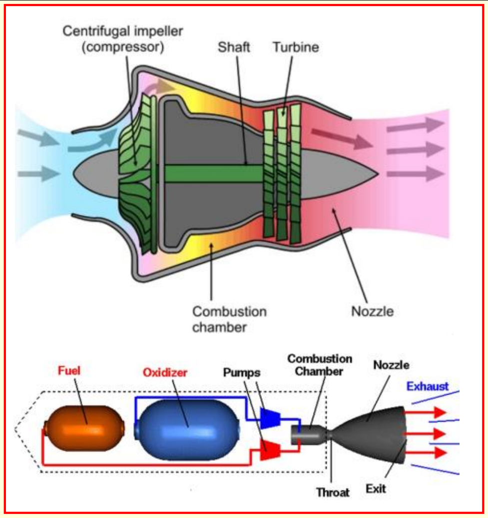
Gasoline engines allowed us to travel through the air as well as on the ground. The first flight of a heavier than air vehicle was that or Orville and Wilbur Wright.

In the photograph Wilbur Wright is piloting the plane. He lies on his stomach. The small gasoline engine operates the propellers which are located behind the wings. Orville is running alongside the wing.

Jets and Rockets

The first patent for a turbojet, an air-breathing jet engine, was that of the English RAF cadet Frank Whittle in 1932. The first plane to use such an engine was manufactured by the Heinkel Company in Germany.

Rockets have been around ever since China's invention of gunpowder. The first rockets using liquid fuels were constructed by the American physicist Robert Goddard in 1926

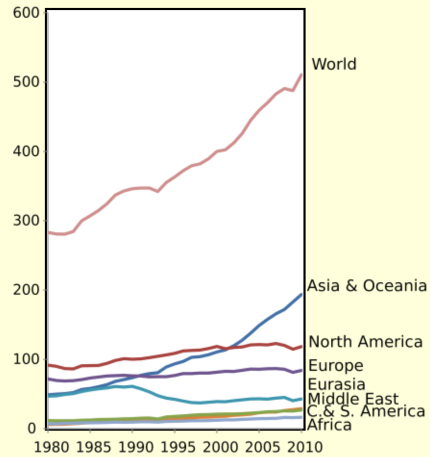


The most common fuel used in jet and rocket propulsion is kerosene. This is a light oil derived from petroleum. Its molecules typically contain 10-16 carbon atoms. Some rockets use hydrogen. Most rockets using liquid fuels use liquid oxygen as the oxidizer.

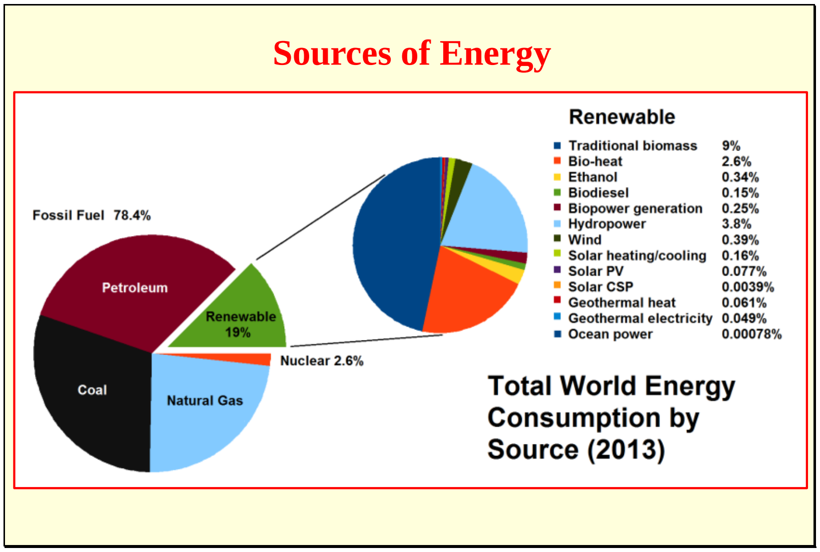
Werner von Braun used the ideas of Goddard to build the German rockets that were used to bomb England at the end of World War II. The most successful of these was the V2 rocket. The V stood for *Vergeltungswaffen* (reprisal or vengeance weapon). The main designer behind these weapons was Wernher von Braun. After the war he was recruited to the US to help build ballistic missiles. Ultimately he became involved in NASA and the space program.

World Energy Consumption

Human beings are using more energy than ever before and this in increasing as the world population increases. Before 1990 most of the energy was consumed in Europe and North America. At present Asia an Oceania have become the greatest users in keeping with their rapid industrial development. Our current high levels of energy consumption will soon exhaust the world's supply of fossil fuels.



The unit on the y axis is quadrillion (10^{15}) Btu. Btu is the British Thermal Unit - the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. It is equivalent to 1055 joules in the metric system.



Fossils fuels supply by far the most of our present energy needs. At our current rates of consumption we shall probably run out of oil by 2050 and coal by 2080.

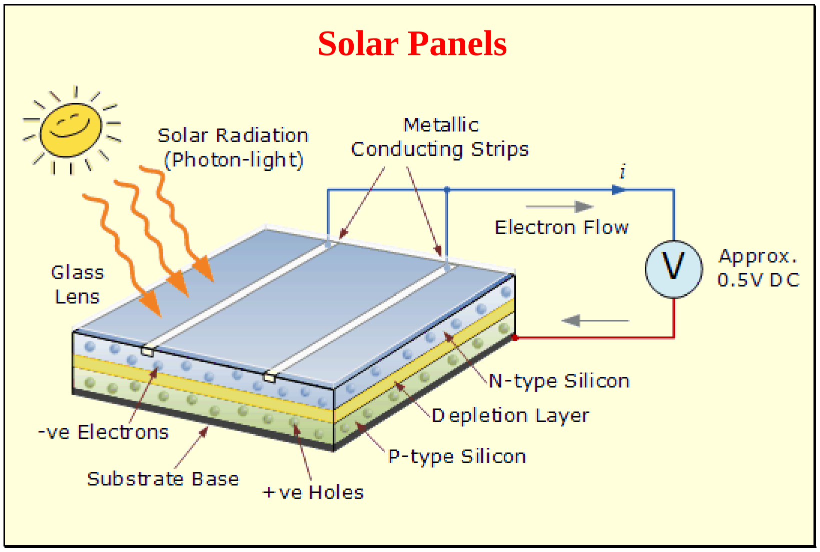
In the mid 20th Century, nuclear energy was considered to be the next great power source. The problem is that catastrophic accidents can occur. Because these are so rare it is difficult to pay appropriate attention to their prevention. They hardly ever occur. Yet when they do the result is calamitous.

So we need to change to renewable sources of energy. Hydroelectricity is by far the most important renewable source being used at present because it contributes no greenhouse gases and therefore does not affect the world's climate.

The list of renewable sources also includes traditional biomass, e.g., wood, peat and biological waste. These can be used instead of coal or oil. Theoretically these sources are renewable but the rate of renewal of our forests in far too slow. Furthermore biomass energy sources will produce carbon dioxide.

Ethanol can be produced from plants and biodiesel is a mixture of petroleum oil and plant oil.

We need to get much more of our power from the sun, the tides, and the wind.



Edmond Becquerel (1820-1891), a French physicist, observed the photovoltaic effect in 1839. The first practical solar panels were produced in 1954 by Bell Laboratories using silicon semiconductors. This was based on the earlier research of Russell Shoemaker Ohl.

The n-type silicon was "doped" with small amounts of phosphorus to make electrons free to move in the crystalline structure. P-type silicon used boron which made the material easily able to absorb electrons. This is usually described as having "holes" which could absorb electrons.

An array of solar panels in Pennsylvania.

Photograph by Edward Burtynsky, *PS10 Solar Power Plant, Seville, Spain*

Another way to use the sun’s energy is to boil water so that the steam can be used to run turbines to generate electricity. In this power plant arrays of mirrors focus the sun’s rays onto a boiler located at the top of the towers. The mirrors move during the day to maintain the focus.

Tidal Power

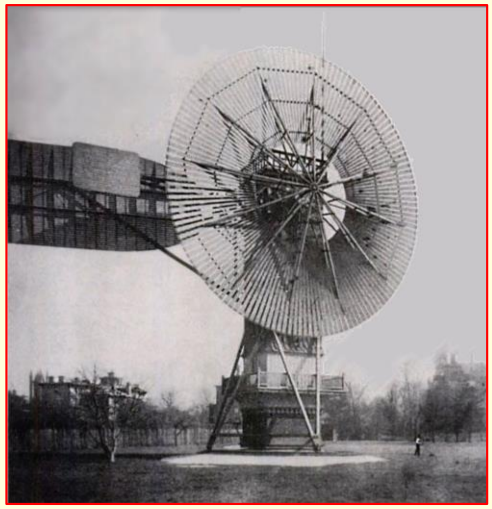
Tidal power can be harnessed to generate electricity. Tidal mills for grinding flour were common in the middle ages. The first power plant to generate electricity from the tides opened in 1966 in St Malo, France. This placed a dam across the estuary of the Rance River and worked in much the same way as other hydroelectric plants. The modern approach is to place turbines on the sea floor as in this video.

Voith Company was founded by Johann Voith in 1867 in Heidenheim Germany. Currently, a third of the world's hydroelectric power is produced with turbines and generators manufactured by the Voith Hydro.

https://www.youtube.com/watch?v=8-sFLGMSMac

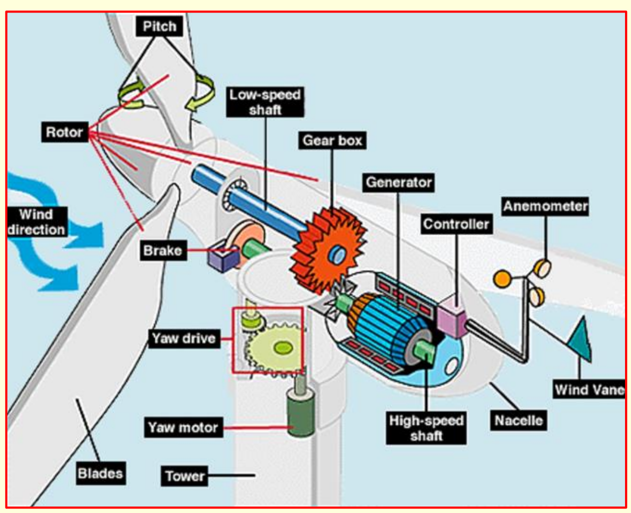
Wind Turbines

With the invention of electrical generators, the wind was quickly used to generate electricity. The illustration shows Charles Brush's windmill of 1888 in Cleveland. The diameter of the rotor was 17 m. During the early part of the 20th Century windmill generators were widely used by American farmers on homesteads out of reach of the electrical distribution systems.



We started this presentation with a windmills. And now we come full circle by considering modern windmills which are used to generate electrical energy.

Modern Wind Turbines



The first modern wind turbines capable of generating multiple megawatts of power was constructed in Denmark in 1978. Denmark continues to be a world leader in using wind power to generate electricity.

Current industrial wind turbines use blades that are commonly between 100 and 150 feet (30-45 meters) long. The largest turbines have blades that are 80 meters long. These machines stand at a height of 195 meters (from sea level to the topmost reach of the blades).

The nacelle is the outer casing of the turbines gears and generator. The word comes from the Latin *navicella* little ship.

Modern wind turbines rotate clockwise when viewed face-on. Older windmills rotated counter-clockwise.

Waubra Wind Farm in Australia. Canola field and wind turbines.

Energy

Ratcliffe Power Station 46, 2003
Michael Kenna

We come to the end of this history of energy with a photograph of the huge cooling towers at an electrical power station in England. Most of our electricity comes from the burning of fossil fuels, which generates steam to drive turbines. The steam needs then to be condensed to water in these large cooling towers. The gas coming out the top of the towers is mainly excess steam.

The photograph portrays the size and power of these cooling towers as well as the abstract geometry of their curves and the interplay of light and shadow.