409.319A

ATHENA: Aero Thermo Hydro Engineers Nexus Application

Thermofluid Systems

Fall 2018

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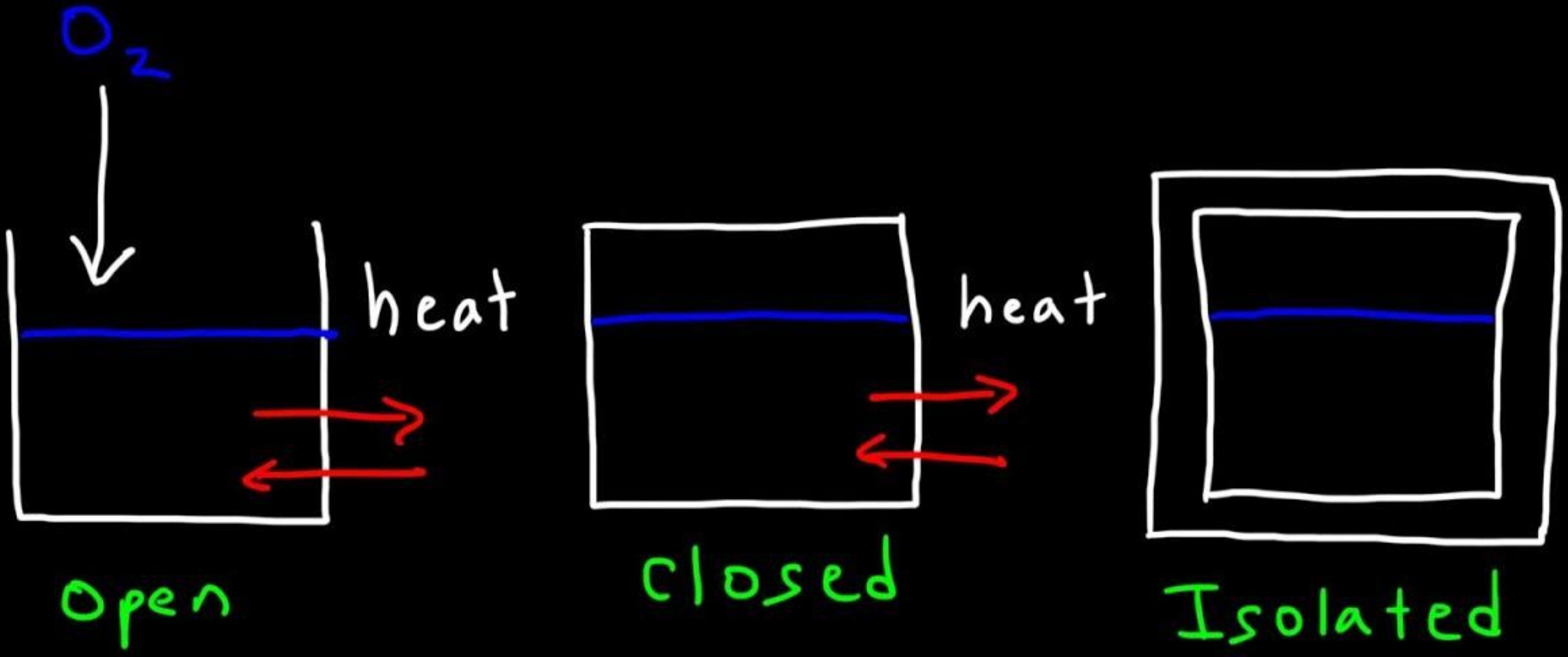
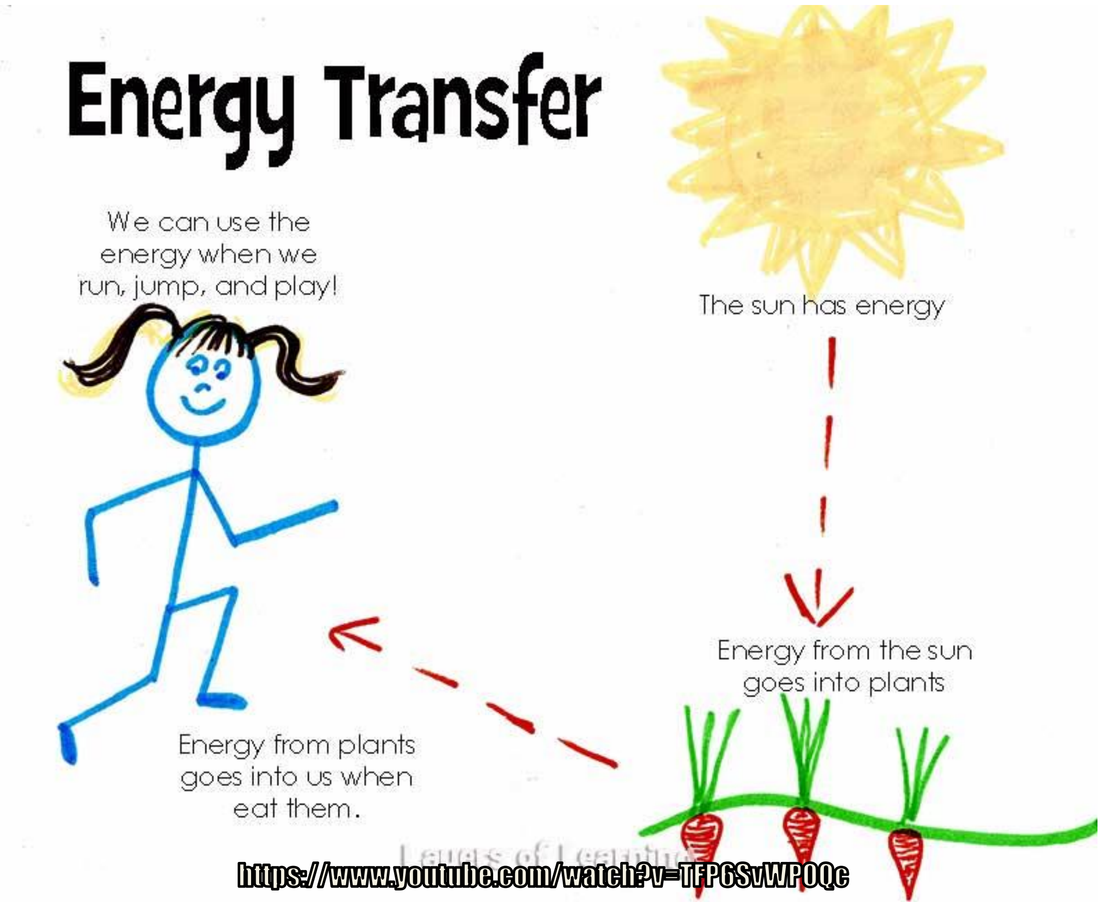
Open vs Closed System



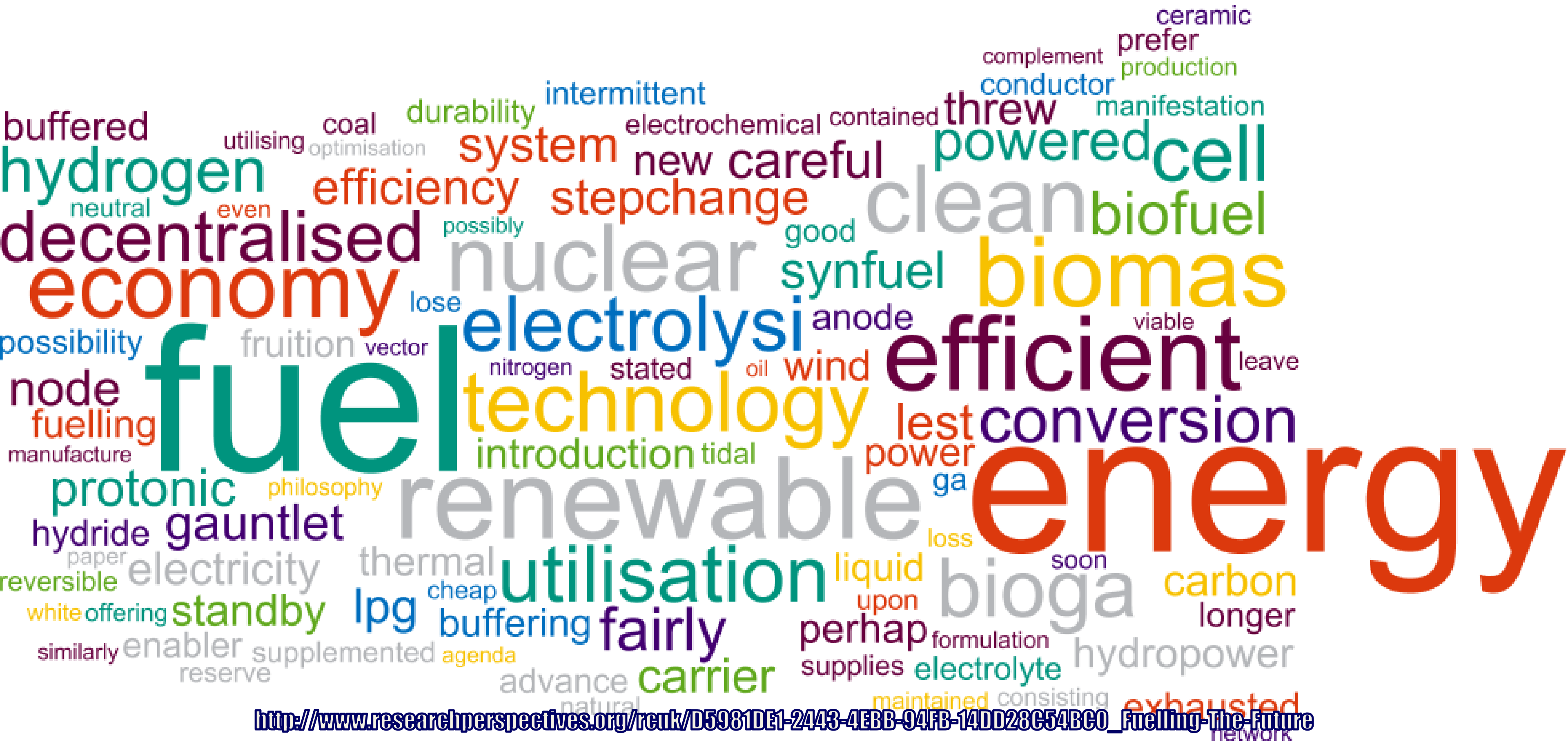
https://www.youtube.com/watch?v=TFPGSvWPOQc

Energy-Conversion-Sunshine-City0003



https://www.youtube.com/watch?v=TFP6SvWPOQc

Fueling the Future: Energy Conversion Systems



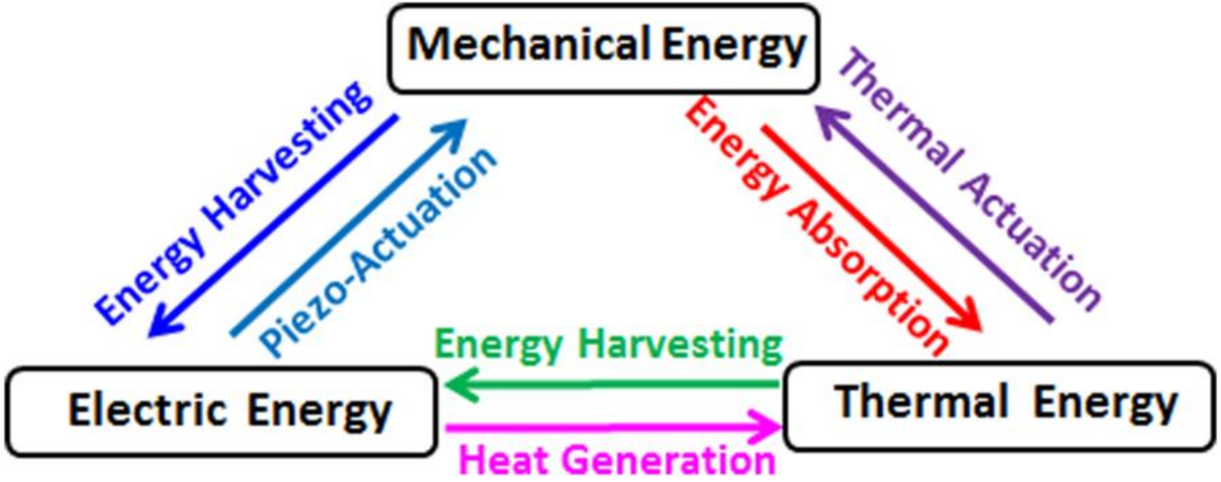
http://www.researchperspectives.org/rcuk/D5981DE1-2443-4EBB-94FB-14DD28C54BC0_Fuelling-The-Future

Energy Conversion

- Energy conversion involves the transformation of energy from forms provided by nature to forms that can be used by us.
- Some energy converters are simple. The early windmills transformed the kinetic energy of wind into mechanical energy for pumping water and grinding grain. Other energy conversion systems are more complex, particularly those that take raw energy from fossil and nuclear fuels to generate electricity.
- Many energy converters widely used today involve the transformation of thermal energy into electrical energy. The efficiency of such systems is, however, subject to fundamental limitations, as dictated by the laws of thermodynamics and other scientific principles.
- In recent years, considerable attention has been devoted to certain direct energy conversion devices, notably solar cells and fuel cells.

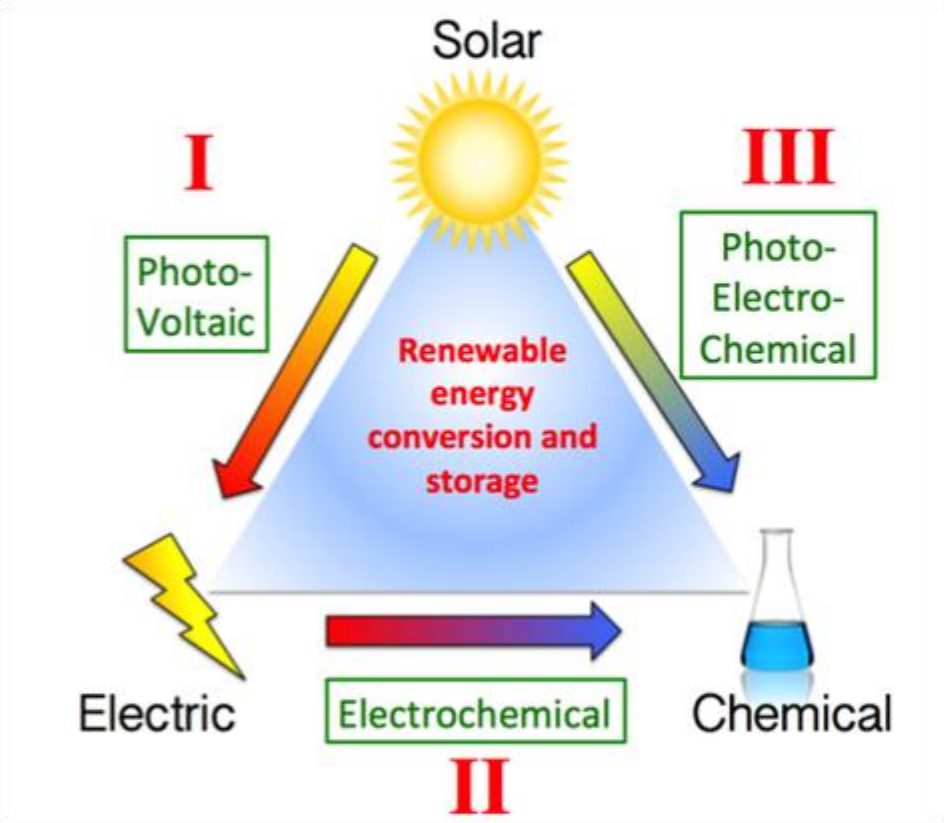
https://www.britannica.com/technology/energy-conversion

Energy Conversion



http://appliedmechanicsreviews.asmedigitalcollection.asme.org/article.aspx?articleid=1882100

Solar to Fuel Energy Conversion



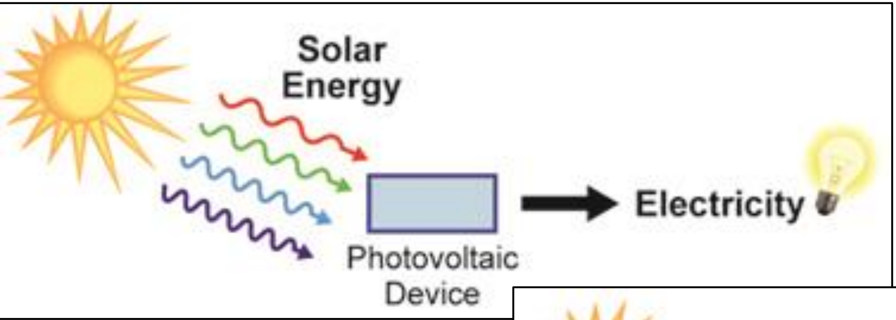
http://www.smithelectrolab.com/research.html

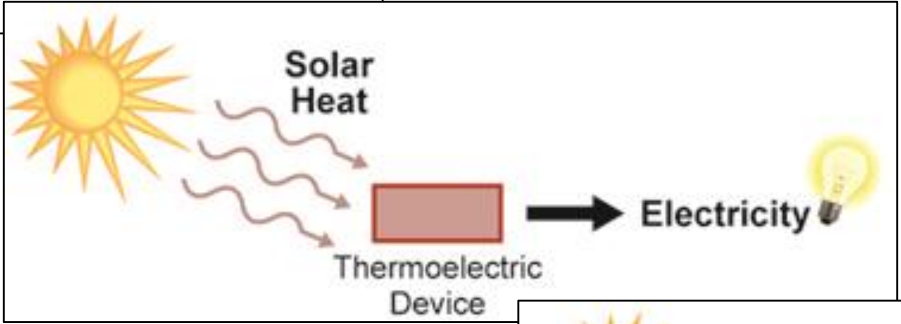
Renewable Energy Conversion & Storage

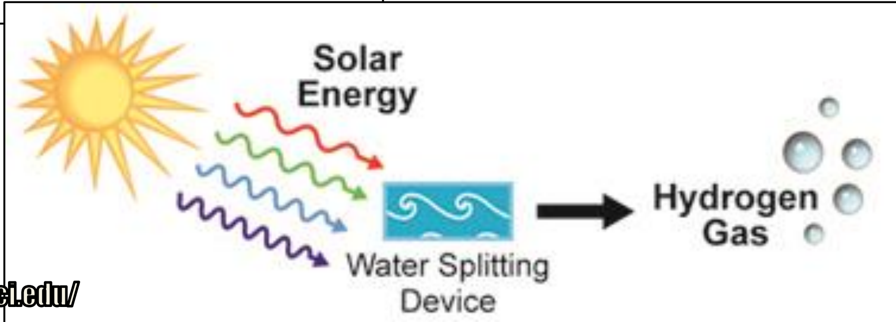
- There is an immediate need to find renewable and sustainable energy sources that can replace fossil fuels. The Sun provides an enormous amount of energy that can easily surpass the global energy demand by more than an order of magnitude. However, solar energy needs to be stored in a robust way in order to use energy on demand when the sun is not shining. Solar water splitting has shown to be an efficient way to convert solar energy into chemical energy, when water is broken down into its principle components, oxygen and hydrogen.
- Hydrogen can be used as a clean alternative to fossil fuels without emitting any CO_2, and thus solar water splitting offers a long-term solution to the global energy needs, while maintaining a clean environment. In addition, using CO_2 as a feedstock to synthesize highly valuable chemicals and fuels also can also help to reduce our growing atmospheric CO_2 concentration.

http://www.smithelectrolab.com/research.html

Solar Energy Conversion







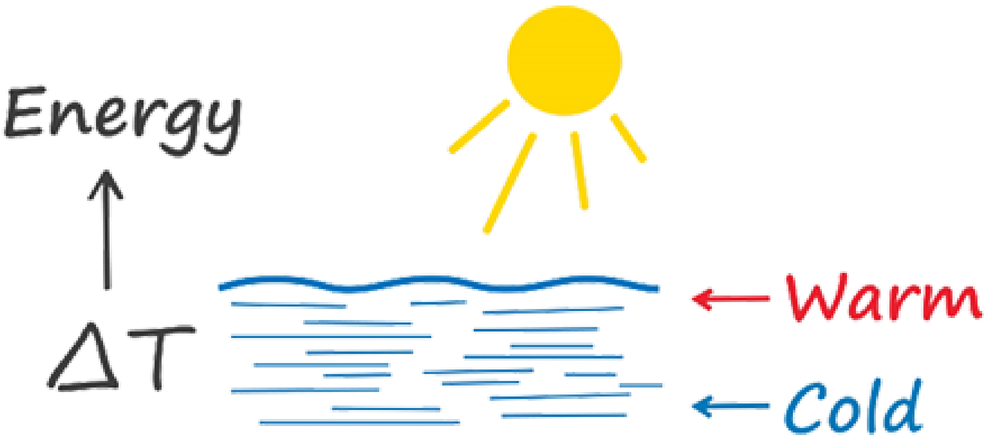
https://cfse.ps.uci.edu/

Enabling Technologies for Solar Energy

- Solar to Electric Power Generation
  - Photovoltaics (PV) or solar cells directly convert the energy from the sun to direct current (DC) electricity. Researchers are developing cheap, easy to manufacture, and high efficiency solar cells. Fundamental insights and new materials and design developments will help drive down the cost.
- Solar Heat to Electric Power Generation
  - Thermoelectrics (TE) directly convert heat to electricity. These devices can utilize wasted solar heat as well as wasted heat from other sources like car braking, making this technology very exciting for many areas of the clean energy sector. Researchers are studying the fundamental obstacles that limit the efficiency in these devices and developing morphologies and materials.
- Water Splitting for Chemical Fuel Production
  - Photoelectrochemical water splitting uses the energy from the sun to directly split water molecules into hydrogen and oxygen gas.

https://cfse.ps.uci.edu/

OTEC: Ocean Thermal Energy Conversion



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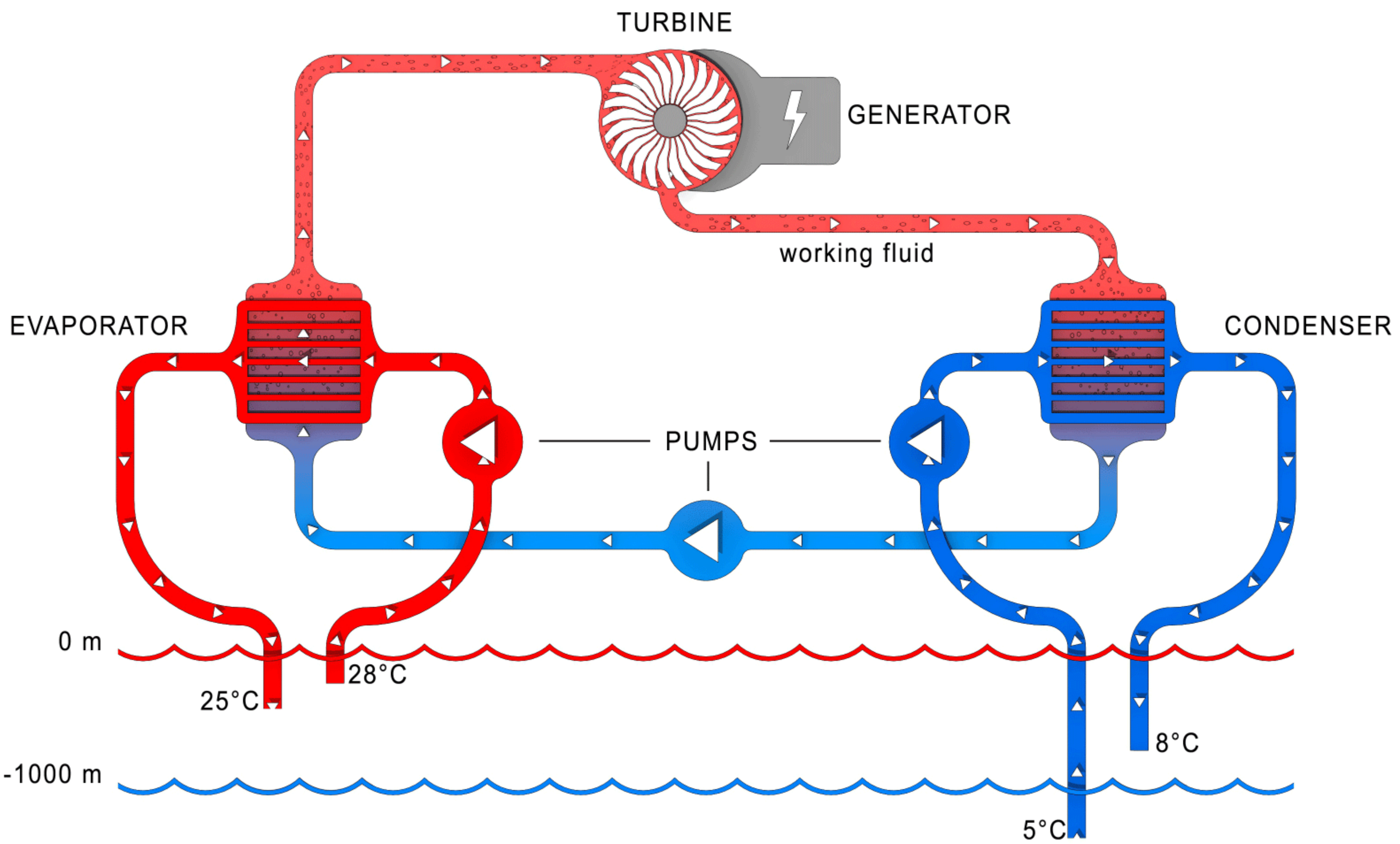
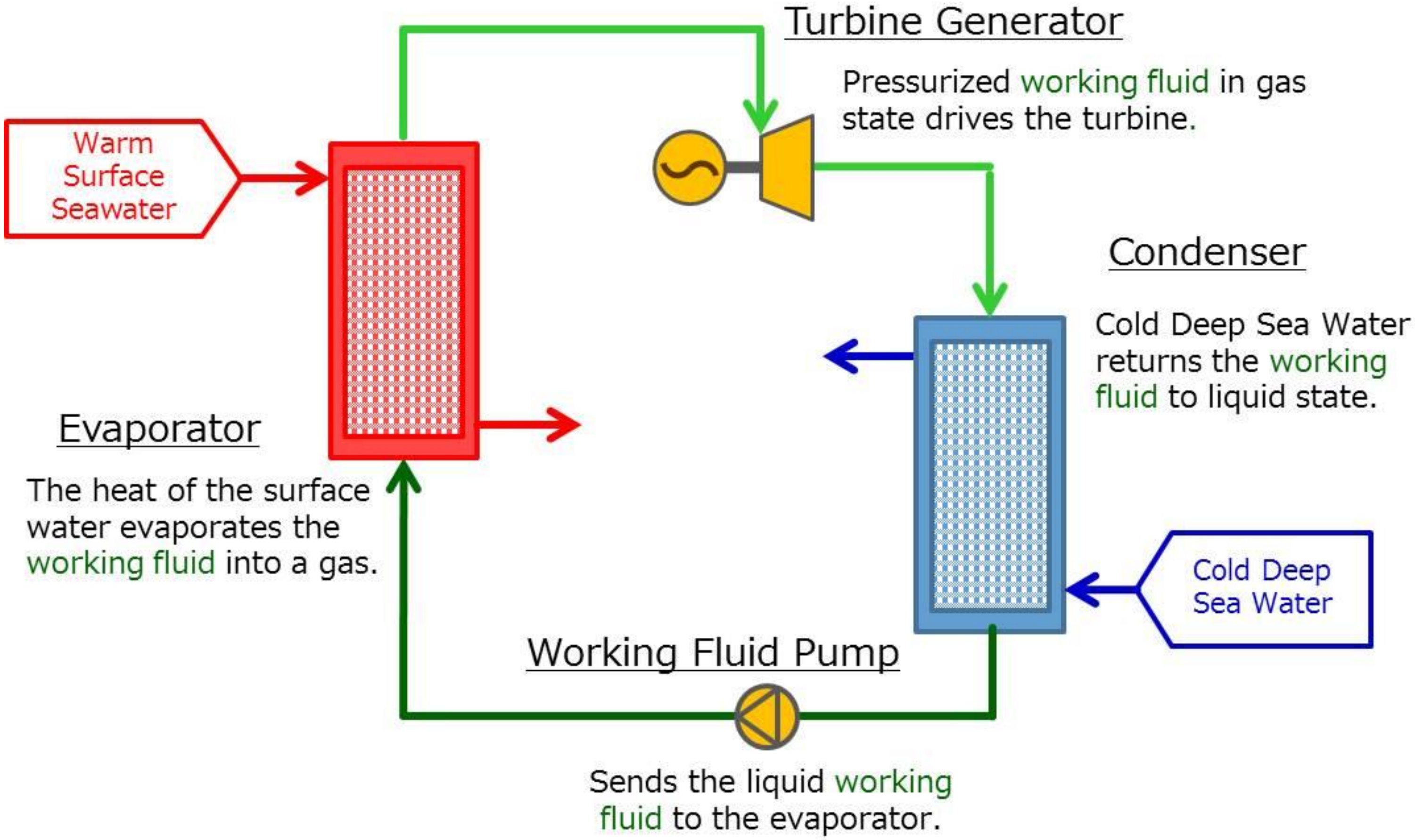


https://www.naval-energies.com/en/our-offer/lenergie-thermique-des-mers/

Ocean Thermal Energy Conversion



http://otecokinawa.com/en/OTEC/index.html

Ocean Thermal Energy Conversion

- OTEC technology uses a turbine generator to create renewable energy from the temperature difference between cold, deep seawater circulating in the ocean and surface seawater warmed by the sun. In order to produce power with the low temperature range, a working fluid with low boiling point is used.
- The amount of energy created is dependent on the amount of water available to cool or heat the working fluid. The Okinawa OTEC project has a maximum capacity of 100 kW, but since it does not always have access to the maximum capacity due to other seawater users, will often produce less electricity.
- This is due to the previous use of water by local industries and the Okinawa Deep Seawater Research Center, and does not hinder the project's goal of demonstration and testing.

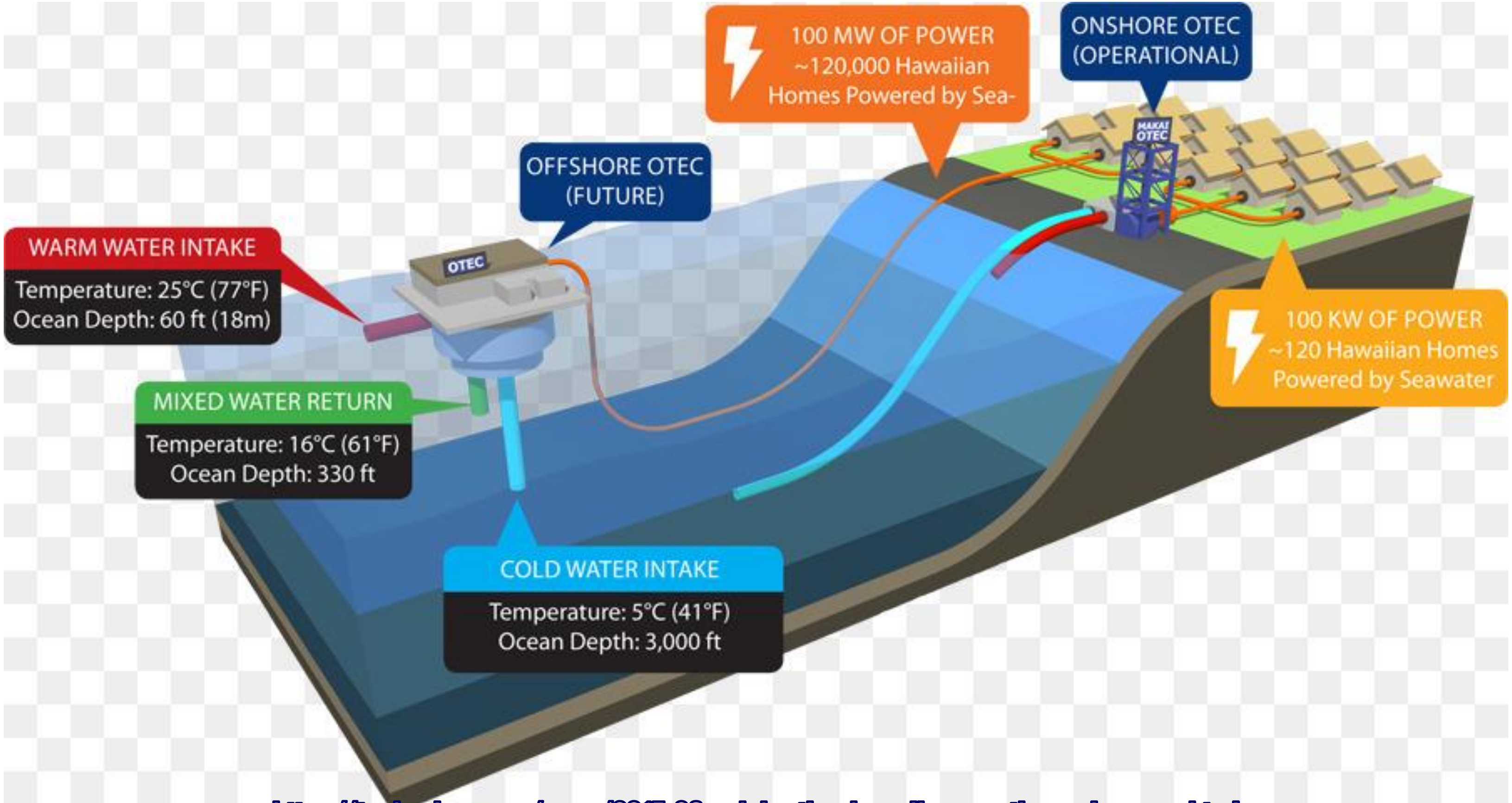
http://otecokinawa.com/en/OTEC/index.html

Ocean Thermal Energy Conversion

- Since seawater temperature does not change rapidly, the power output is stable and prediction of potential power generation is more reliable than many other renewable sources. The seawater pumped in for use at an OTEC plant can be used for many different applications, offsetting the cost of initial pipeline investment.
- Physicist Jacques-Arsène d'Arsonval of France first proposed the idea in 1881. Development has been intermittent since, but in response to the recent growth in interest in renewable energy, development has increased in countries such as the United States, France, China, and Japan.
- With current technology, an annual temperature difference of 20°C or more is needed. This difference is found in subtropical and tropical regions such as the Okinawa, Kuroshio, and Ogasawara areas in Japan.
- The potential power generation is 5,952 MW within 30 km of the shore.

http://otecokinawa.com/en/OTEC/index.html

Ocean Thermal Energy Conversion Power Plant



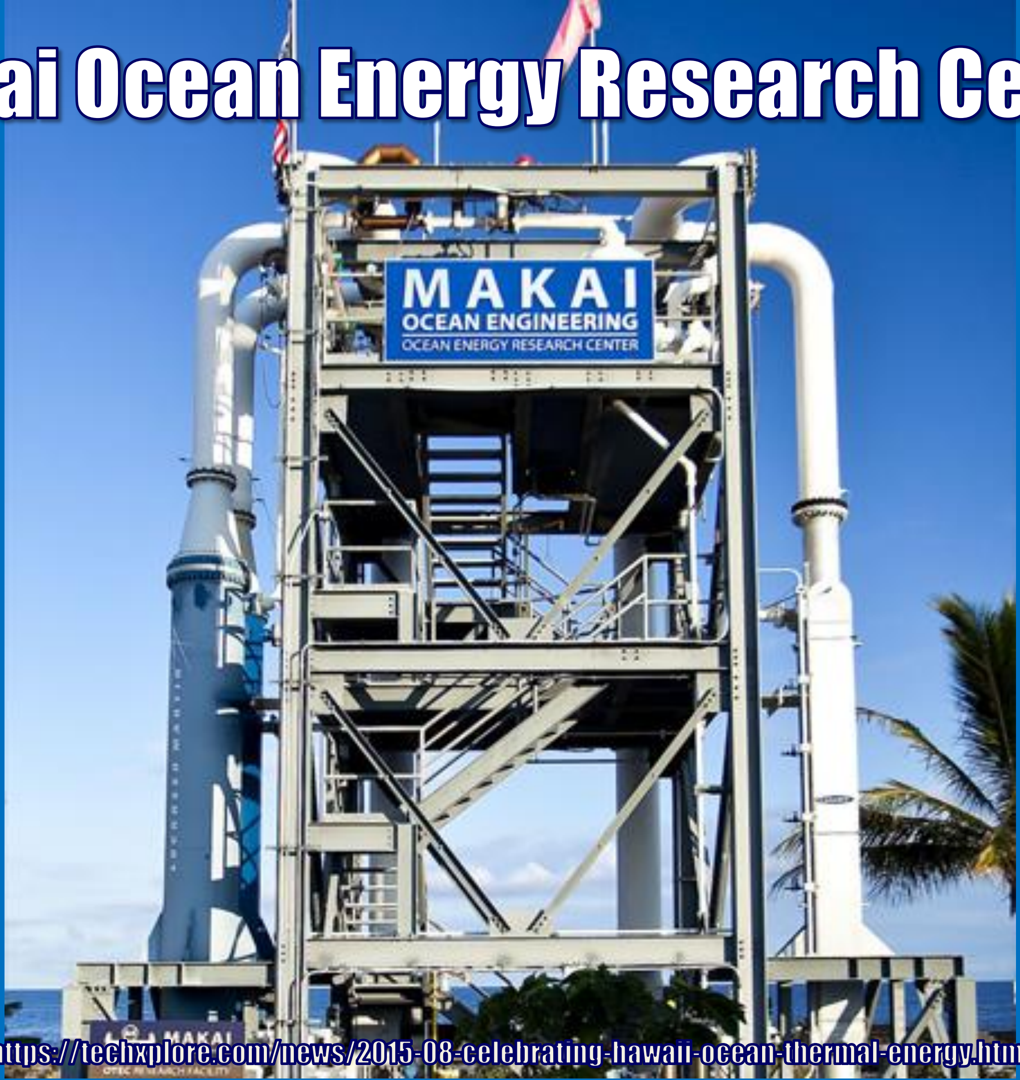
https://techxplore.com/news/2015-08-celebrating-hawaii-ocean-thermal-energy.html

Celebrating Hawaii OTEC Power Plant

- An ocean thermal energy conversion power plant has gone operational; it was celebrated at the Natural Energy Laboratory of Hawaii Authority earlier this month. The governor of Hawaii, David Ige, flipped the switch to activate the plant. This is the first true closed-cycle OTEC plant to be connected to a U.S. electrical grid.
- The process involves power derived from ocean temperature differences between the warm, shallow seawater lapping up against a beach and the icy depths of the ocean. The plant situated at the Natural Energy Laboratory of Hawaii Authority expects to generate enough energy to power 120 homes per year and is the largest plant of its kind in the world. OTEC plants pump large quantities of deep cold seawater and surface seawater to run a power cycle and produce electricity. The project cost ~US$ 5 Million to build and this was the world's largest plant to date utilizing the renewable source.

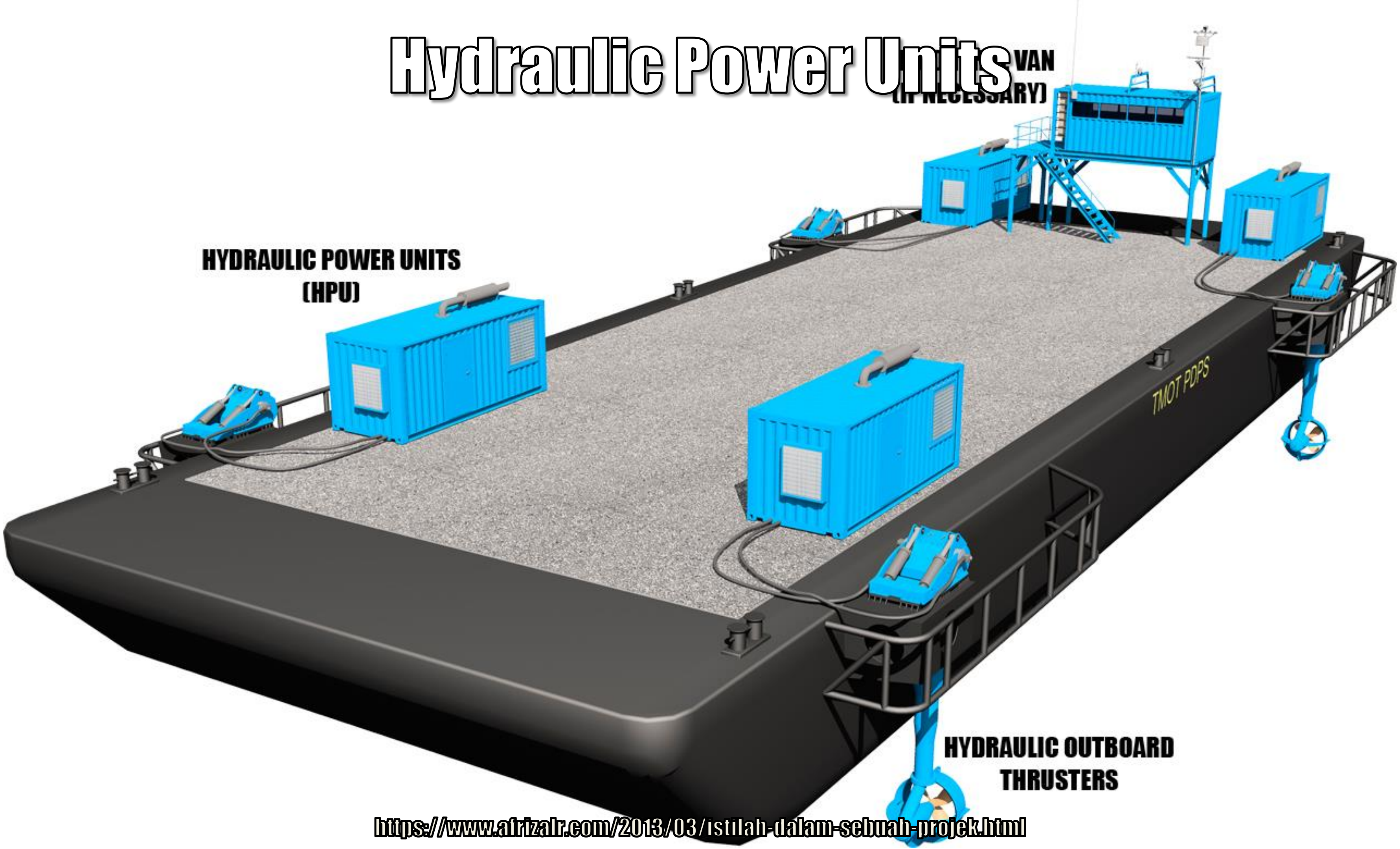
https://techxplore.com/news/2015-08-celebrating-hawaii-ocean-thermal-energy.html

Makai Ocean Energy Research Center



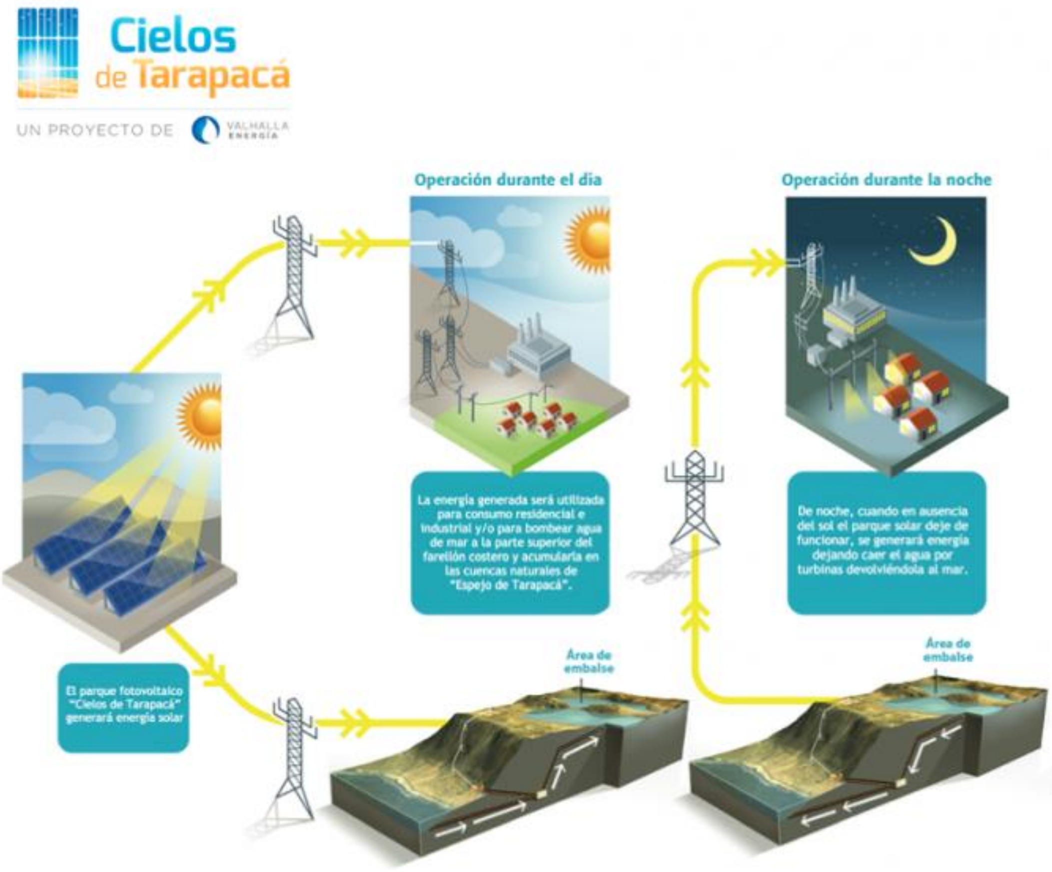
https://techxplore.com/news/2015-08-celebrating-hawaii-ocean-thermal-energy.html

Hydraulic Power Units



https://www.afrizalr.com/2013/03/istilah-dalam-sebuah-projek.html

24/7 Solar Plus Pumped Storage Plant



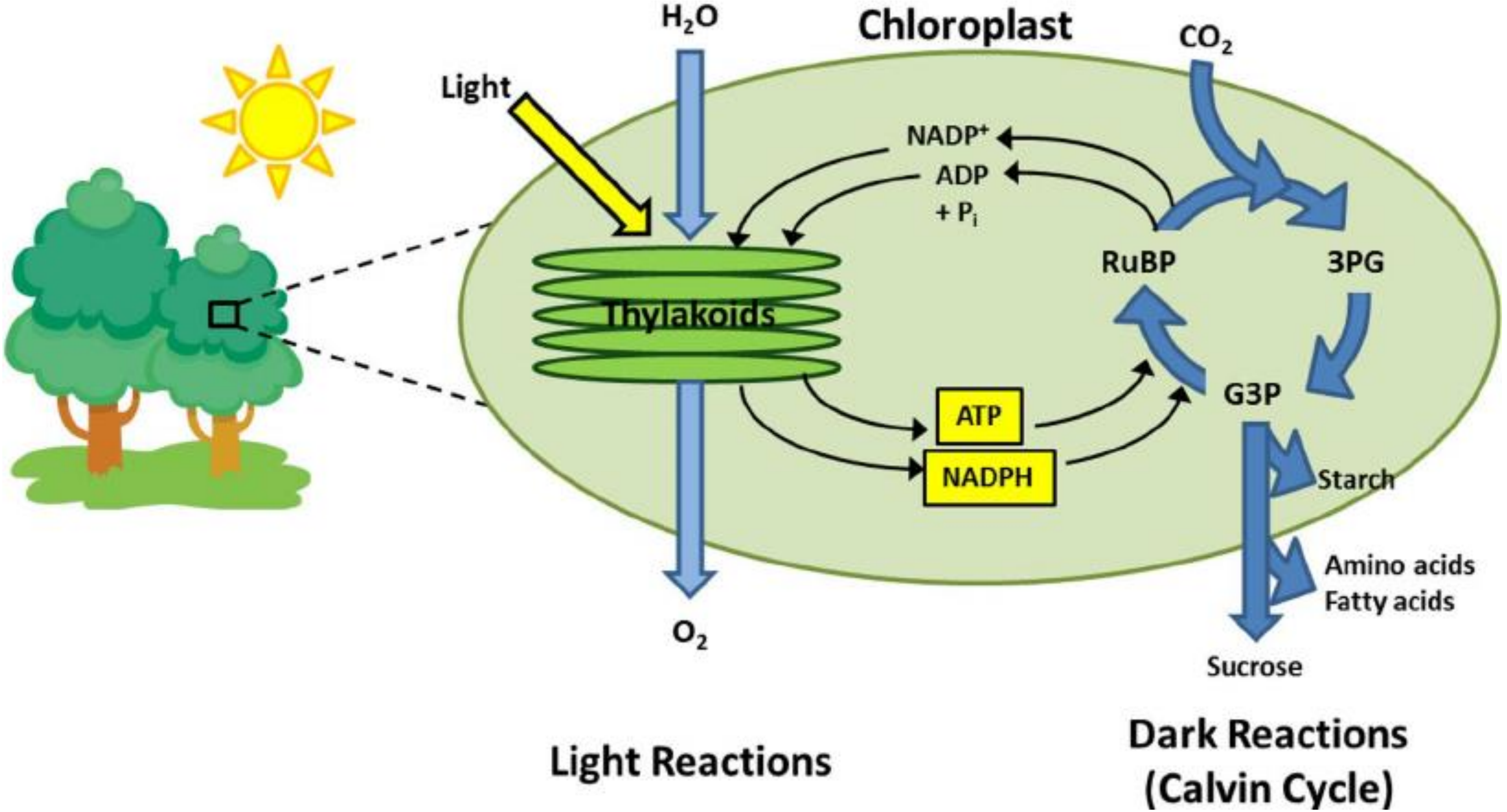
https://www.energy-storage.news/news/plan-for-24-7-solar-plus-pumped-storage-plant-could-join-chiles-rapidly-gro

Chile's Rapidly Growing Renewable Efforts

- Chilean authorities have received plans for an ambitious 600 MW PV plant project which could be connected to a 300 MW pumped hydro energy storage plant, from developer Valhalla Energy.
- The plant's combined technologies could allow the electricity generated to be used 24 hours a day, although there are still some decisions to be made on the overall scope of the project.
- Earmarked for the northern Tarapaca region, the project could require as many as 600 workers on site, according to plans submitted to Chile's environmental assessment service (Servicio de Evaluación Ambiental, SEIA).
- The project will require the building of substations and some 18 km of transmission wires in addition to the photovoltaic plant and the "Mirror of Tarapaca," as Valhalla has named the seawater pumped hydro facility.

https://www.energy-storage.news/news/plan-for-24-7-solar-plus-pumped-storage-plant-could-join-chiles-rapidly-gro

Conversion of Solar Energy into Chemical Energy



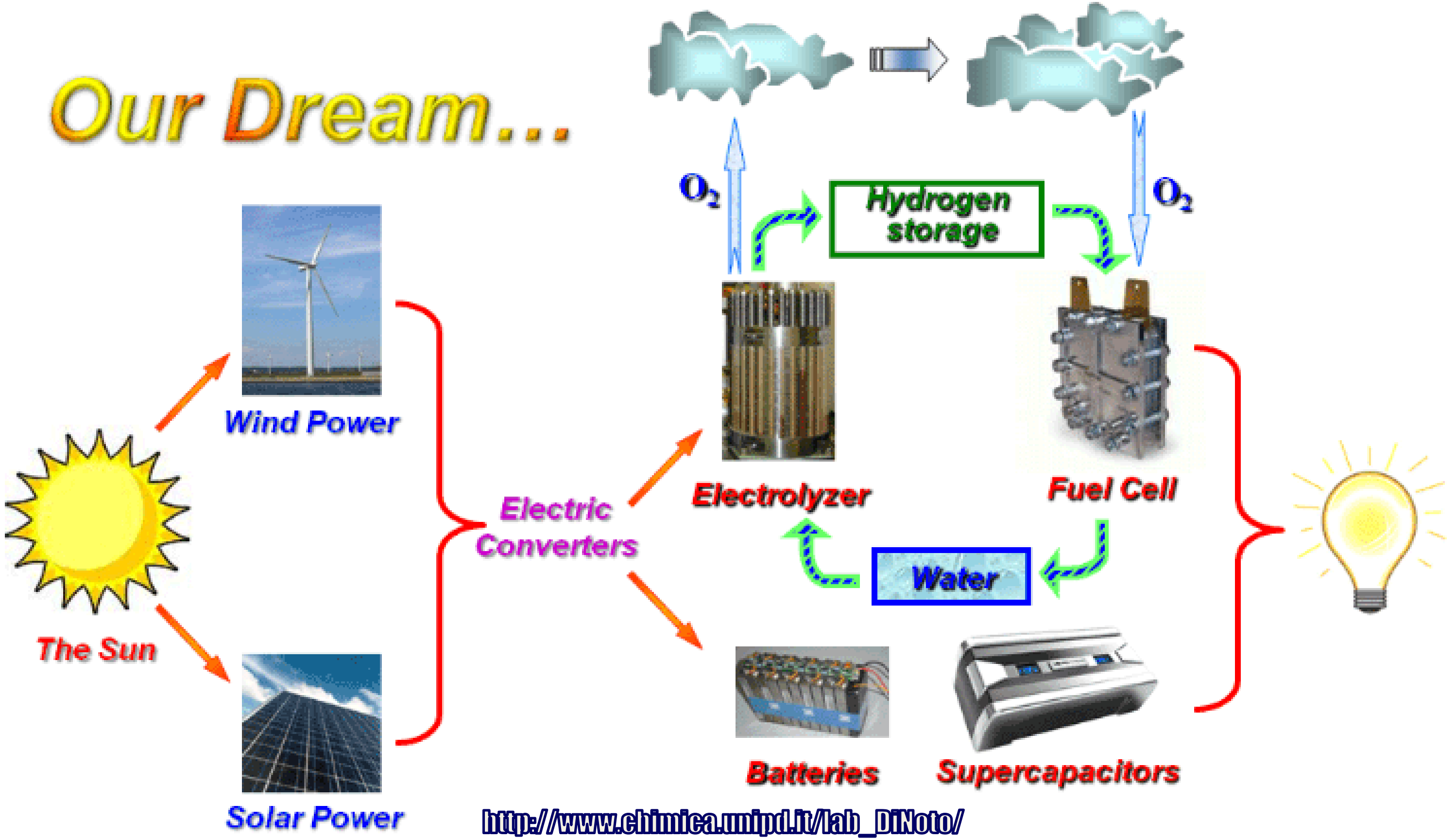
https://www.researchgate.net/figure/Photosynthesis-is-an-energy-conversion-process-which-occurs-in-plants-and-certain-types_fig1_264047223

Photobioelectrochemistry

- Photosynthesis, the conversion of solar energy into chemical energy, is an essential process for life on Earth. This process occurs in plants and certain types of bacteria. In photosynthesis, carbon dioxide in the atmosphere and water is converted into oxygen and carbohydrates, providing an energy source for the photosynthetic organism as well as food for other organisms.
- The light-dependent reactions of photosynthesis result in the production of ATP and NADPH which are then used in the dark reactions to drive the conversion of CO_2 to carbohydrates. The light reactions occur in the membrane and make up an electron transport chain similar to that in mitochondria. Photosynthetic bacteria act as light harvesting complexes where energy from absorbed photons is passed from molecule to molecule until reaching a photosynthetic reaction center.

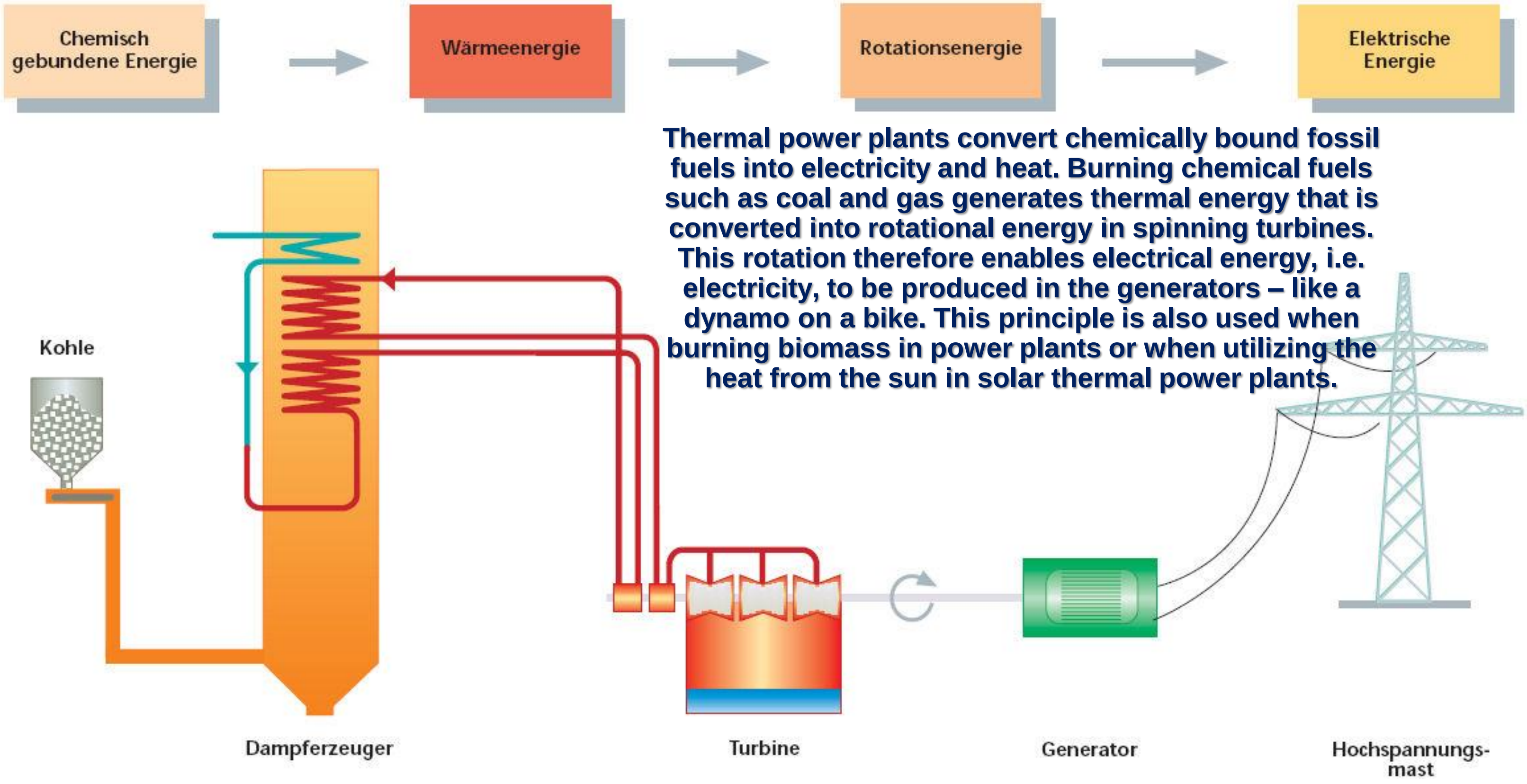
https://www.researchgate.net/figure/Photosynthesis-is-an-energy-conversion-process-which-occurs-in-plants-and-certain-types_fig1_264047223

Dream Come True...



http://www.chimica.unipd.it/lab_DiNoto/

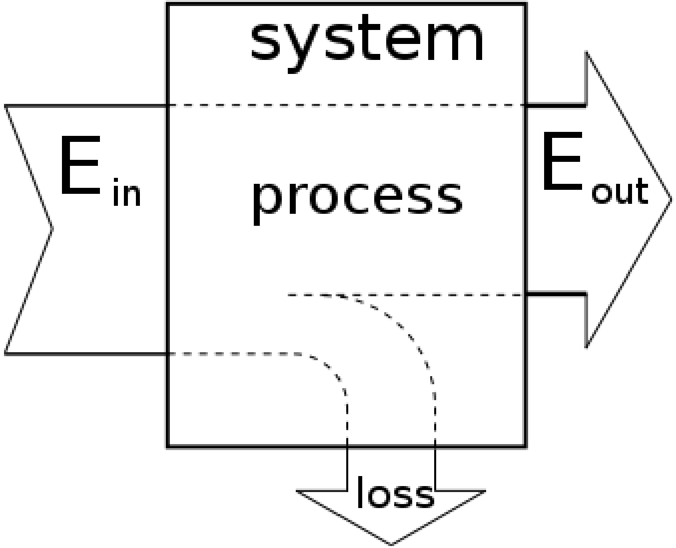
Multiple Energy Conversion



Thermal power plants convert chemically bound fossil fuels into electricity and heat. Burning chemical fuels such as coal and gas generates thermal energy that is converted into rotational energy in spinning turbines. This rotation therefore enables electrical energy, i.e. electricity, to be produced in the generators – like a dynamo on a bike. This principle is also used when burning biomass in power plants or when utilizing the heat from the sun in solar thermal power plants.

http://kraftwerkforschung.info/en/quickinfo/basic-concepts/triple-energy-conversion-energy-sources-heat-rotation-electricity/

Energy Conversion Efficiency



Useful output energy, or exergy, is always lower than input energy.

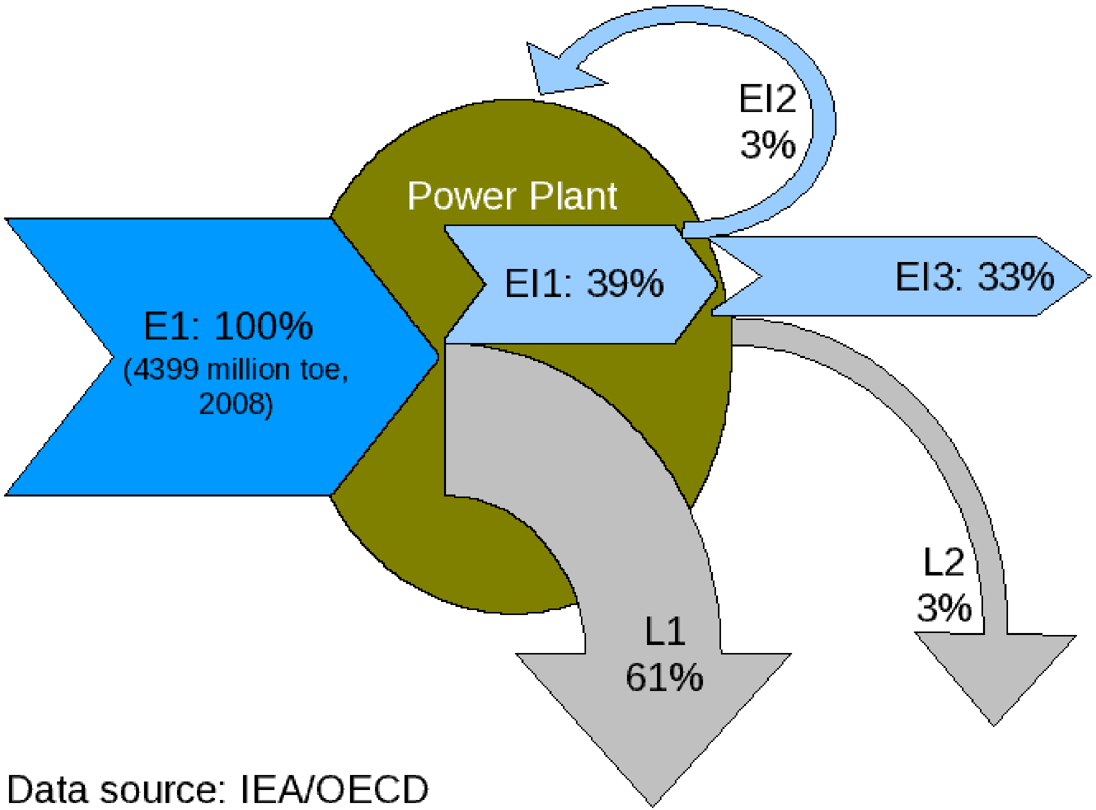
https://en.wikipedia.org/wiki/Energy_conversion_efficiency

Energy Conversion Efficiency

- Energy conversion efficiency η is the ratio between the useful output of an energy converter and the input, in energy terms. The input, as well as the useful output may be chemical, electrical, mechanical, ocular, or thermal.
- Energy conversion efficiency depends on the usefulness of the output. All or part of the heat produced from burning a fuel may become rejected waste heat if work is the desired output from a thermodynamic cycle. Energy converter is an example of an energy transformation. For example a light bulb falls into the categories energy converter.
- Even though the definition includes the notion of usefulness, efficiency is considered a technical or physical term. Goal or mission oriented terms include effectiveness and efficacy. Generally, energy conversion efficiency is a dimensionless number. Efficiencies may not exceed 100%. However, other effectiveness measures can exceed 100%.

https://en.wikipedia.org/wiki/Energy_conversion_efficiency

Efficiency of Power Plants, World Total 2008

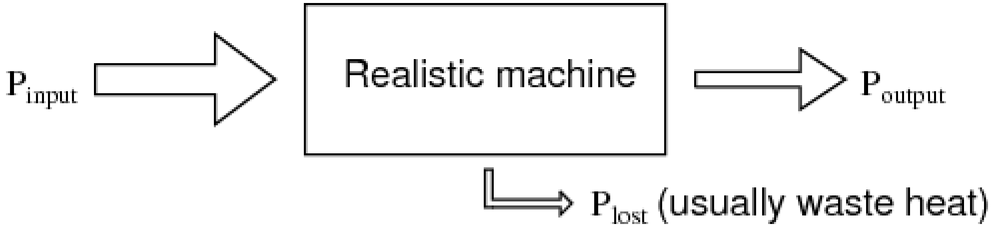


Data source: IEA/OECD

https://en.wikipedia.org/wiki/Energy_conversion_efficiencye

Perfect v. Realistic Machine

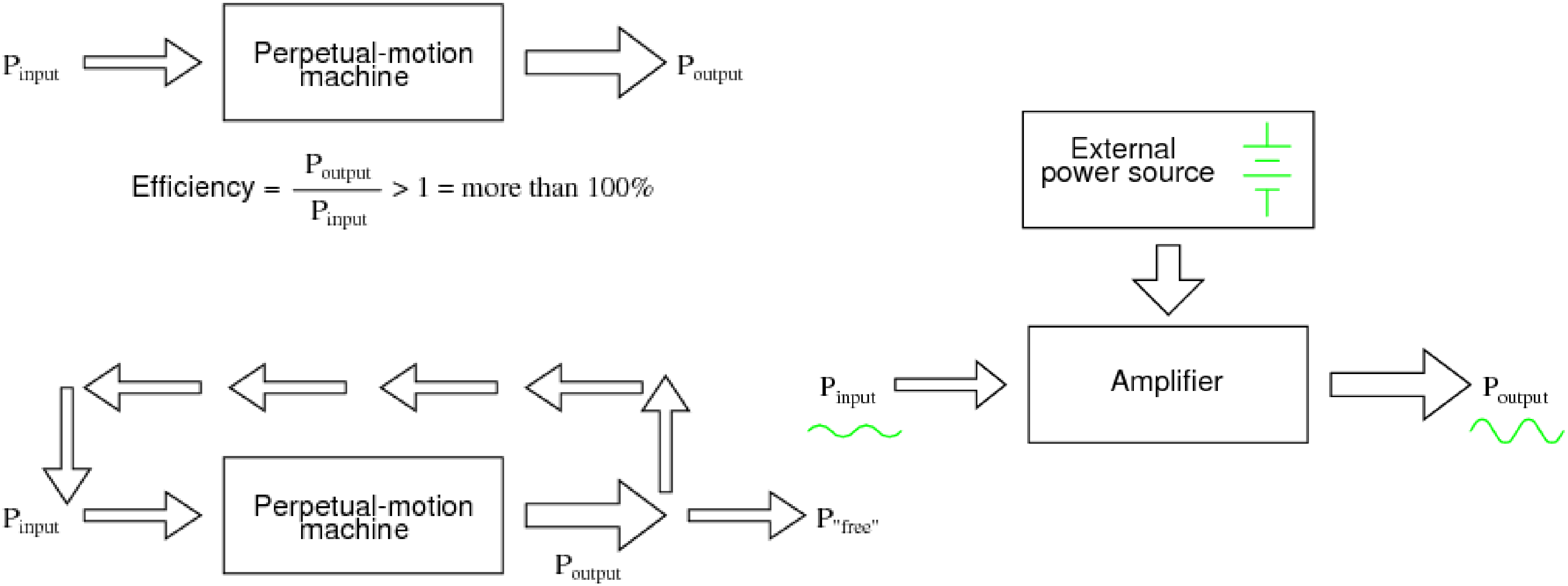
$$\text{Efficiency} = \frac{P_{output}}{P_{input}} = 1 = 100\%$$



$$\text{Efficiency} = \frac{P_{output}}{P_{input}} < 1 = \text{less than } 100\%$$

http://uwave.blogsky.com/1395/09/04/post-51

Perpetual Motion Machine & Amplifier



http://uwave.blogsky.com/1395/09/04/post-51

Thermodynamic Considerations

- We'll trace the development of energy conversion technology, highlighting not only conventional systems but also alternative and experimental converters with considerable potential.
- It delineates their distinctive features, basic principles of operation, major types, and key applications.
- We'll be discussing the laws of thermodynamics and their impact on system design and performance.
- Energy is usually and most simply defined as the equivalent of or capacity for doing work.
- The word itself is derived from the Greek energeia: en, "in"; ergon, "work." Energy can either be associated with a material body, as in a coiled spring or a moving object, or it can be independent of matter, as light and other electromagnetic radiation traversing a vacuum.

https://www.britannica.com/technology/energy-conversion

The Idea of Energy

- The energy in a system may be only partly available for use. The dimensions of energy are those of work, which, in classical mechanics, is defined formally as the product of mass (m) and the square of the ratio of length (l) to time (t): ml^2/t^2.
- This means that the greater the mass or the distance through which it is moved or the less the time taken to move the mass, the greater will be the work done, or the greater the energy expended.
- The term energy was not applied as a measure of the ability to do work until rather late in the development of the science of mechanics.
- Indeed, the development of classical mechanics may be carried out without recourse to the concept of energy.
- The idea of energy, however, goes back at least to Galileo in the 17th century.

https://www.britannica.com/technology/energy-conversion

https://undark.org/2012/08/23/npr-angel-heavenly-mirror-man-eyes-earth/

The Concept of Vis Viva

- Galileo recognized that, when a weight is lifted with a pulley system, the force applied multiplied by the distance through which that force must be applied remains constant even though either factor may vary.
- The concept of vis viva, or living force, was introduced in the 17th century. In the 19th century the term energy was applied to the concept of the vis viva.
- Newton's first law of motion recognizes force as being associated with the acceleration of a mass. It is almost inevitable that the integrated effect of the force acting on the mass would then be of interest. Of course, there are two kinds of integral of the effect of the force acting on the mass that can be defined.
- One is the integral of the force acting along the line of action of the force, or the spatial integral of the force; the other is the integral of the force over the time of its action on the mass, or the temporal integral.

https://www.britannica.com/technology/energy-conversion

Energy of a Harmonized Future

VIS VIVA

ENERGY OF A HARMONIZED FUTURE

http://www.vis-viva-energija.com/en/

Development of the Concept of Energy

- Evaluation of the spatial integral leads to a quantity that is now taken to represent the change in kinetic energy of the mass resulting from the action of the force and is just one half the vis viva.
- On the other hand, the temporal integration leads to the evaluation of the change in momentum of the mass resulting from the action of the force.
- For some time there was debate as to which integration led to the proper measure of force, Leibniz arguing for the spatial integral as the only true measure, while Descartes had defended the temporal integral.
- Eventually, in the 18th century, d'Alembert showed the legitimacy of both approaches to measuring the effect of a force acting on a mass.
- Force is associated with the acceleration of a mass; kinetic energy, or energy resulting from motion, is the result of the spatial integration of a force acting on a mass.

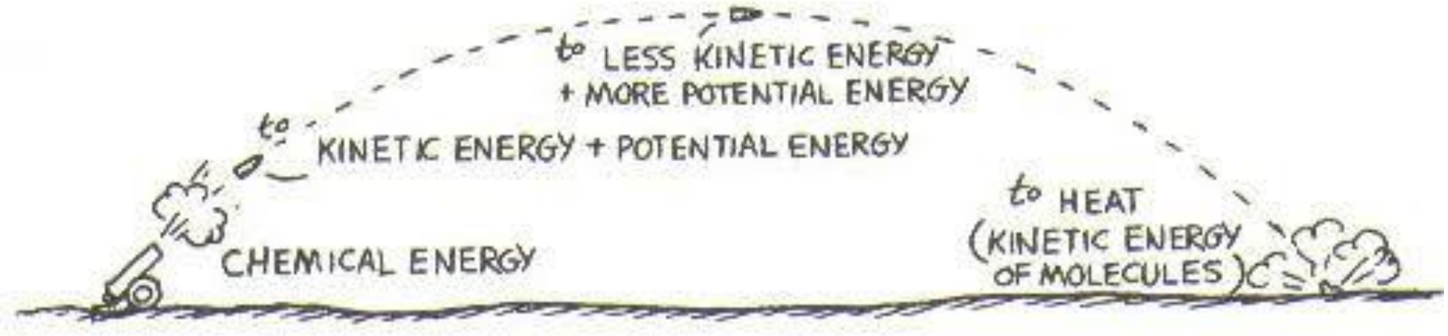
https://www.britannica.com/technology/energy-conversion

Conservation of Energy

- Momentum is the result of the temporal integration of the force acting on a mass; and energy is a measure of the capacity to do work. Power is defined as the time rate at which energy is transferred to a mass as a force acts on it, or through transmission lines from the generator to the consumer.
- Conservation of energy was independently recognized by many scientists in the first half of the 19^{th} century. The conservation of energy as kinetic, potential, and elastic energy in a closed system under the assumption of no friction has proved to be a valid and useful tool.
- Further, upon closer inspection, the friction, which serves as the limitation on classical mechanics, is found to express itself in the generation of heat, whether at the contact surfaces of a block sliding on a plane or in the bulk of a fluid in which a paddle is turning or any of the other expressions of friction.

https://www.britannica.com/technology/energy-conversion

Energy Just Changes Forms



Energy Cannot Be Created or Destroyed

(It just changes forms)

https://www.britannica.com/technology/energy-conversion

From Chemical to Nuclear Processes

- Heat was identified as a form of energy by Helmholtz and Joule during the 1840s. Joule also proved experimentally the relationship between mechanical and thermal energy at this time. As more detailed descriptions of the various processes in nature became necessary, the approach was to seek rational theories or models for the processes that allow a quantitative measure of the energy change in the process and then to include it and its attendant energy balance within the system of interest, subject to the overall need for the conservation of energy.
- This approach has worked for the chemical energy in the molecules of fuel and oxidizer liberated by their burning in an engine to produce thermal energy that subsequently is converted to mechanical energy to run a machine.
- It has also worked for the conversion of nuclear mass into energy in the nuclear fusion and nuclear fission processes.

https://www.britannica.com/technology/energy-conversion

Conservation of Energy, Still…

- A fundamental law that has been observed to hold for all natural phenomena requires the conservation of energy that the total energy does not change in all the many changes that occur in nature.
- The conservation of energy is a statement that the quantity called energy remains constant regardless of when it is evaluated or what processes, possibly including transformations of energy from one form into another, go on between successive evaluations.
- Conservation of energy is applied not only to nature as a whole but to closed or isolated systems within nature as well. Thus, if the boundaries of a system can be defined in such a way that no energy is either added to or removed from the system, then energy must be conserved within that system regardless of the details of the processes going on inside the system boundaries.

https://www.britannica.com/technology/energy-conversion

Transformation of Energy

- Energy can exist in many forms within a system and may be converted from one form to another within the constraint of the conservation law. These different forms include gravitational, kinetic, thermal, elastic, electrical, chemical, radiant, nuclear, and mass energy.
- It is the universal applicability of the concept of energy, as well as the completeness of the law of its conservation within different forms, that makes it so attractive and useful.
- A simple example of a system in which energy is being converted from one form to another is provided in the tossing of a ball with mass m into the air. When the ball is thrown vertically from the ground, its speed and thus its kinetic energy decreases steadily until it comes to rest momentarily at its highest point. It then reverses itself, and its speed and kinetic energy increase steadily as it returns to the ground.

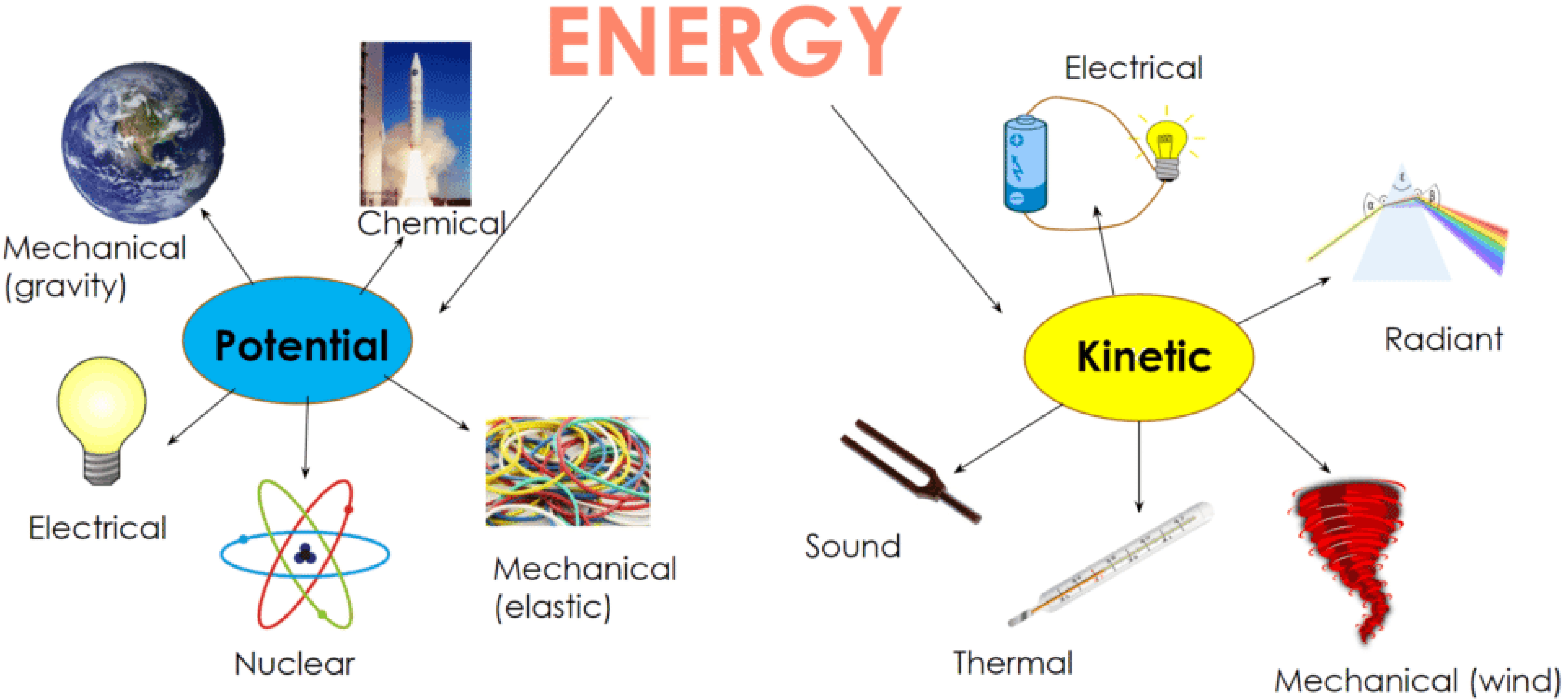
https://www.britannica.com/technology/energy-conversion

Energy Transformation

Conservation of Energy

ENERGY IN = ENERGY OUT

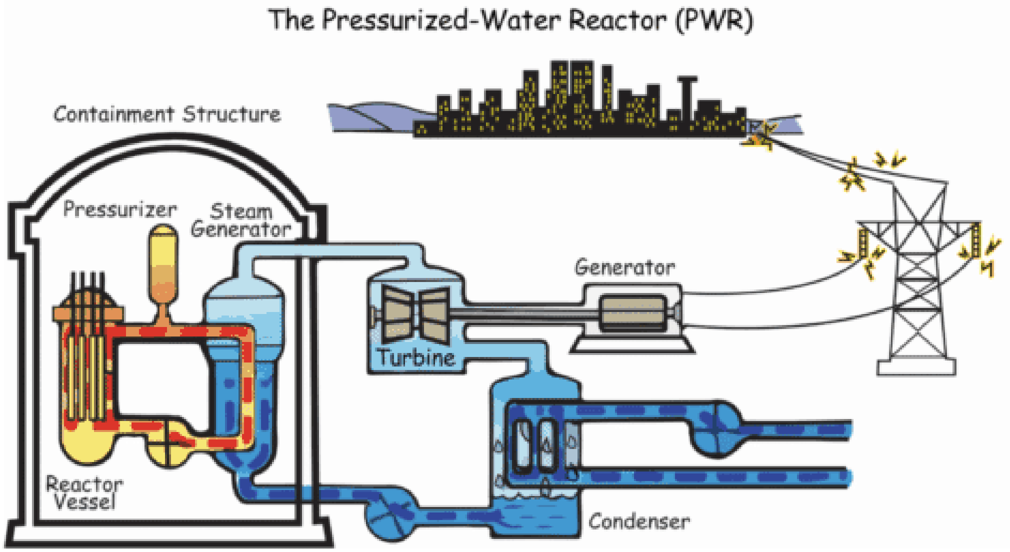
Energy Transformations



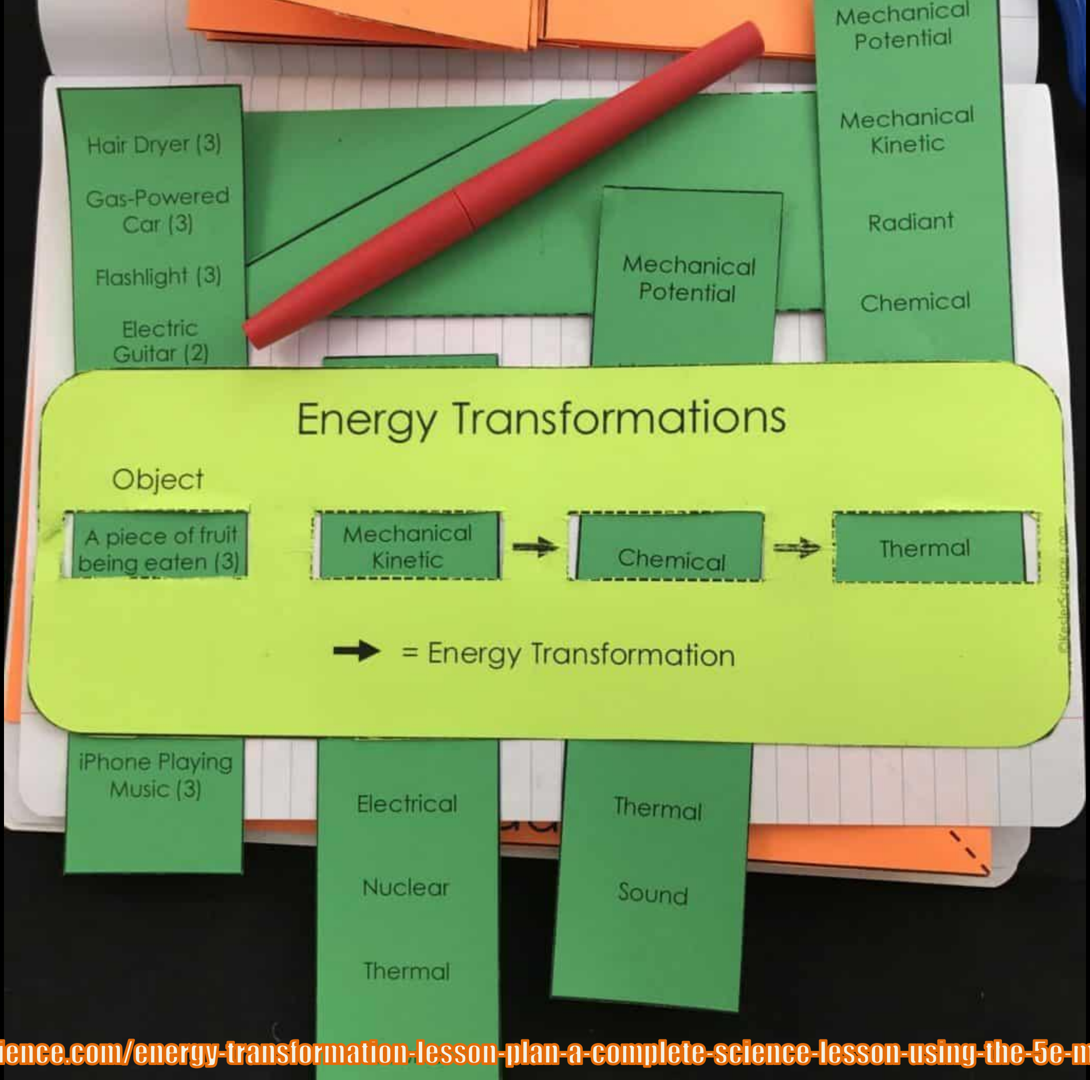
https://www.keslerscience.com/energy-transformation-lesson-plan-a-complete-science-lesson-using-the-5e-method-of-instruction/

Energy Transformations

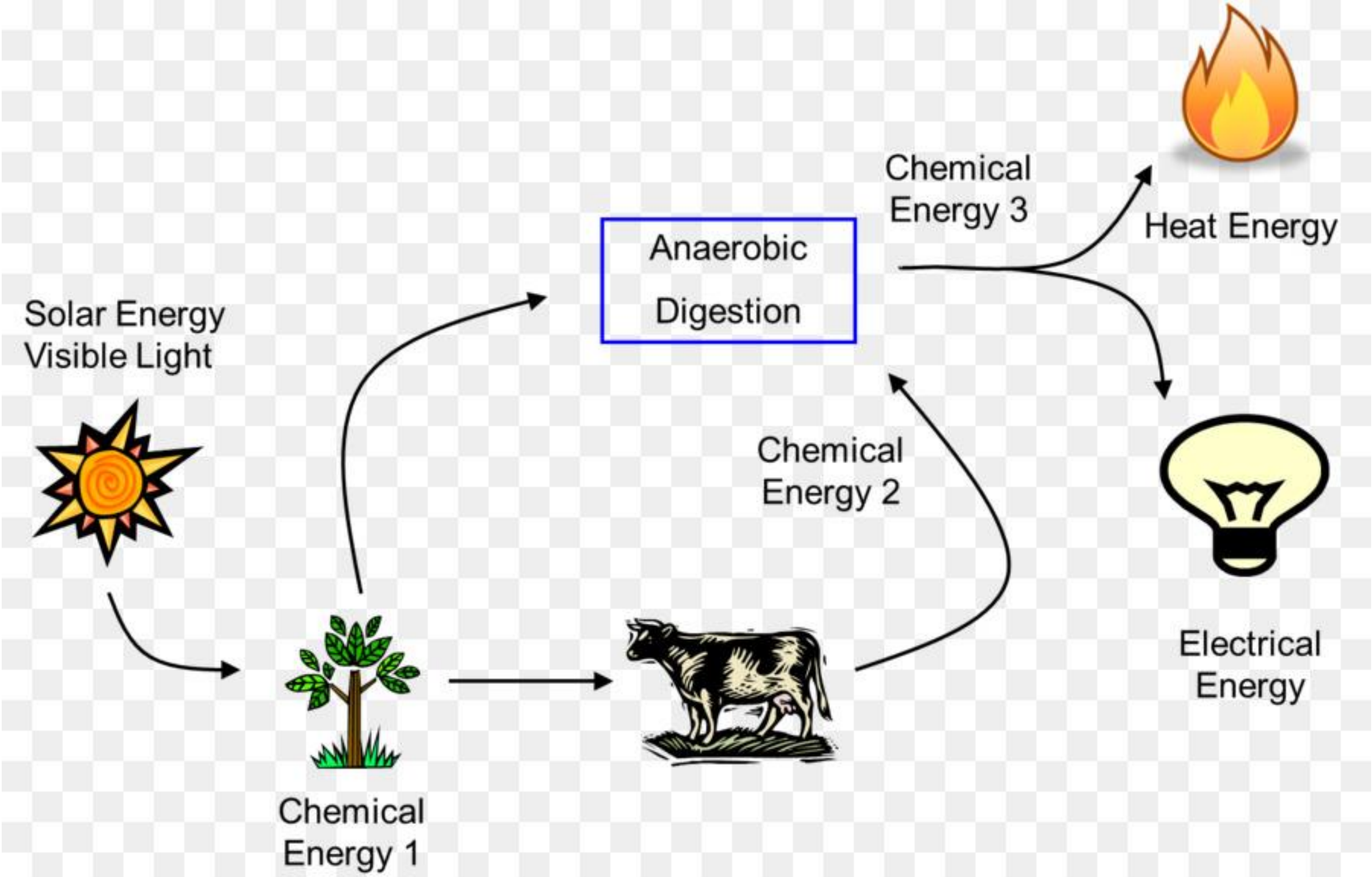
Can you follow the energy flow?



- Nuclear energy PE (fusion)
- Mechanical energy KE (turbine)
- Electrical energy KE (generator/wires)



https://www.keslerscience.com/energy-transformation-lesson-plan-a-complete-science-lesson-using-the-5e-method-of-instruction/


Solar Energy
Visible Light
Chemical
Energy 1
Anaerobic
Digestion
Chemical
Energy 2
Chemical
Energy 3
Heat Energy
Electrical
Energy

An Ideal System

- The kinetic energy E_k of the ball at the instant it left the ground (point 1) was half the product of the mass and the square of the velocity, or $^1/_2mv_1^2$, and decreased steadily to zero at the highest point (point 2). As the ball rose in the air, it gained gravitational potential energy E_p.
- Potential in this sense does not mean that the energy is not real but rather that it is stored in some latent form and can be drawn upon to do work. Gravitational potential energy is energy that is stored in a body by virtue of its position in the gravitational field. Gravitational potential energy of a mass m is observed to be given by the product of the mass, the height h attained relative to some reference height, and the acceleration g of a body resulting from the Earth's gravity pulling on it, or mgh. At the instant the ball left the ground at height h_1 its potential energy E_{p1} is mgh_1. At its highest point, its potential energy E_{p2} is mgh_2.

https://www.britannica.com/technology/energy-conversion

The Idealized Example

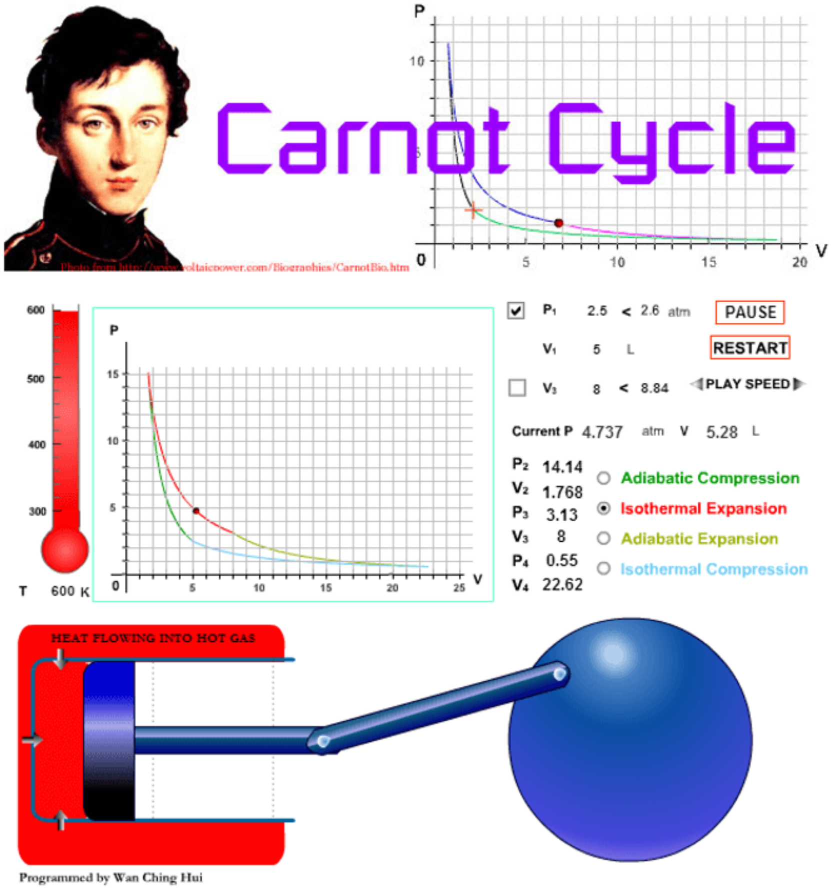
- Applying the law of conservation of energy and assuming no friction in the air, these add up to form the conservation equations.
- In this idealized example the kinetic energy of the ball at ground level is converted into work in raising the ball to h_2 where its gravitational potential energy has been increased by mg (h_2 - h_1). As the ball falls back to the ground level h_1, this gravitational potential energy is converted back into kinetic energy and its total energy at h_1 again is $\frac{1}{2}mv_1^2 + mgh_1$. In this chain of events the kinetic energy of the ball is unchanged at h_1; thus the work done on the ball by the force of gravity acting on it in this cycle of events is zero. This system is said to be a conservative one.
- Although the total amount of energy in an isolated system remains unchanged, there may be a great difference in the quality of different forms of energy.

https://www.britannica.com/technology/energy-conversion

Carnot Engine

- Many forms of energy can be transformed completely into work or into other forms of energy. This is true for mechanical energy and electrical energy.
- Carnot described in 1824 a theoretical power cycle of maximum efficiency for converting thermal into mechanical energy. He demonstrated that this efficiency is determined by the magnitude of the temperatures at which heat is added and waste heat is given off during the cycle.
- A practical engine operating on the Carnot cycle has never been devised, but the Carnot cycle determines the maximum efficiency of thermal energy conversion into any form of directed energy.
- The Carnot criterion renders 100% efficiency impossible for all heat engines. It constitutes the basis for what is now the second law of thermodynamics.

https://www.britannica.com/technology/energy-conversion



http://juntadigital.casadasciencias.org/recurso/6590

History of Energy Conversion Technology

- Early humans first made controlled use of an external, nonanimal energy source when they discovered how to use fire. Burning dried plant matter (primarily wood) and animal waste, they employed the energy from this biomass for heating and cooking. The generation of mechanical energy to supplant human or animal power came very much later—only about 2,000 years ago—with the development of simple devices to harness the energy of flowing water and of wind.
- The earliest machines were waterwheels, first used for grinding grain. They were subsequently adopted to drive sawmills and pumps, to provide the bellows action for furnaces and forges, to drive tilt hammers or trip-hammers for forging iron, and to provide direct mechanical power for textile mills. Until the development of steam power during the Industrial Revolution at the end of the 18th century, waterwheels were the primary means of mechanical power production, rivaled only occasionally by windmills. Thus, many industrial towns, especially in early America, sprang up at locations where water flow could be assured all year.

https://www.britannica.com/technology/energy-conversion

Smeaton's Waterwheel

- The first analysis of the performance of waterwheels was published in 1759 by Smeaton. Smeaton built a test apparatus with a small wheel to measure the effects of water velocity, as well as head and wheel speed. He found that the maximum efficiency (work produced divided by potential energy in the water) he could obtain was 22% for an undershot wheel and 63% for an overshot wheel (i.e., one in which water enters the wheel above its centre).
- In 1776 Smeaton became the first to use a cast-iron wheel, and two years later he introduced cast-iron gearing, thereby bringing to an end the all-wood construction that had prevailed since Roman times. Based on his model tests, Smeaton built an undershot wheel for the London Bridge waterworks that measured 4.6 m wide and 9.75 m in diameter. The results of Smeaton's experimental work came to be widely used throughout Europe for designing new wheels.

https://www.britannica.com/technology/energy-conversion

https://www.flickr.com/photos/23651645@N03/2483135204

Barker's Mill & Poncelet's Wheel

- During the mid-1700s a reaction waterwheel for generating small amounts of power became popular in the rural areas of England. In this type of device, commonly known as a Barker's mill, water flowed into a rotating vertical tube before being discharged through nozzles at the end of two horizontal arms. These directed the water out tangentially, much in the way that a modern rotary lawn sprinkler does. A rope or belt wound around the vertical tube provided the power takeoff.
- Early in the 19th century Poncelet designed curved paddles for undershot wheels to allow the water to enter smoothly. His design was based on the idea that water would run up the surface of the curved vanes, come to rest at the inner diameter, and then fall away with practically no velocity. This design increased the efficiency of undershot wheels to 65%.

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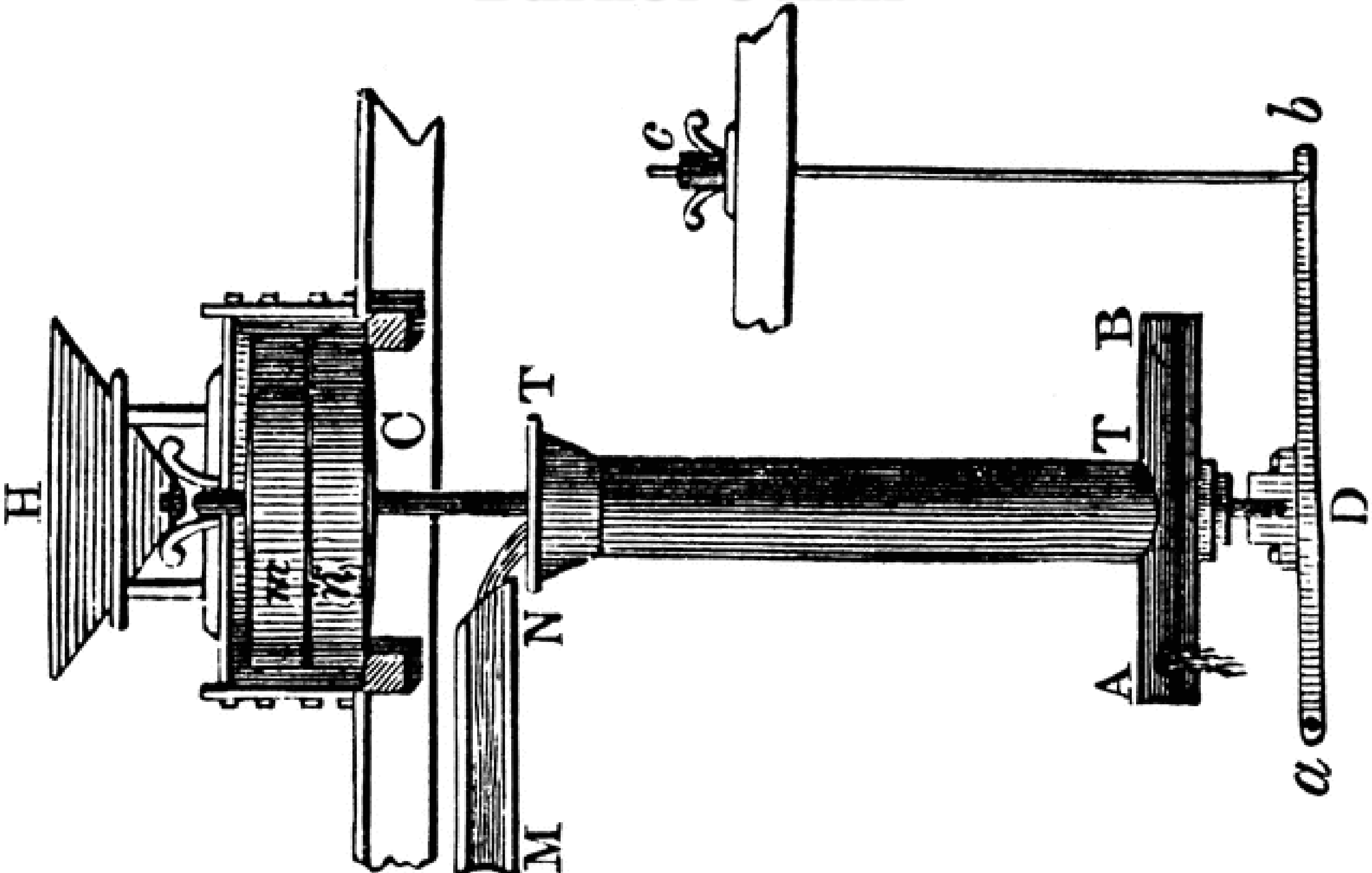
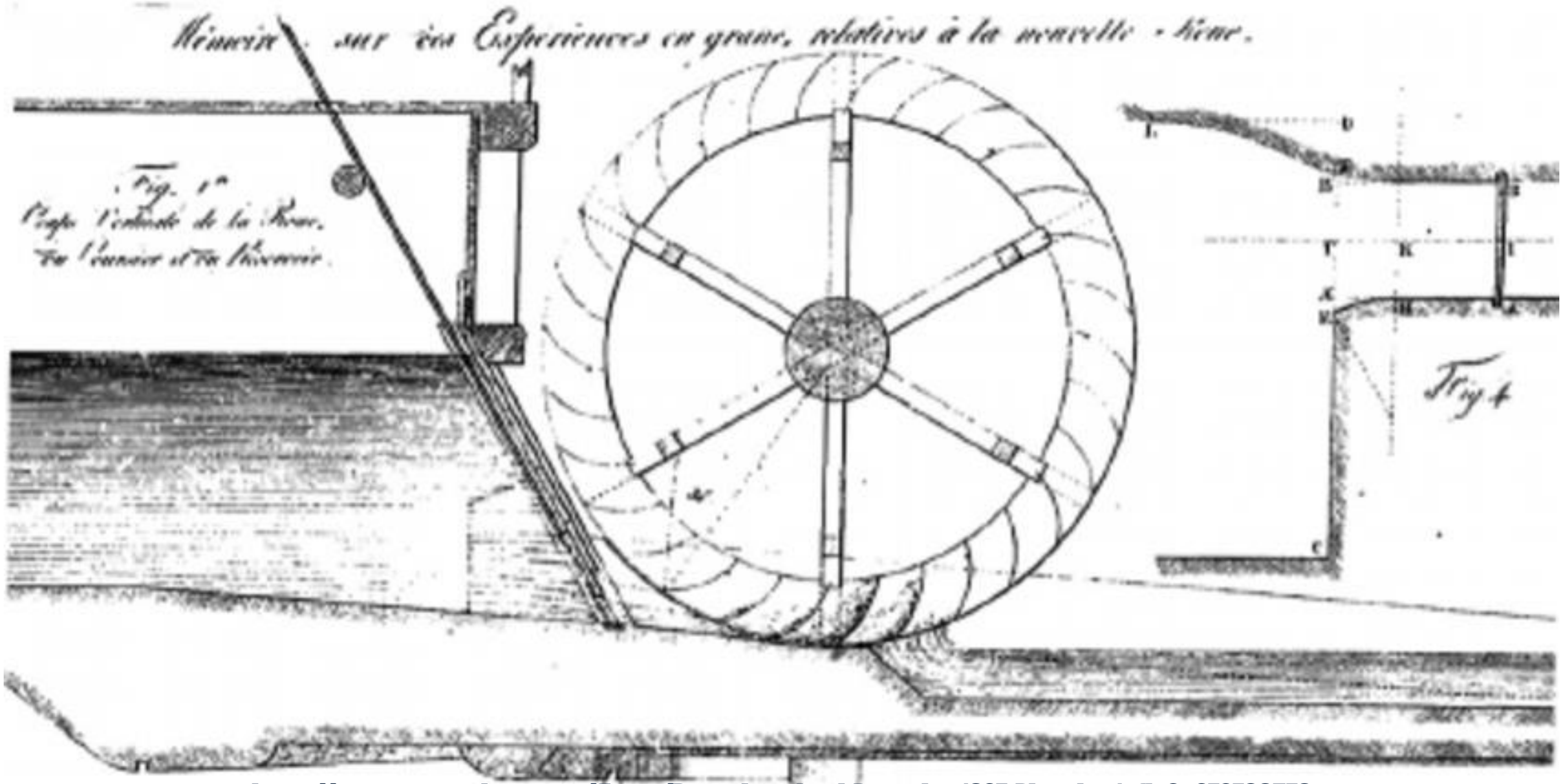
Barker’s Mill



https://etc.usf.edu/clipart/73800/73831/73831_barkersmill.htm

Poncelet's Wheel



https://www.researchgate.net/figure/Poncelet-wheel-Poncelet-1827-Planche-1_fig2_270768578

Fairbairn's Breast Wheels & More…

- At about the same time, Fairbairn showed that breast wheels (i.e., those in which water enters at the 10- or two-o'clock position) were more efficient than overshot wheels and less vulnerable to flood damage. He used curved buckets and provided a close-fitting masonry wall to keep the water from flowing out sideways. In 1828 Fairbairn introduced ventilated buckets in which gaps at the bottom of each bucket allowed trapped air to escape. Other improvements included a governor to control the sluice gates and spur gearing for the power takeoff.
- During the course of the 19th century, waterwheels were slowly supplanted by water turbines. Water turbines were more efficient; design improvements eventually made it possible to regulate the speed of the turbines and to run them fast enough to drive electric generators.
- In the early 1970s there were more than 1,000 grain mills in use in Portugal.

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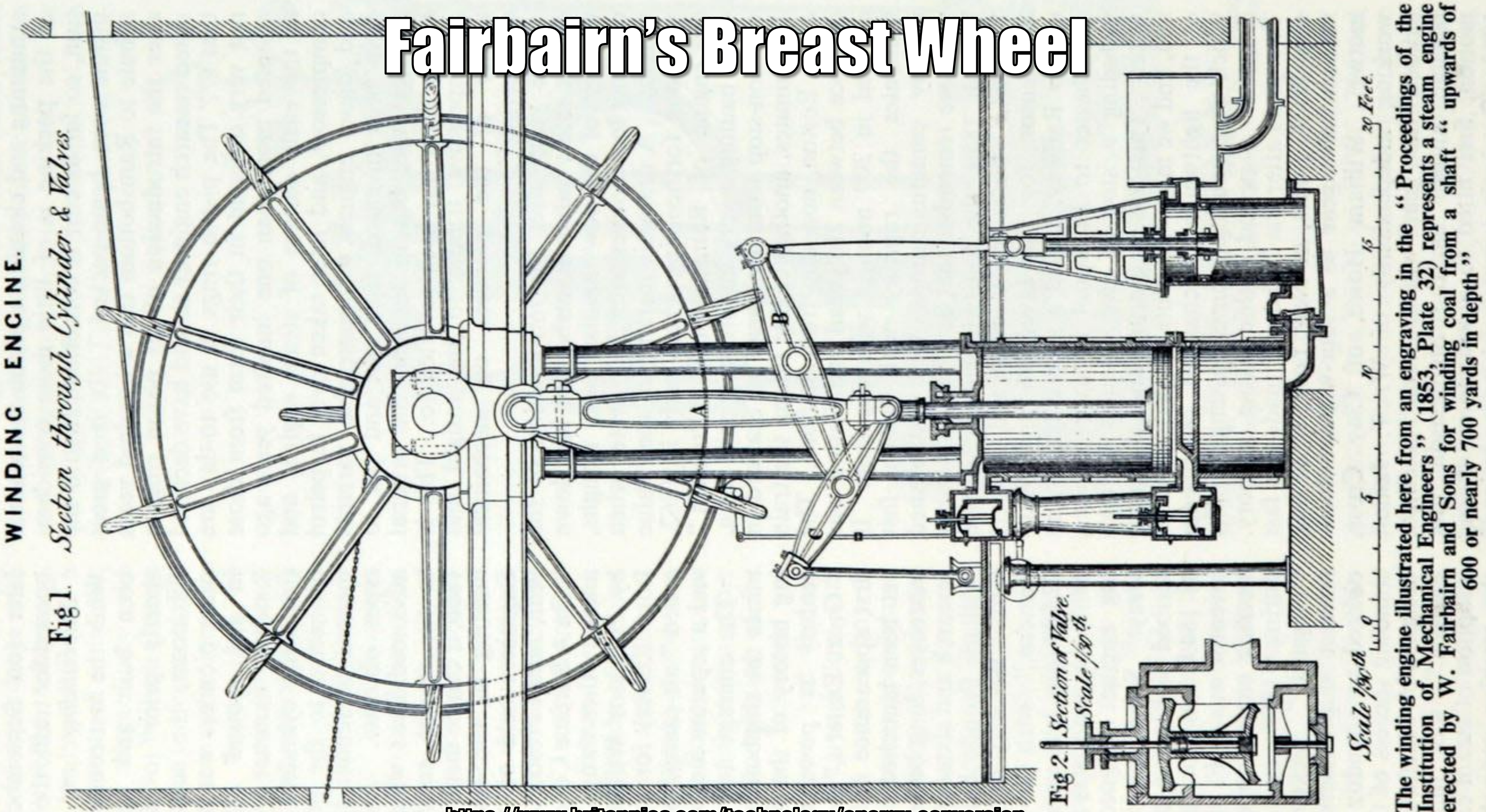
Fairbairn's Breast Wheel



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Windmills

- Windmills, like waterwheels, were among the original prime movers that replaced animal muscle as a source of power. They were used for centuries in various parts of the world, converting the energy of the wind into mechanical energy for grinding grain, pumping water, and draining.
- The first known wind device was described by Hero of Alexandria. It was modeled on a water driven paddle wheel and was used to drive a piston pump that forced air through a wind organ to produce sound. The earliest known references to wind driven grain mills refer to a Persian millwright, although windmills may actually have been used earlier. These mills, erected near what is now the Iran–Afghanistan border, had a vertical shaft with paddle-like sails radiating outward and were located in a building with diametrically opposed openings for the inlet and outlet of the wind. Each mill drove a single set of stones without gearing.

https://www.britannica.com/technology/energy-conversion


https://www.getyourguide.co.kr/amsterdam-l36/tour-mezza-giornata-zaanse-schans-partenza-da-amsterdam-t56832/?utm_force=0

The First Mills

- The first mills were built with the millstones above the sails, patterned after the early waterwheels from which they were derived. Similar mills were known in China by the 13th century.
- Windmills with vertical sails on horizontal shafts reached Europe through contact with the Arabs. Adopting the ideas from existing waterwheels, builders began to use fabric-covered, wood-framed sails located above the millstone, instead of a waterwheel below, to drive the grindstone through a set of gears. The whole mill with all its machinery was supported on a fixed post so that it could be rotated and faced into the wind. The millworks were initially covered by a boxlike wooden frame structure and later often by a round-house, which also provided storage. A brake wheel on the shaft allowed the mill to be stopped by a rim brake. A heavy lever then had to be raised to release the brake, an early example of a fail-safe device.

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Wind Pump

- Windmills persisted throughout the 19th century in newly settled areas.
- The primary exception to the steady abandonment of windmills was resurgence in their use in rural areas for pumping water from wells. The first wind pump was introduced in the U.S. by David Hallay in 1854. After another American, Stewart Perry, began constructing wind pumps made of steel and equipped with metal vanes in 1883, this new and simple device spread around the world.
- Wind-driven pumps remain important today in many rural parts of the world. They continued to be used in large numbers, even in the U.S., well into the 20th century until low-cost electric power became readily available in rural areas. Although rather inefficient, they are rugged and reliable, need little attention, and remain a prime source for pumping small amounts of water wherever electricity is not economically available.

https://www.britannica.com/technology/energy-conversion


Mobil
254
https://www.youtube.com/watch?v=7dFcyKcvtfk

Developments of the Industrial Revolution

- The rapid growth of industry in Britain from about the mid-18th century (and somewhat later in various other countries) created a need for new sources of motive power, particularly those independent of geographic location and weather conditions. This situation, together with certain other factors, set the stage for the development and widespread use of the steam engine, the first practical device for converting thermal energy to mechanical energy.
- The foundations for the use of steam power are often traced to the experimental work of Papin. In 1679 he invented a type of pressure cooker, a closed vessel with a tightly fitting lid that confined steam until high pressure was generated. Observing that the steam in the vessel raised the lid, he conceived the idea of using steam to power a piston and cylinder engine.

https://www.britannica.com/technology/energy-conversion

https://www.futurity.org/guns-war-industrial-revolution-1751012/

Newcomen Engine

- Newcomen developed a more efficient steam pump consisting of a cylinder fitted with a piston—a design inspired by Papin's aforementioned idea. When the cylinder was filled with steam, a counterweighted pump plunger moved the piston to the extreme upper end of the stroke. With the admission of cooling water, the steam condensed, creating a vacuum. The atmospheric pressure in the mine acted on the piston and caused it to move down in the cylinder, and the pump plunger was lifted by the resulting force.
- Newcomen entered into a partnership with Savery, and together they built, in 1712, the first piston-operated steam pump. Several years later Smeaton improved the Newcomen engine, almost doubling its efficiency. Although engines of this kind converted only about 1% of the thermal energy in the steam to mechanical energy, they remained unrivaled for over 50 years.

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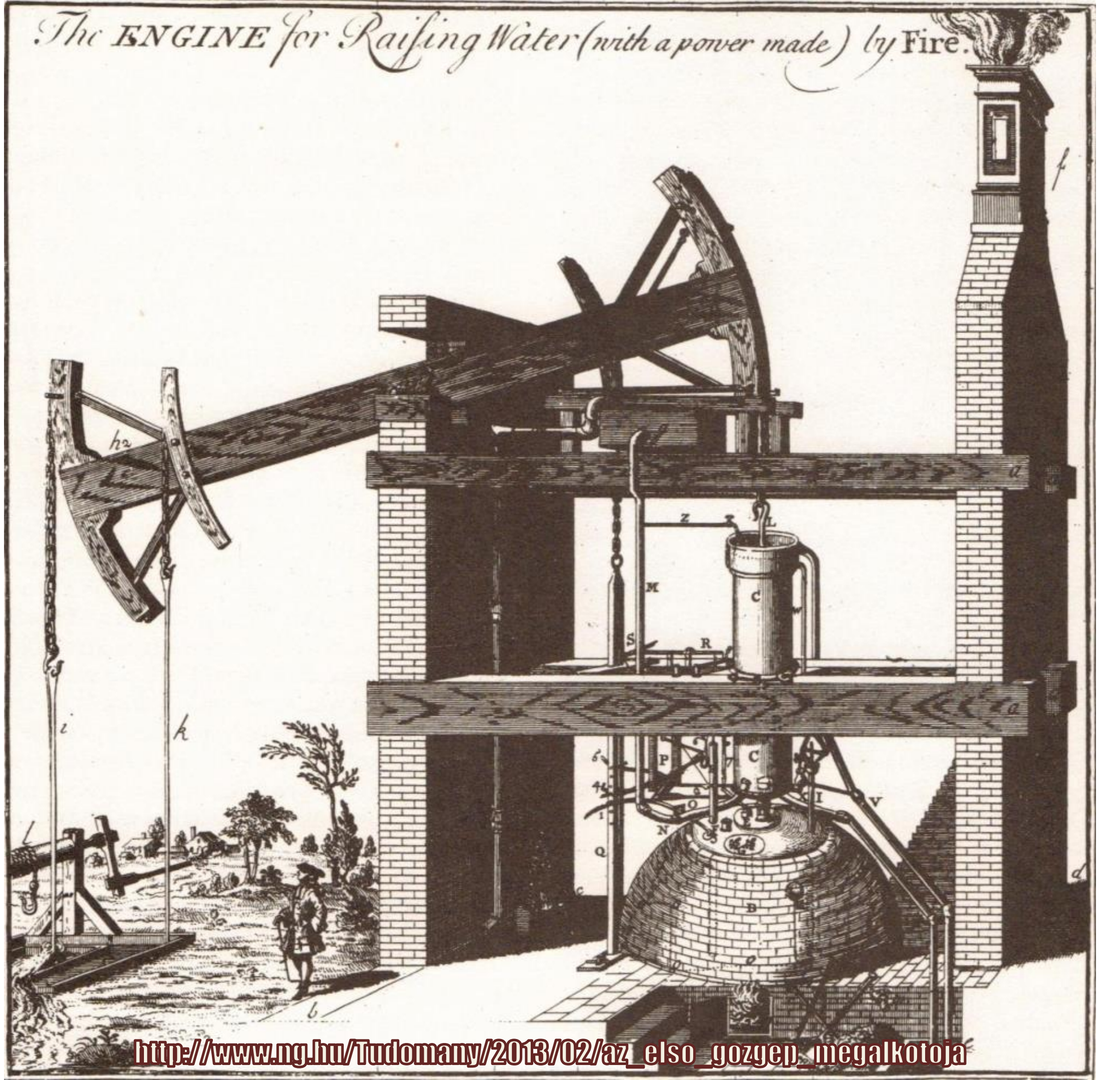
The ENGINE for Raising Water (with a power made) by Fire.

Watt's Engine

- n 1765 James Watt, a Scottish instrument maker and inventor, modified a Newcomen engine by adding a separate condenser to make it unnecessary to heat and cool the cylinder with each stroke. Because the cylinder and piston remained at steam temperature while the engine was operating, fuel costs dropped by about 75%. Watt entered into a partnership with Matthew Boulton, who owned a factory in Soho, England.
- Watt set out to develop a new kind of engine that rotated a shaft instead of providing simple up-and-down motion. He found a way to obtain an inflexible connection between piston and rod (beam) and invented special gear arrangements to convert the up-and-down movement of the beam into circular motion. A heavy flywheel was added to smooth out the variations in the force delivered to the engine shaft by the action of the piston in the cylinder. The flow of steam to the engine was regulated by a governor.

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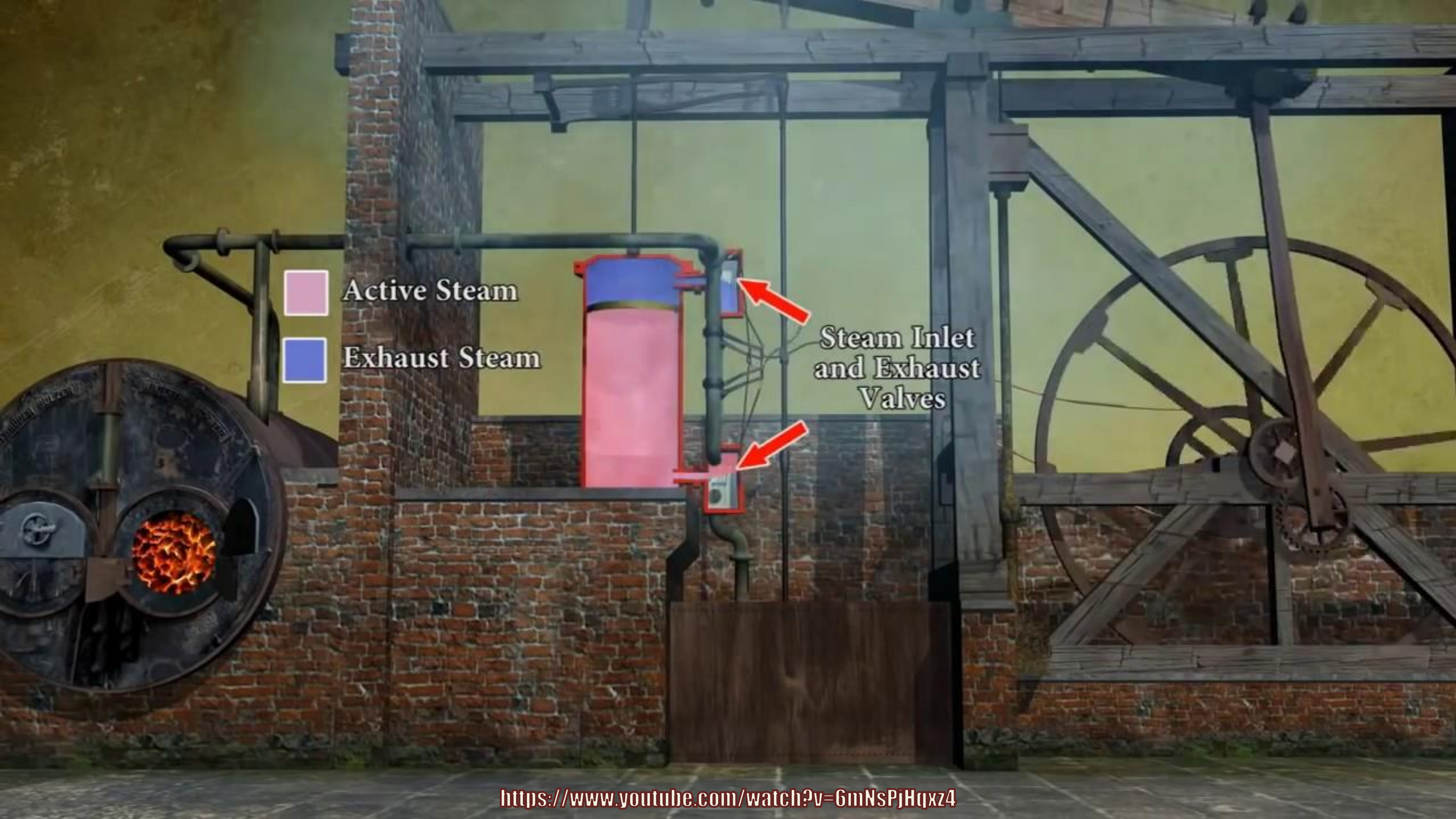

https://www.youtube.com/watch?v=6mNsPjHqxz4

High Pressure Steam Engines

- Although Watt understood the advantages of utilizing the expansive power of steam within a cylinder, he refused to use steam under high pressure for reasons of safety. This limited the application of steam engines.
- By the early years of the 19th century, however, the American inventor Oliver Evans had built a stationary high pressure steam engine for driving a rotary crusher to produce pulverized limestone for agricultural use.
- Within a few years Evans had designed lighter-weight high-pressure steam engines that could do various other tasks, such as drive sawmills, sow grain, and power a dredge. From 1806 to about 1816 he produced more than 100 steam engines that were employed with screw presses for processing paper, cotton, and tobacco.
- Other major advances in the use of high-pressure steam were achieved by Richard Trevithick in England during the early years of the 19th century.

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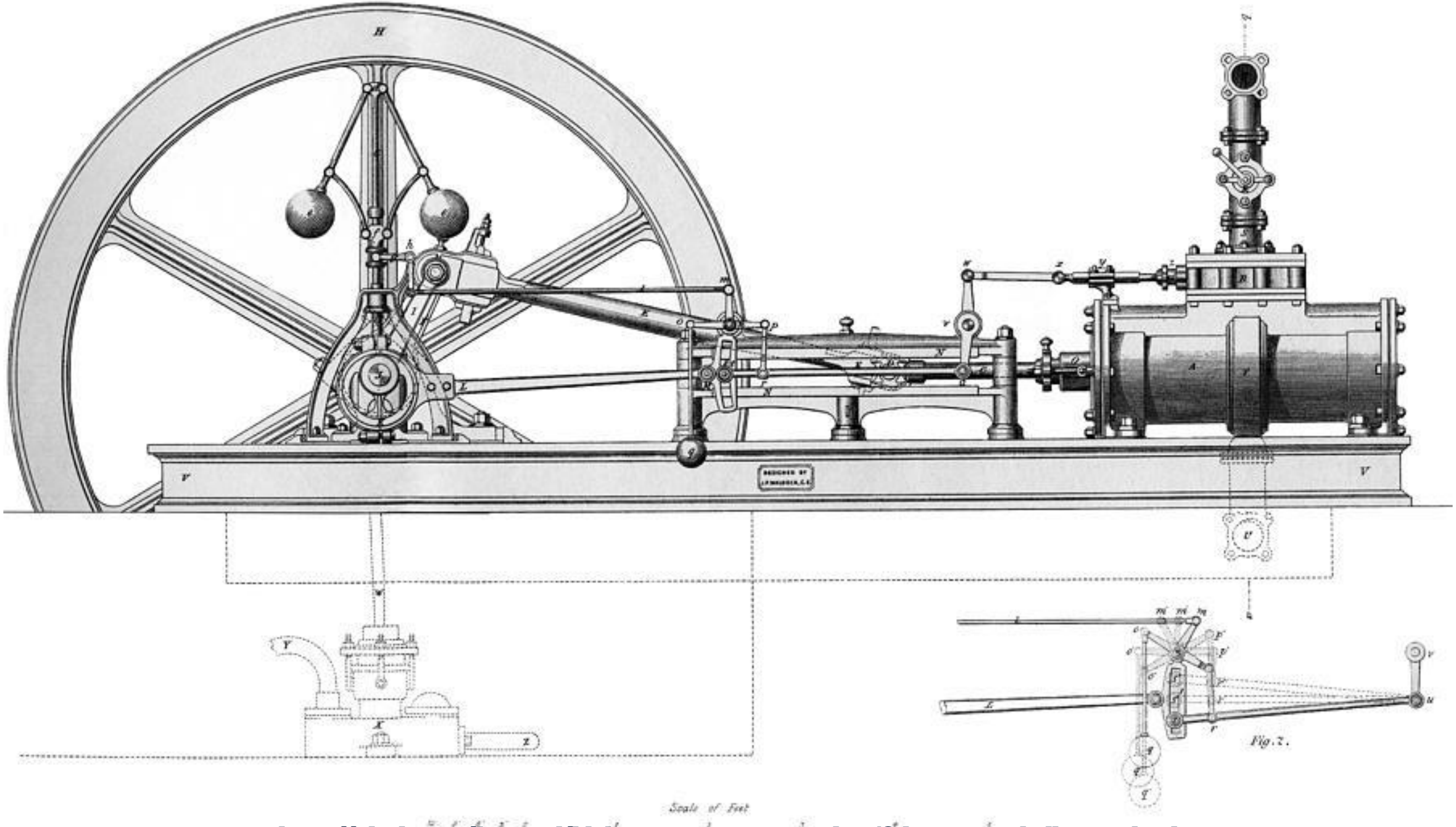

Fig. 2.

Improved Steam Engines

- Trevithick built the world's first steam powered railway locomotive in 1803. Two years later he adapted his high pressure steam engine to drive an iron rolling mill and to propel a barge with the help of paddle wheels.
- Watt's engine was able to convert only a little more than 2% of the thermal energy in steam to work.
- The improvements introduced by Evans, Trevithick, and others (e.g., three separate expansion cycles and higher steam temperatures) increased the efficiency of the steam engine to roughly 17% by 1900.
- Yet, within the next decade the steam engine was supplanted for various important applications by the more efficient steam turbine.
- Owing to technological advances and the use of high temperature steam, steam turbines have attained an efficiency of thermal energy conversion of ~40%.

https://www.britannica.com/technology/energy-conversion

Stirling Engine

- Many of the early high pressure steam boilers exploded because of poor materials and faulty methods of construction. The resultant casualties and property losses motivated Robert Stirling to invent a power cycle that operated without a high pressure boiler.
- In his engine patented in 1816, air was heated by external combustion through a heat exchanger and then was displaced, compressed, and expanded by two pistons.
- Stirling also conceived the idea of a regenerator to store thermal energy during part of the cycle and then return this energy to the working fluid. A successful Stirling engine was built for factory use in 1843, but general use was restricted by the high cost of the device. Nevertheless, until about 1920, small engines of this type were used to pump water on farms and to generate electricity for small communities.

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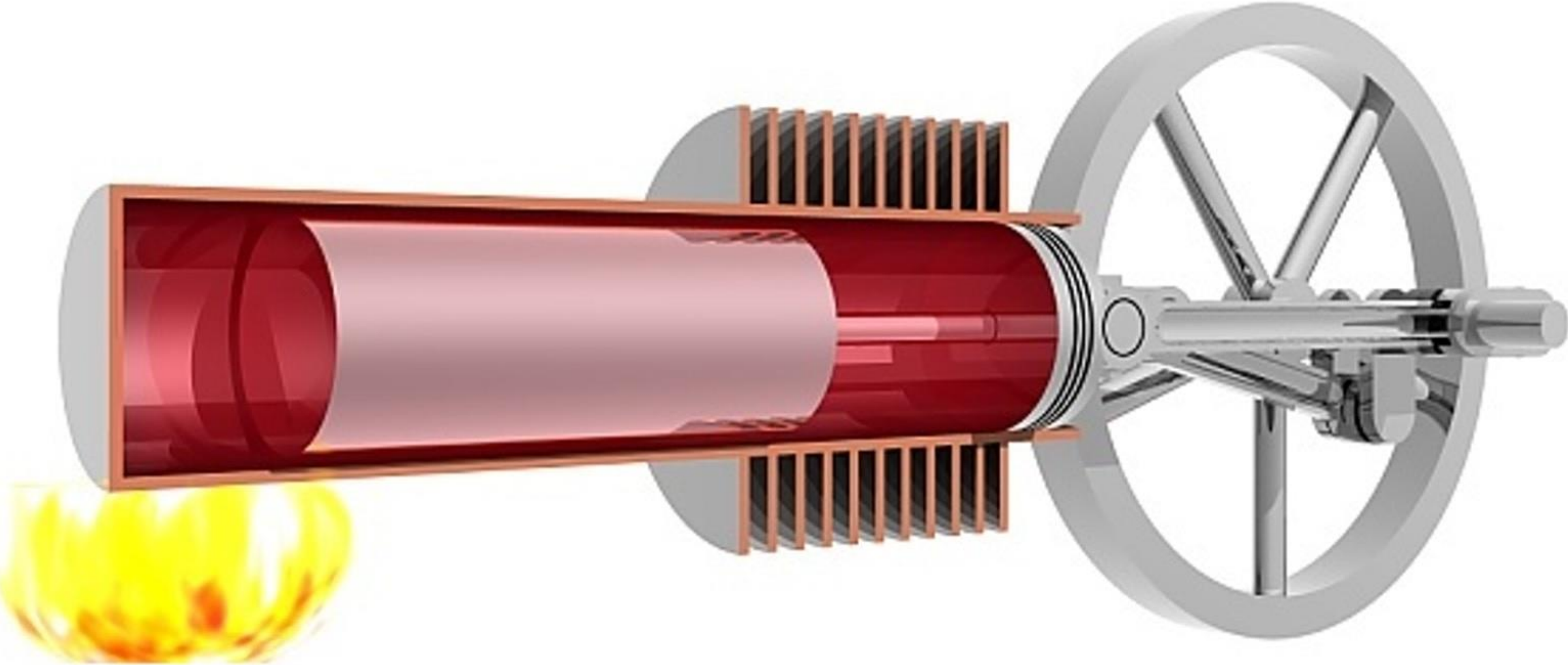

https://www.kickstarter.com/projects/672465444/low-cost-sterling-engine

Other Sources & Converters of Energy

- Since the Stirling engine is efficient, produces less pollution than most other kinds of engines, and operates on virtually any kind of fuel, efforts have been made intermittently since the late 1930s to reduce its manufacturing costs. Modern versions of the Stirling engine employ pressurized hydrogen or helium instead of air. Since the 1970s the engine has been adapted for many uses, including cryogenic refrigeration, submarine propulsion, and electrical production.
- While the steam engine remained dominant in industry and transportation during much of the 19th century, engineers and scientists began developing other sources and converters of energy. One of the most important of these was the internal combustion engine. In such a device a fuel and oxidizer are burned within the engine and the products of combustion act directly on piston or rotor surfaces.

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Internal Combustion Engine

- By contrast, an external combustion device, such as the steam engine, employs a secondary working fluid that is interposed between the combustion chamber and power producing elements.
- By the early 1900s the internal combustion engine had replaced the steam engine as the most broadly applied power generating system not only because of its higher thermal efficiency (there is no transfer of heat from combustion gases to a secondary working fluid that results in losses in efficiency) but also because it provided a low weight, reasonably compact, self-contained power plant.
- Nikolaus August Otto is generally credited with having built the first practical internal combustion engine (1876), though several rudimentary devices had appeared earlier in the century.

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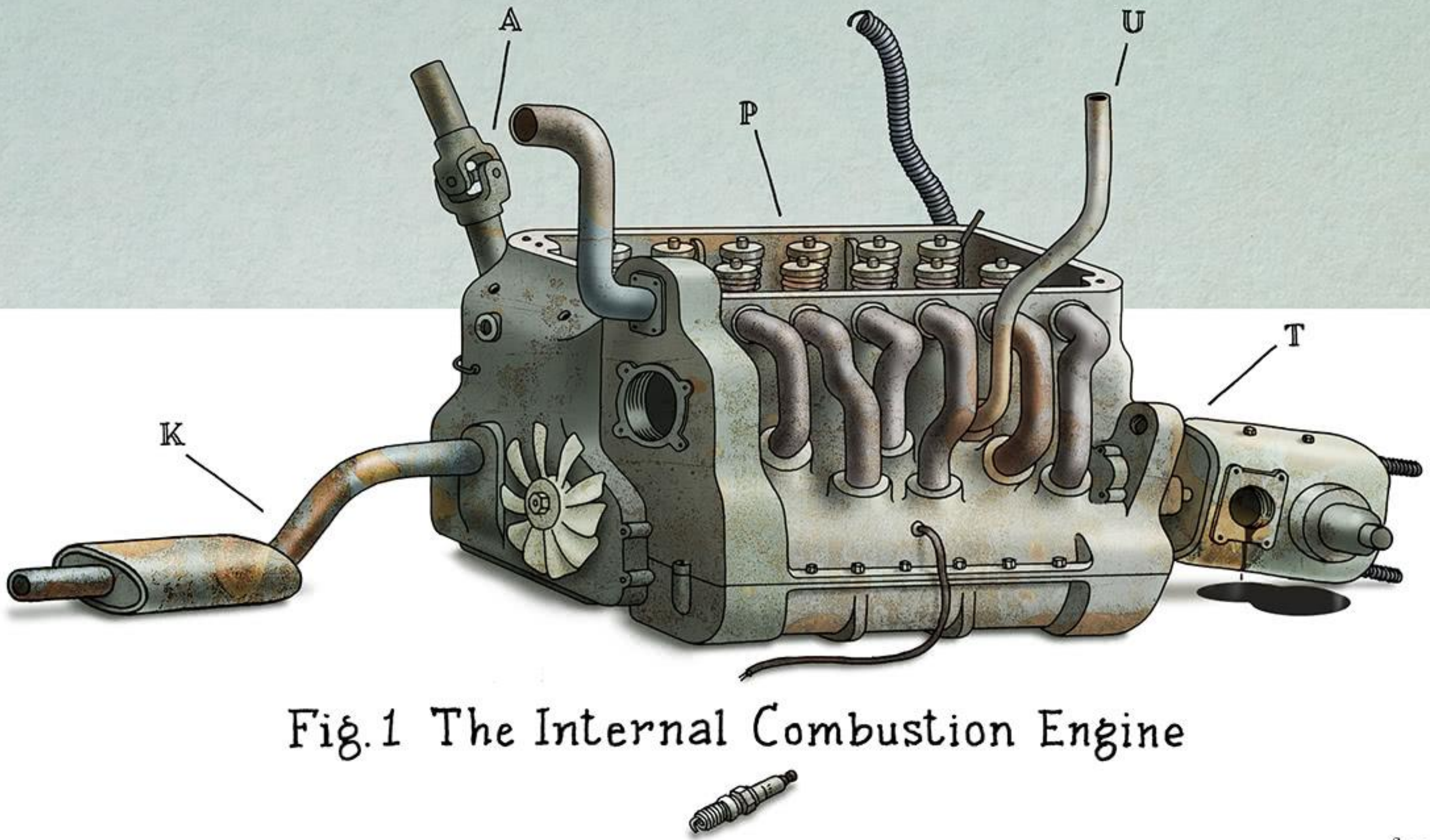

Fig.1 The Internal Combustion Engine

https://www.economist.com/leaders/2017/08/12/the-death-of-the-internal-combustion-engine

Jon Berkeley

Gasoline & Diesel Engines

- In 1885 Gottlieb Daimler modified the four cycle Otto engine so that it burned gasoline instead of coal powder and built the first successful high speed internal combustion engine.
- Within several decades the gasoline engine found wide application in motorcycles, automobiles, and small trucks.
- Another type of internal combustion engine was introduced by Rudolf Diesel in the early 1890s. Named for its inventor, the diesel engine was more efficient than engines of the Otto variety and was fueled by heavy oil, which is cheaper and less volatile than gasoline.
- As a result, it was adopted as the primary power plant for submarines, railway locomotives, and heavy machinery.
- An internal-combustion engine quite different from the reciprocating piston type was developed around the turn of the century.

https://www.britannica.com/technology/energy-conversion

Gas Turbine & Rocket Engine

- This was the gas-turbine engine, the first successful version of which was built in 1903 in France. Modern gas turbines have been used for electric power generation and various other purposes, but its primary application has been jet propulsion. In a gas turbine system compressed air, heated by the combustion of petroleum, is used to turn a turbine to drive the compressor while excess energy accelerates the exhaust gas to high velocity for producing thrust.
- Another form of propulsive engine, the rocket, attracted increasing attention during the final decades of the 19th century due in part to the imaginative portrayals of space travel fabricated by Jules Verne and other science fiction writers. From about 1880, various scientists and inventors began investigating theoretical problems of rocket motion and propulsion system design.

https://www.britannica.com/technology/energy-conversion

As your plant ages, a longer planning horizon creates both more options to consider as well as time to assess and quantify risk. Changing generation patterns and operating demands, regulatory uncertainty, and increasing cost pressures all illustrate the need to cost-effectively manage and maintain gas turbine rotor assets to keep operating your fleet while reducing downtime for the long term.

https://www.ge.com/power/services/gas-turbines/rotor-life-extension

The Falcon Heavy has the most engines of any rocket ever to reach orbit — it's not even close. The highly reliable Russian Soyuz has five engines, as did the American Saturn V vehicle (in the first stage). The ESA's Ariane 5 has just three engines, if you count the two solid boosters. The previous record was nine engines, jointly held by SpaceX's Falcon 9 and the Rocket Lab Electron. The only rocket in the same league as the Falcon Heavy is the 30-engine Soviet N-1 moon rocket, which never successfully reached space.

https://www.extremetech.com/extreme/263579-elon-musk-explains-spacex-prefers-smaller-rocket-engines

Electric Generators

- Other important energy conversion devices emerged during the 19th century. During the early 1830s Michael Faraday discovered a means by which to convert mechanical energy into electricity on a large scale. While engaged in experimental work on magnetism, Faraday found that moving a permanent magnet into and out of a coil of wire induced an electric current in the wire. This process, called electromagnetic induction, provided the working principle for electric generators.
- During the late 1860s Zénobe-Théophile Gramme built a continuous current generator. Dubbed the Gramme dynamo, this device contributed much to the general acceptance of electric power. By the early 1870s Gramme had developed several other dynamos, one of which was reversible and could be used as an electric motor. Electric motors run virtually every kind of machine that uses electricity.

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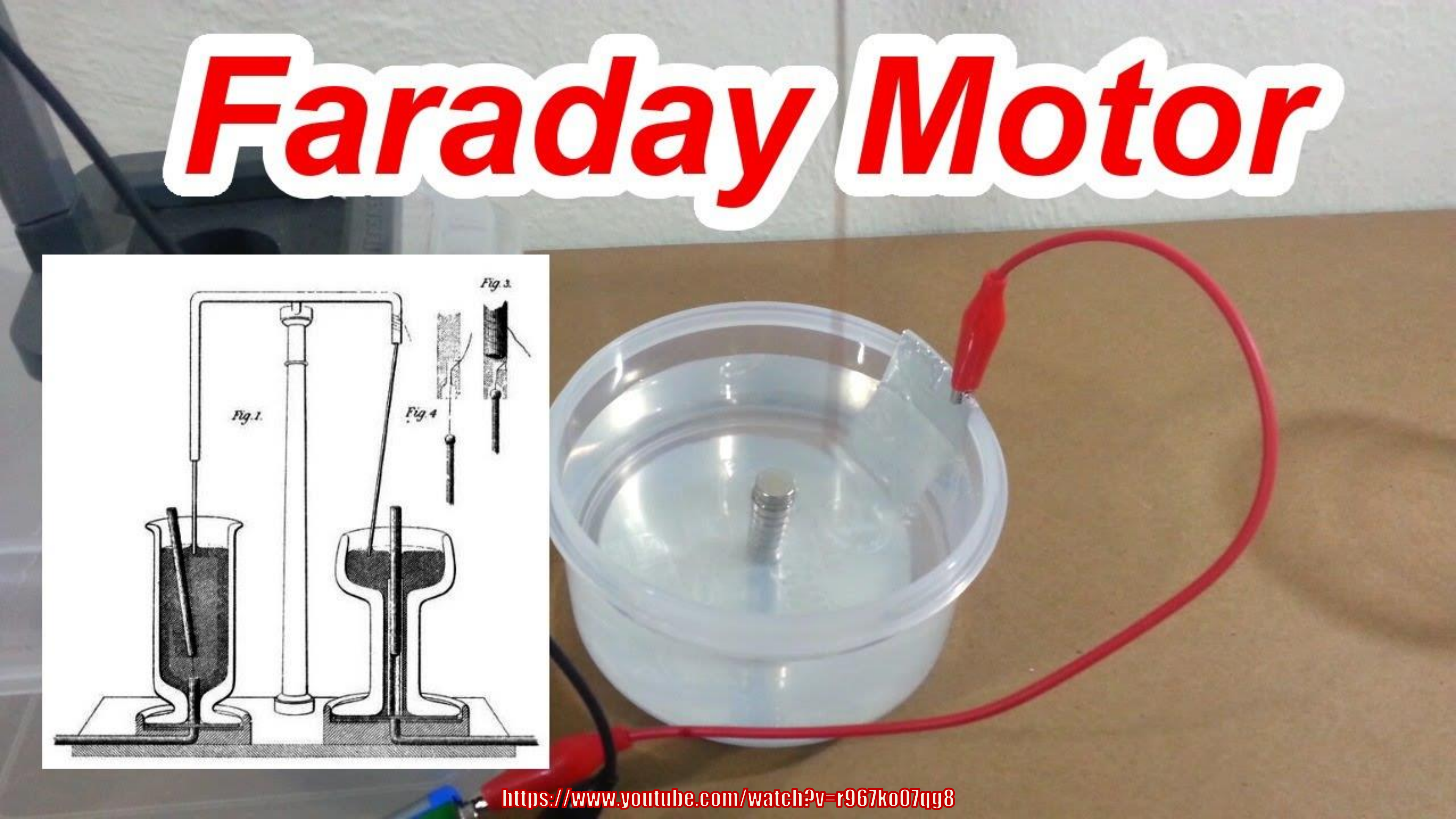
Faraday Motor
Fig. 3.
Fig. 1.
Fig. 4
https://www.youtube.com/watch?v=r967ko07qg8

Direct Energy Conversion Devices

- Most of these energy converters, sometimes called static energy conversion devices, use electrons as their "working fluid" in place of the vapor or gas employed by such dynamic heat engines as the external combustion and internal combustion engines mentioned above.
- In recent years, direct energy conversion devices have received much attention because of the necessity to develop more efficient ways of transforming available forms of primary energy into electric power. Four such devices—the electric battery, the fuel cell, the thermoelectric generator (or at least its working principle), and the solar cell—had their origins in the early 1800s.
- The battery, invented by Alessandro Volta ~1800, changes chemical energy directly into an electric current. A device of this type has two electrodes, each of which is made of a different chemical.

https://www.britannica.com/technology/energy-conversion

https://www.makerspaces.com/diy-mini-electric-car/

Fuel Cell

- As chemical reactions occur, electrons are released on the negative electrode and made to flow through an external circuit to the positive electrode. The process continues until the circuit is interrupted or one of the reactants is exhausted. The forerunners of the modern dry cell and the lead-acid storage battery appeared during the second half of the 19th century.
- The fuel cell, another electrochemical producer of electricity, was developed by William Robert Grove in 1839. In a fuel cell, continuous operation is achieved by feeding fuel (hydrogen) and an oxidizer (oxygen) to the cell and removing the reaction products.
- With the automotive industry investing heavily in clean fuel vehicles, it is important to understand the risks associated with some of the new technology on the market like the hydrogen fuel cell electric vehicles.

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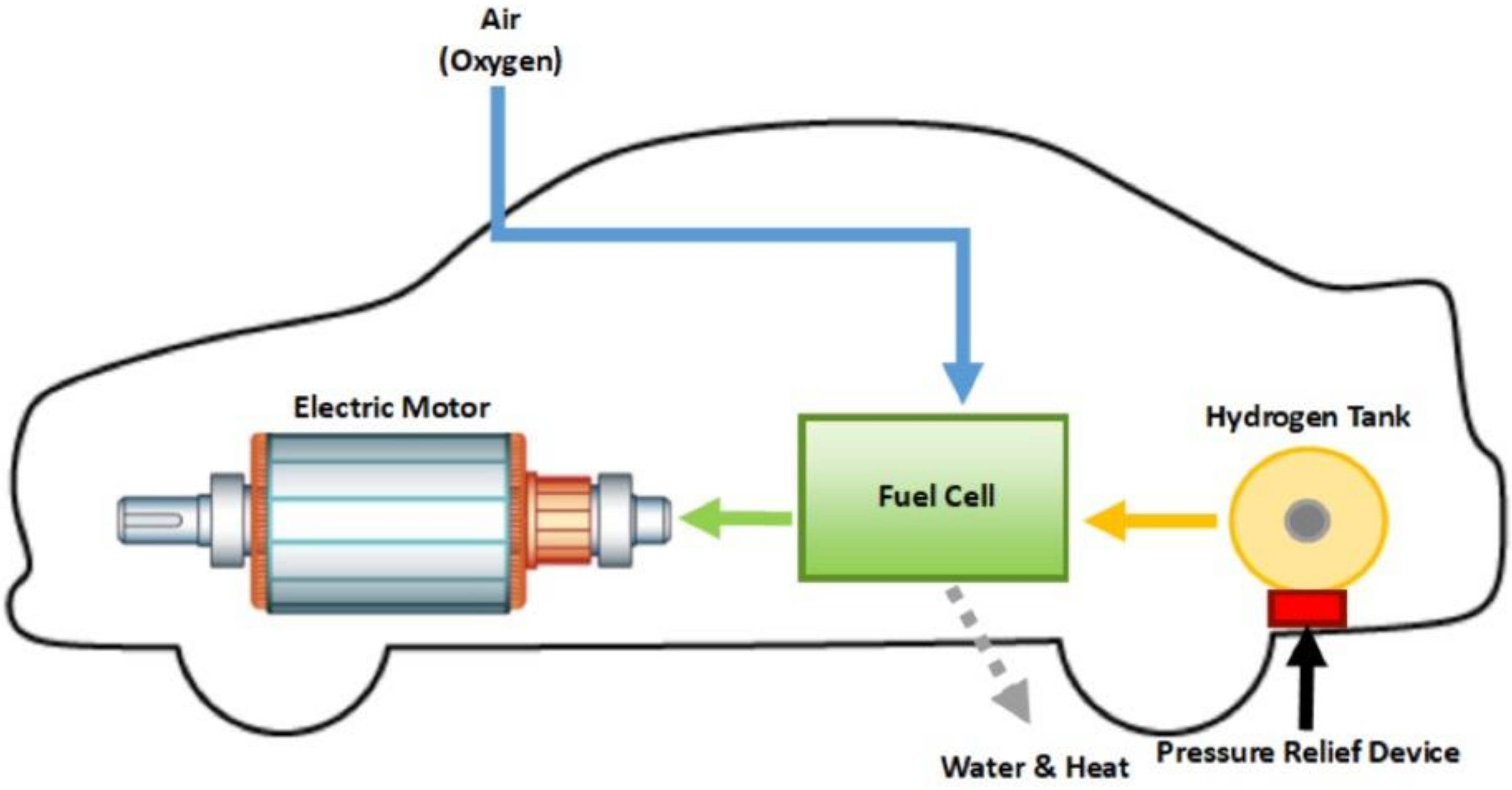

https://www.firehouse.com/rescue/article/12385113/hydrogen-fuel-cell-vehicles-what-first-responders-need-to-know-firehouse

Solar Cell & More…

- A basic theory of thermoelectricity was finally formulated during the early 1900s, though no functional generators were developed until much later. In a solar cell, radiant energy drives electrons across a potential difference at a semiconductor junction in which the concentrations of impurities are different on the two sides of the junction. What is often considered the first genuine solar cell was built in the late 1800s by Charles Fritts, who used junctions formed by coating selenium with an extremely thin layer of gold.
- The 20th century brought a host of important scientific discoveries and technological advances, including new and better materials and improved methods of fabrication. These developments permitted the enhancement and refinement of many of the energy conversion devices and systems that had been introduced during the previous century. They also gave rise to entirely new technologies.

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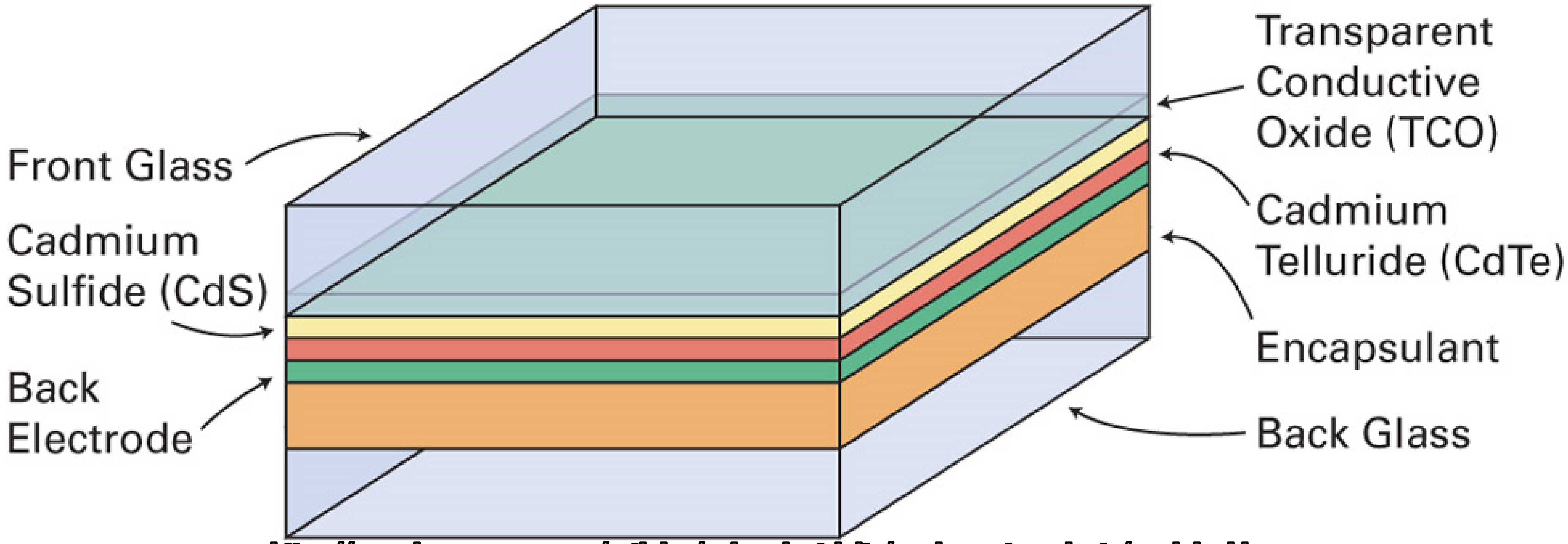
Anatomy of a Thin-Film PV Cell



https://www.homepower.com/articles/solar-electricity/equipment-products/peek-inside-pv

Nuclear Reactors: Fission

- Scientists first learned of the tremendous energy bound in the nucleus of the atom during the early years of the century. In 1942 they succeeded in unleashing that energy on a large scale by means of what was called an atomic pile. This was the first nuclear fission reactor, a device designed to induce a self-sustaining and controlled series of fission reactions that split heavy nuclei to release their energy. It was built for the U.S. Manhattan Project undertaken to develop the atomic bomb.
- Reactors were built for submarine propulsion and for commercial power production. The first full scale commercial nuclear plant was opened in 1956 at Calder Hall, England. In a power generation system of this kind, much of the energy released by the fissioning of heavy nuclei takes the form of heat, which is used to produce steam. This steam drives a turbine, the mechanical energy of which is converted to electricity by a generator.

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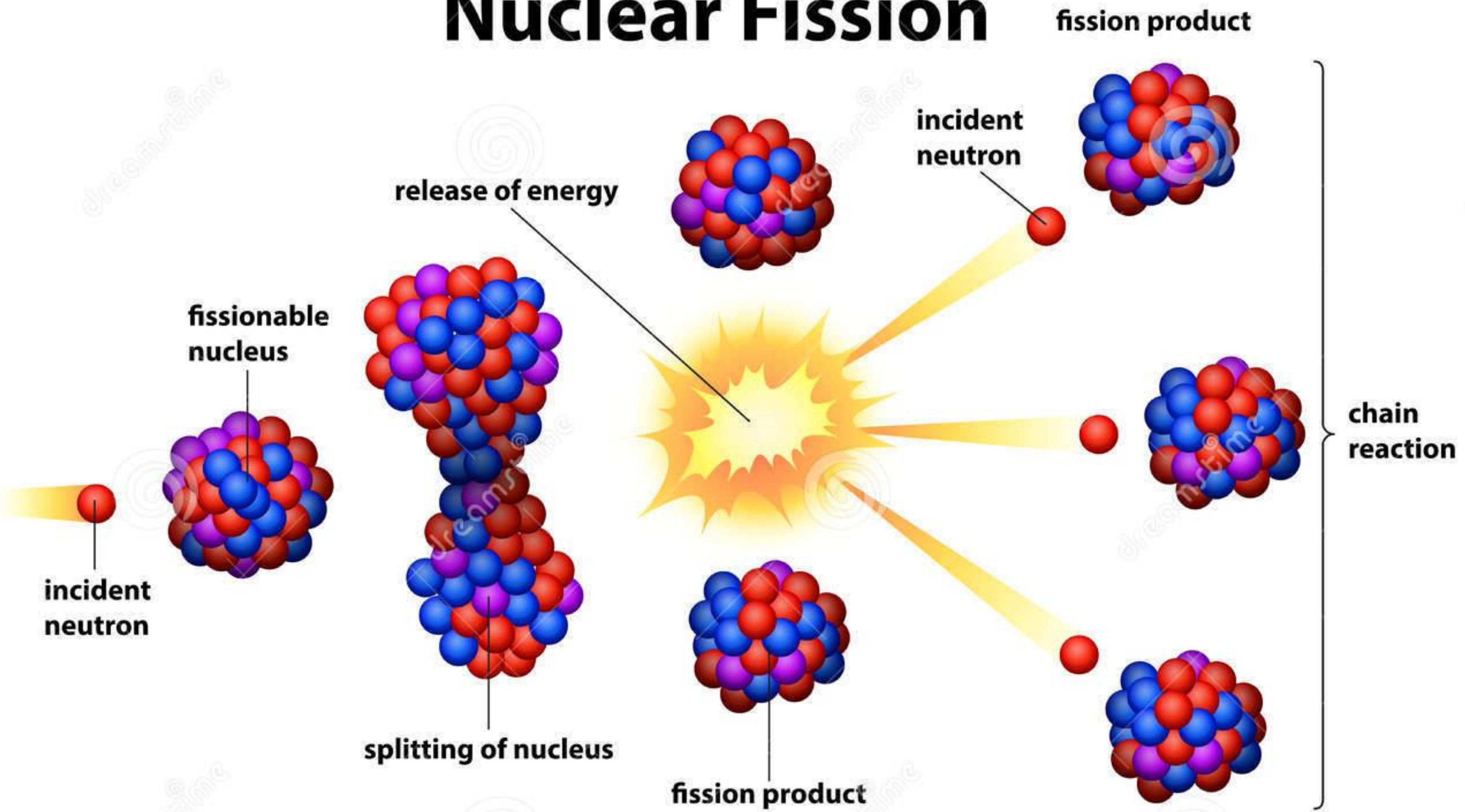
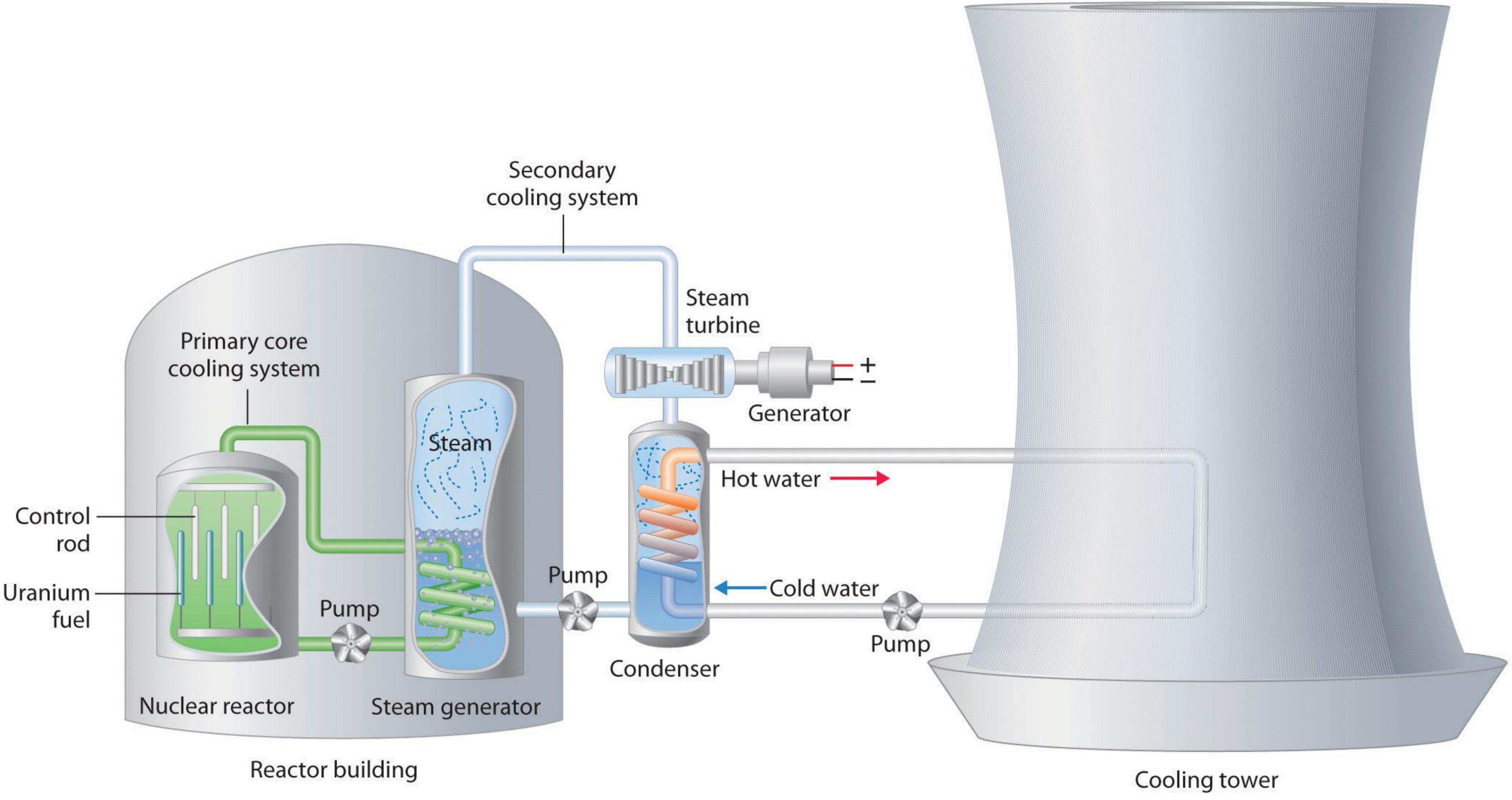
Nuclear Fission



https://www.extremetech.com/extreme/217486-extremetech-explains-how-does-nuclear-energy-work



https://chem.libretexts.org/LibreTexts/Furman_University/CHM101%3A_Chemistry_and_Global_Awareness_(Gordon)/07%3A_Nuclear_Energy/

Nuclear Reactors: Fusion

- In the late 1930s Hans A. Bethe recognized that the fusion of hydrogen nuclei to form deuterium releases energy. Since that time scientists have sought to harness such thermonuclear reactions for practical energy production. Much of their work has centered on the use of magnetic fields and electromagnetic forces to confine plasma, an exceedingly hot gas composed of unbound electrons, ions, and neutral atoms and molecules.
- Plasma is the only state of matter in which thermonuclear reactions can be induced and sustained to generate usable amounts of thermal energy. The difficulty is in confining plasma long enough for this to happen. Although researchers have made significant headway toward constructing fusion reactors capable of such confinement, no device of this kind has been developed sufficiently for commercial application.

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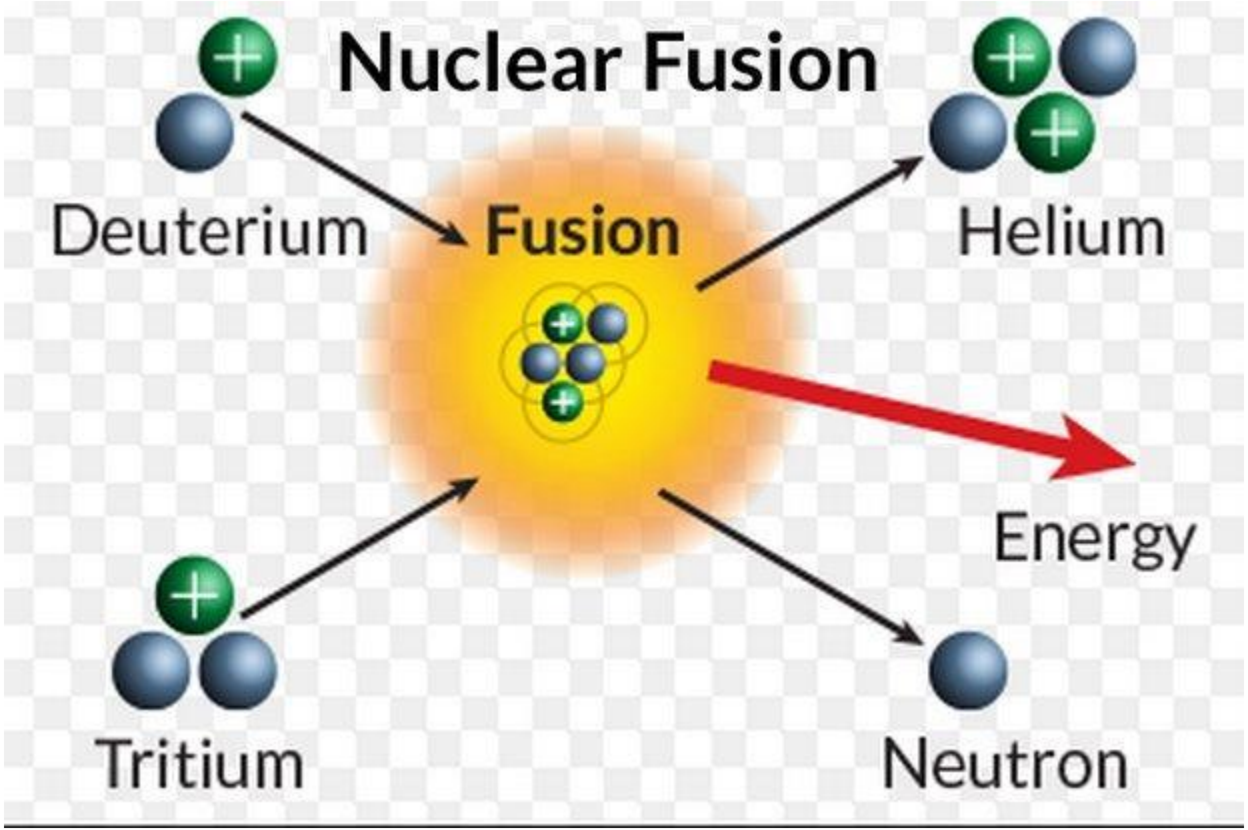
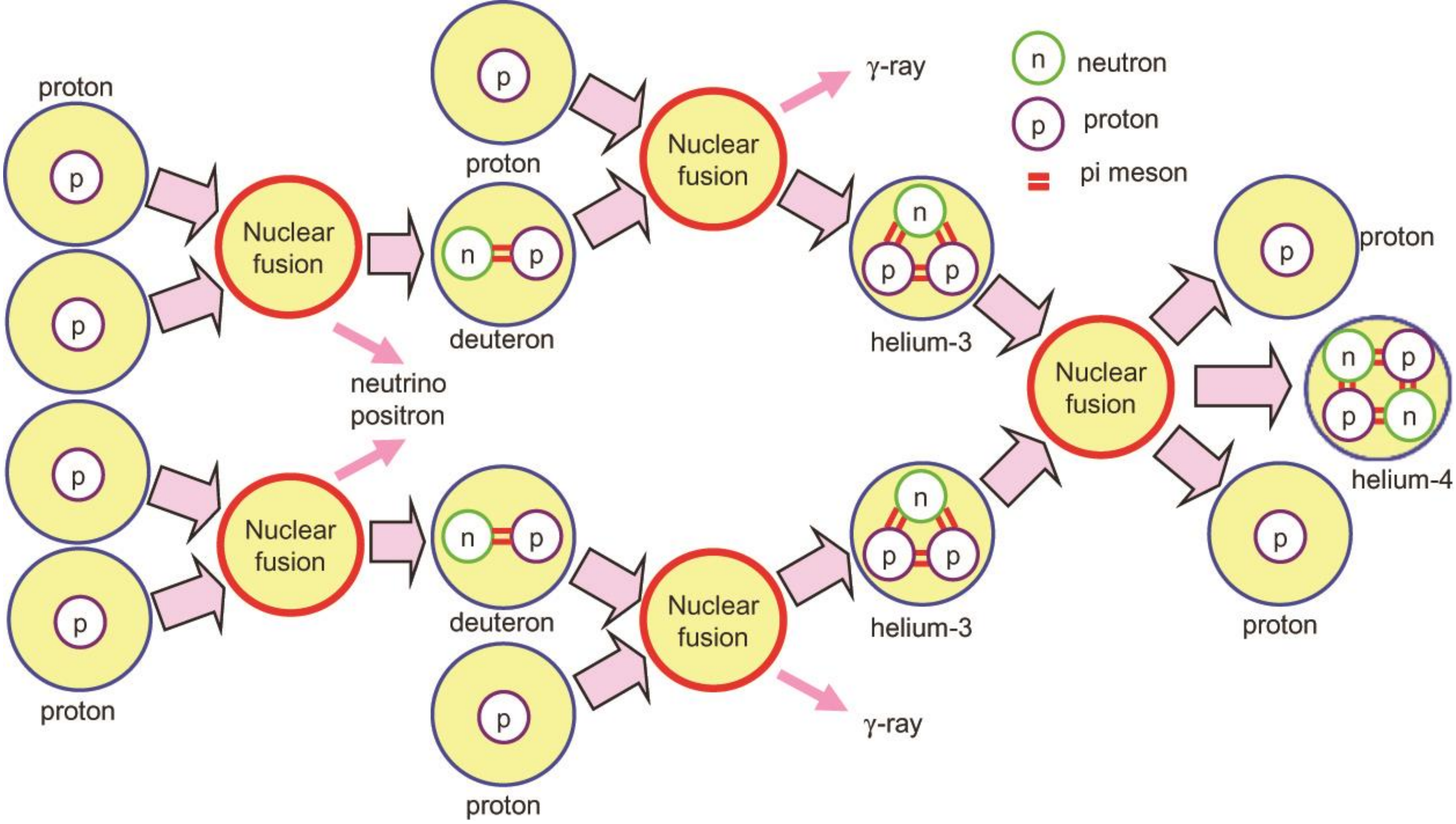
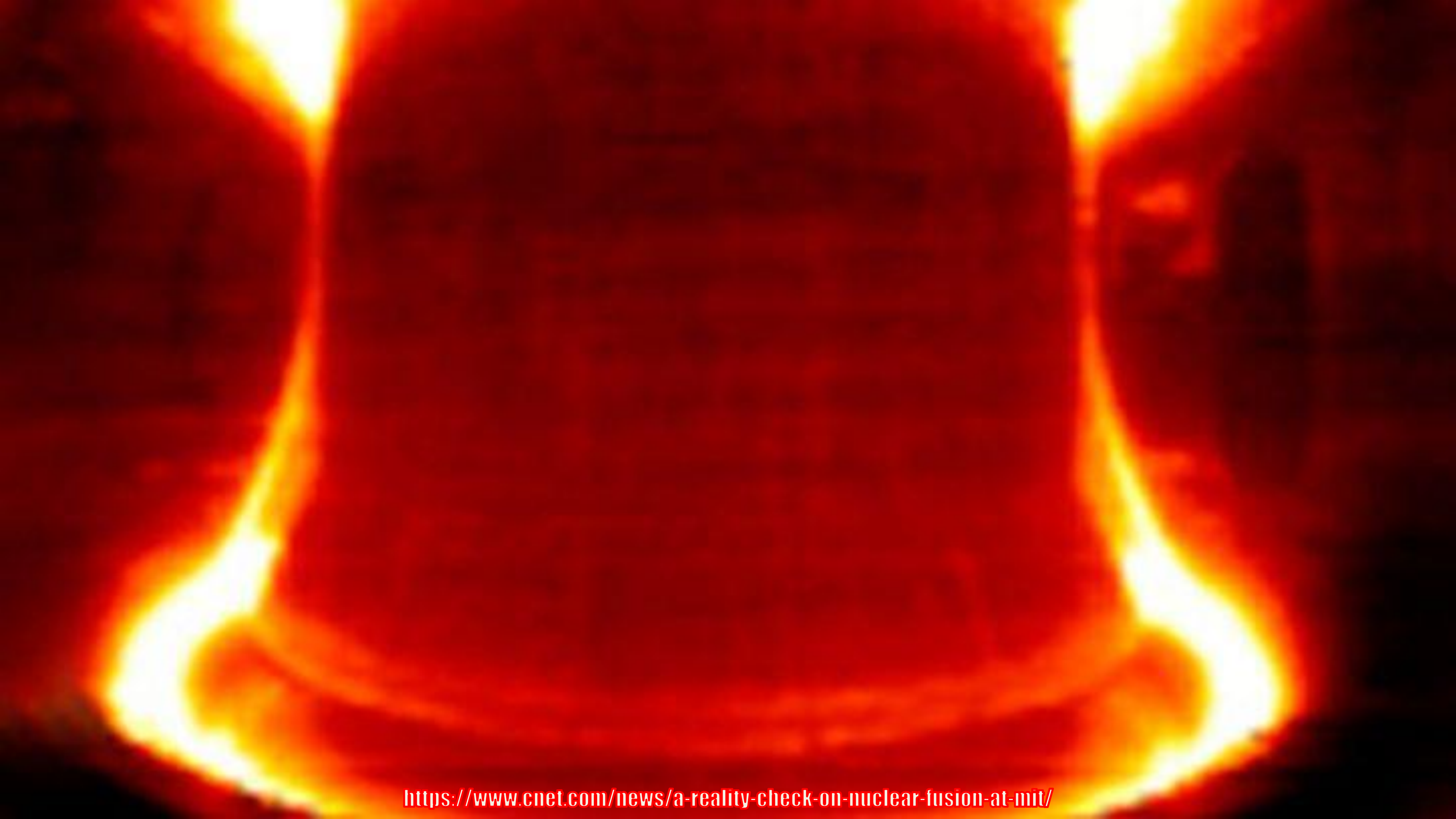


https://www.bangkokpost.com/opinion/opinion/937073/forging-a-role-in-low-end-nuclear-fusion



https://www.degruyter.com/view/j/ehs.2018.5.issue-1-2/ehs-2018-0007/ehs-2018-0007.xml



https://www.cnet.com/news/a-reality-check-on-nuclear-fusion-at-mit/

Other Conversion Technologies

- Energy requirements for space vehicles led to an intensive investigation, from 1955 on, of all possible energy sources. Direct energy conversion devices are of interest for providing electric power in spacecraft because of their reliability and their lack of moving parts. As have solar cells, fuel cells, and thermoelectric generators, thermionic power converters have received considerable attention for space applications. Thermionic generators are designed to convert thermal energy directly into electricity. The required heat energy may be supplied by chemical, solar, or nuclear sources, the latter being the preferred choice for current units.
- Another direct energy converter with considerable potential is the magnetohydrodynamic (MHD) power generator. This system produces electricity directly from a high temperature, high pressure ionized gas moving through a strong magnetic field.

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Renewable Energy Sources

- Growing concern over the world's ever increasing energy needs and the prospect of rapidly dwindling reserves of oil, natural gas, and uranium fuel have prompted efforts to develop viable alternative energy sources. The volatility and uncertainty of the petroleum fuel supply were dramatically brought to the fore during the energy crisis of the 1970s caused by the abrupt curtailment of oil shipments from the Middle East to many of the highly industrialized nations of the world.
- It also has been recognized that the heavy reliance on fossil fuels has had an adverse impact on the environment. Gasoline engines and steam turbine power plants that burn coal or natural gas emit substantial amounts of sulfur dioxide and nitrogen oxides into the atmosphere. When these gases combine with atmospheric water vapour, they form sulfuric acid and nitric acids, giving rise to highly acidic precipitation.

https://www.britannica.com/technology/energy-conversion

Greenhouse Effect & Fusion Devices

- The combustion of fossil fuels also releases carbon dioxide. The amount of this gas in the atmosphere has steadily risen since the mid-1800s largely as a result of the growing consumption of coal, oil, and natural gas. More and more scientists believe that the atmospheric buildup of carbon dioxide along with that of other industrial gases such as methane and chlorofluorocarbons may induce a greenhouse effect, raising the surface temperature of the Earth by increasing the amount of heat trapped in the lower atmosphere. This condition could bring about climatic changes with serious repercussions for natural and agricultural ecosystems.
- Many countries have initiated programs to develop renewable energy technologies. Fusion devices are believed to be the best long term option, since their primary energy source would be the hydrogen isotope deuterium abundantly present in ordinary water.

https://www.britannica.com/technology/energy-conversion

Other Technologies

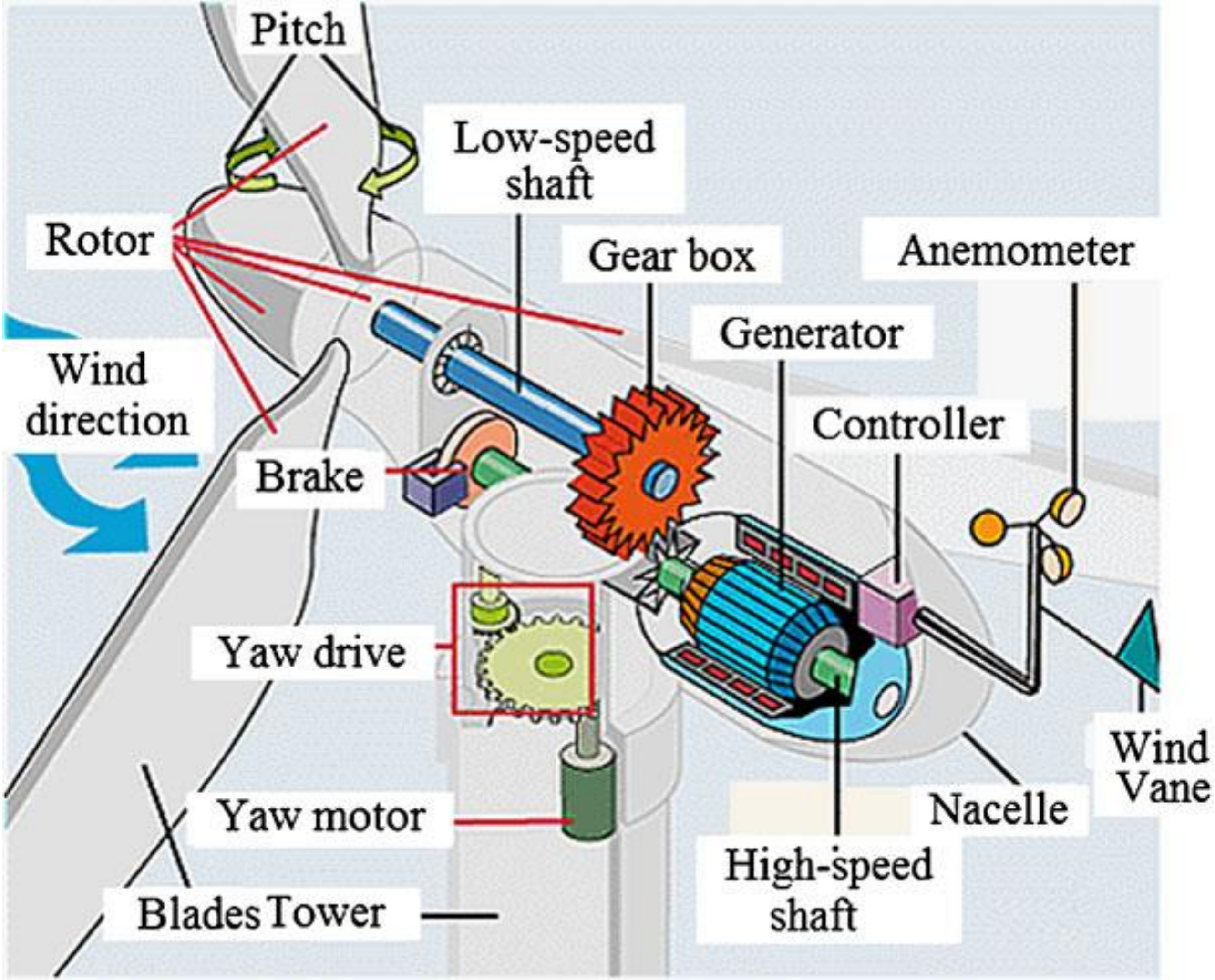
- Other technologies that are being actively pursued are those designed to make wider and more efficient use of the energy in sunlight, wind, moving water, and terrestrial heat (i.e., geothermal energy). The amount of energy in such renewable and virtually pollution-free sources is large in relation to world energy needs, yet at the present time only a small portion of it can be converted to electric power at reasonable cost.
- A variety of devices and systems has been created to better tap the energy in sunlight. Among the most efficient are photovoltaic systems that transform radiant energy from the Sun directly into electricity by means of silicon or gallium arsenide solar cells. Large arrays consisting of thousands of these semiconductor cells can function as central power stations. Other systems, which are still under development, are designed to concentrate solar radiation not only to generate electricity and heat.

https://www.britannica.com/technology/energy-conversion

Wind Energy & Hydroelectric Pwer

- Although wind is intermittent and diffuse, it contains tremendous amounts of energy. Sophisticated wind turbines have been developed to convert this energy to electric power. The utilization of wind energy systems grew discernibly during the 1980s. For example, more than 15,000 wind turbines are now in operation in Hawaii and California at specially selected sites. Their combined power rating of 1,500 MW is roughly equal to that of a conventional steam-turbine power installation.
- Converting the energy in moving water to electricity has been a long standing technology. Yet, hydroelectric power plants are estimated to provide only about 2% of the world's energy requirements. The technology involved is simple enough: hydraulic turbines change the energy of fast flowing or falling water into mechanical energy that drives power generators, which produce electricity.

https://www.britannica.com/technology/energy-conversion



https://www.researchgate.net/figure/Parts-inside-the-wind-turbine_fig5_290094650

https://clipground.com/water-energy-clipart.html

Geothermal Energy

- Hydroelectric power plants, however, generally require the building of costly dams. Another factor that limits any significant increase in hydroelectric power production is the scarcity of suitable sites for additional installations except in certain regions of the world.
- Geothermal energy flows from the hot interior of the Earth to the surface in steam or hot water most often in areas of active volcanism. Geothermal reservoirs with temperatures of 180 °C or higher are suitable for power generation. The earliest commercial geothermal power plant was built in 1904 in Larderello, Italy. Today, steam from wells drilled to depths of hundreds of metres drives the plant's turbine generators to produce about 190 megawatts of electricity. Geothermal plants have been built in El Salvador, Japan, Mexico, New Zealand, and the United States. The principal U.S. plant, located in San Francisco, CA can generate up to 1,900 MW.

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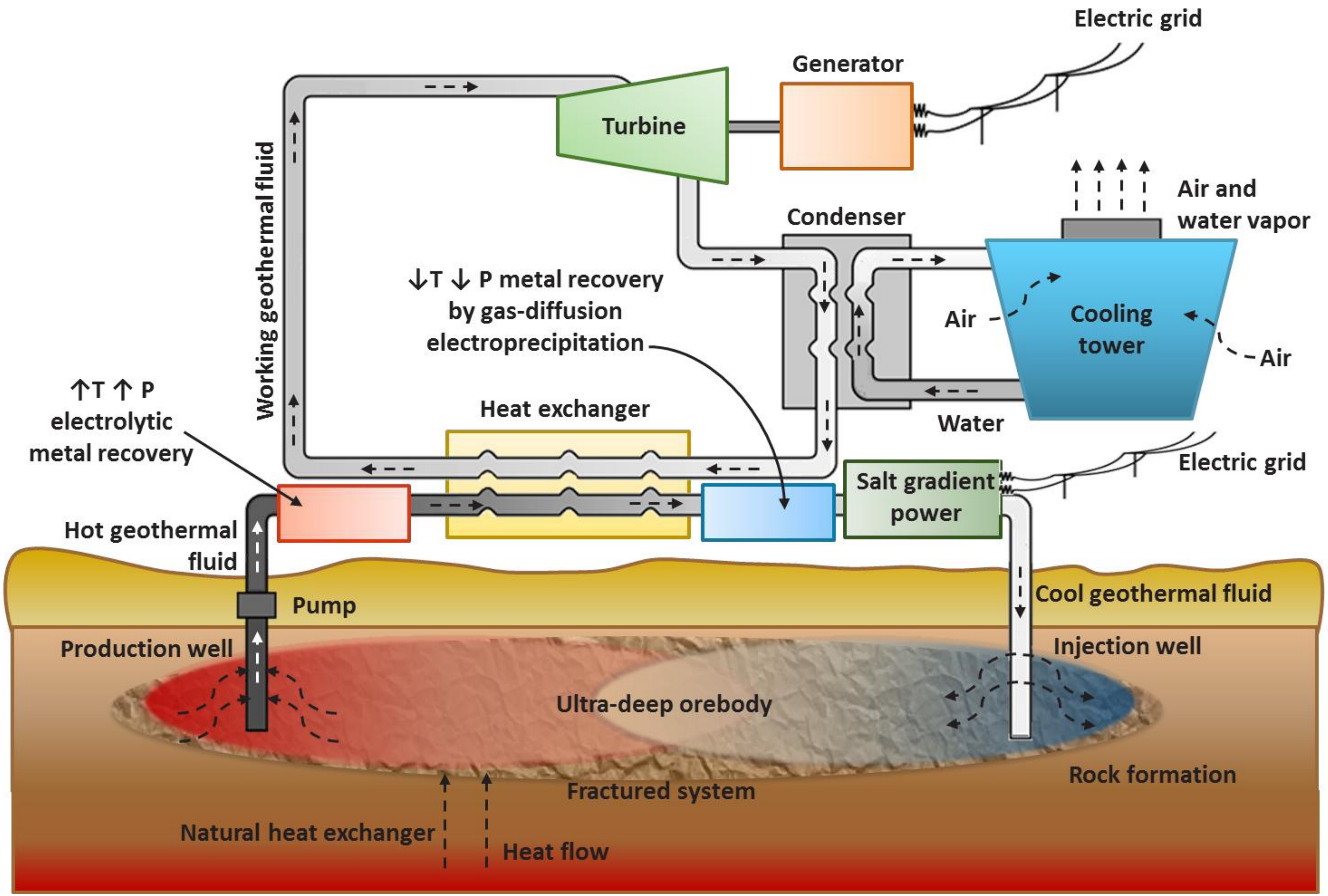
Electric grid
Generator
Turbine
Working geothermal fluid
Air and
water vapor
Condenser
↓T ↓ P metal recovery
by gas-diffusion
electroprecipitation
Air
Cooling
tower
Air
Water
↑T ↑ P
electrolytic
metal recovery
Heat exchanger
Salt gradient
power
Electric grid
Hot geothermal
fluid
Pump
Cool geothermal fluid
Production well
Injection well
Ultra-deep orebody
Rock formation
Fractured system
Natural heat exchanger
Heat flow

Thermoelectric Generators

- They convert heat directly into electricity. Electric current is generated when electrons are driven by thermal energy across a potential difference at the junction of two conductors made of dissimilar materials. This effect was discovered by Thomas Johann Seebeck in 1821.
- Seebeck observed that a compass needle near a circuit made of different conducting materials was deflected when one of the junctions was heated. He investigated various materials that produce electric energy with an efficiency of 3%. This efficiency was comparable to that of the steam engines of the day.
- Yet, the significance of the discovery of the thermoelectric effect went unrecognized as a means of producing electricity because of Seebeck's misinterpretation of the phenomenon as a magnetic effect caused by a difference in temperature.

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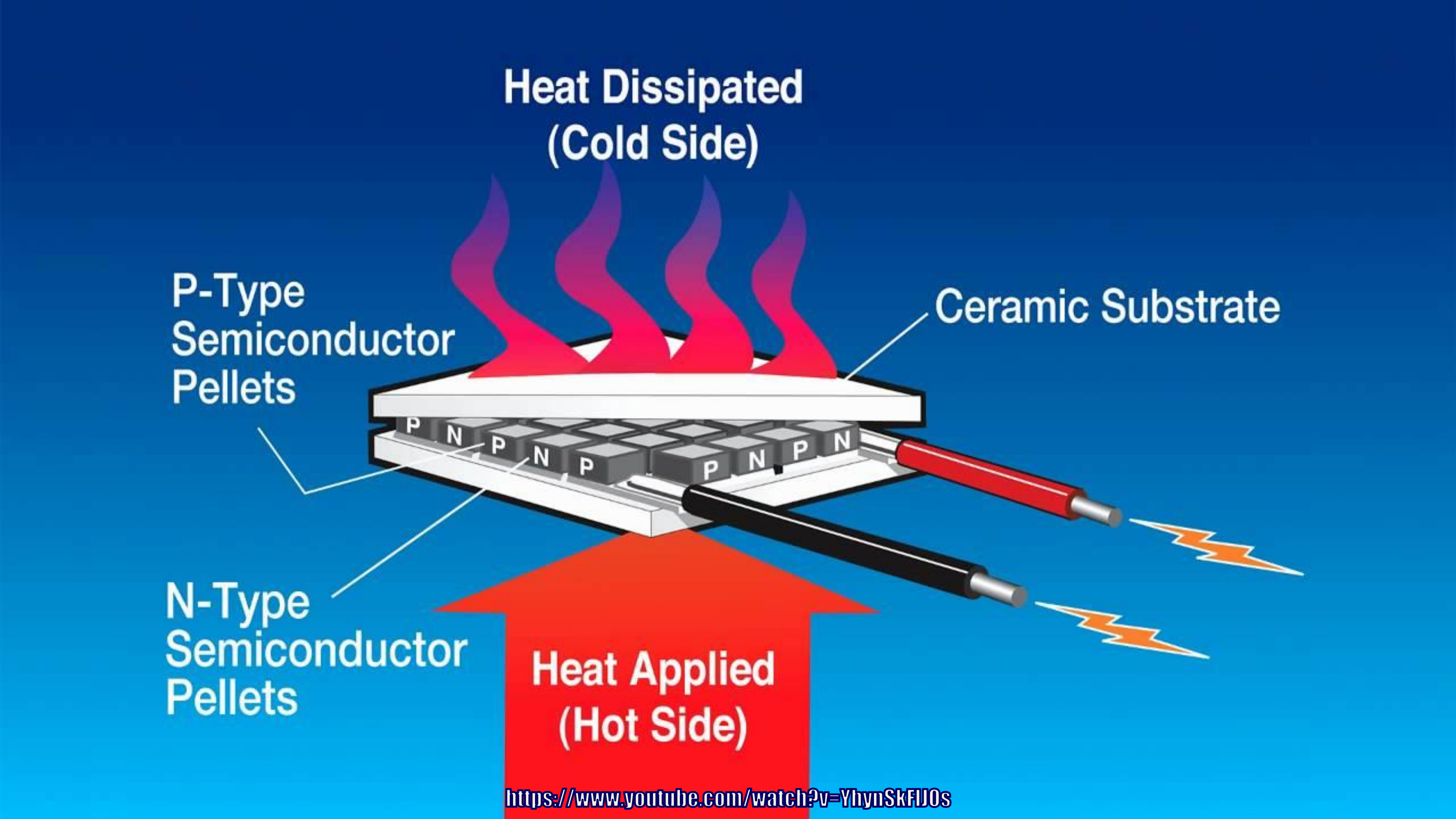
Heat Dissipated
(Cold Side)
P-Type
Semiconductor
Pellets
Ceramic Substrate
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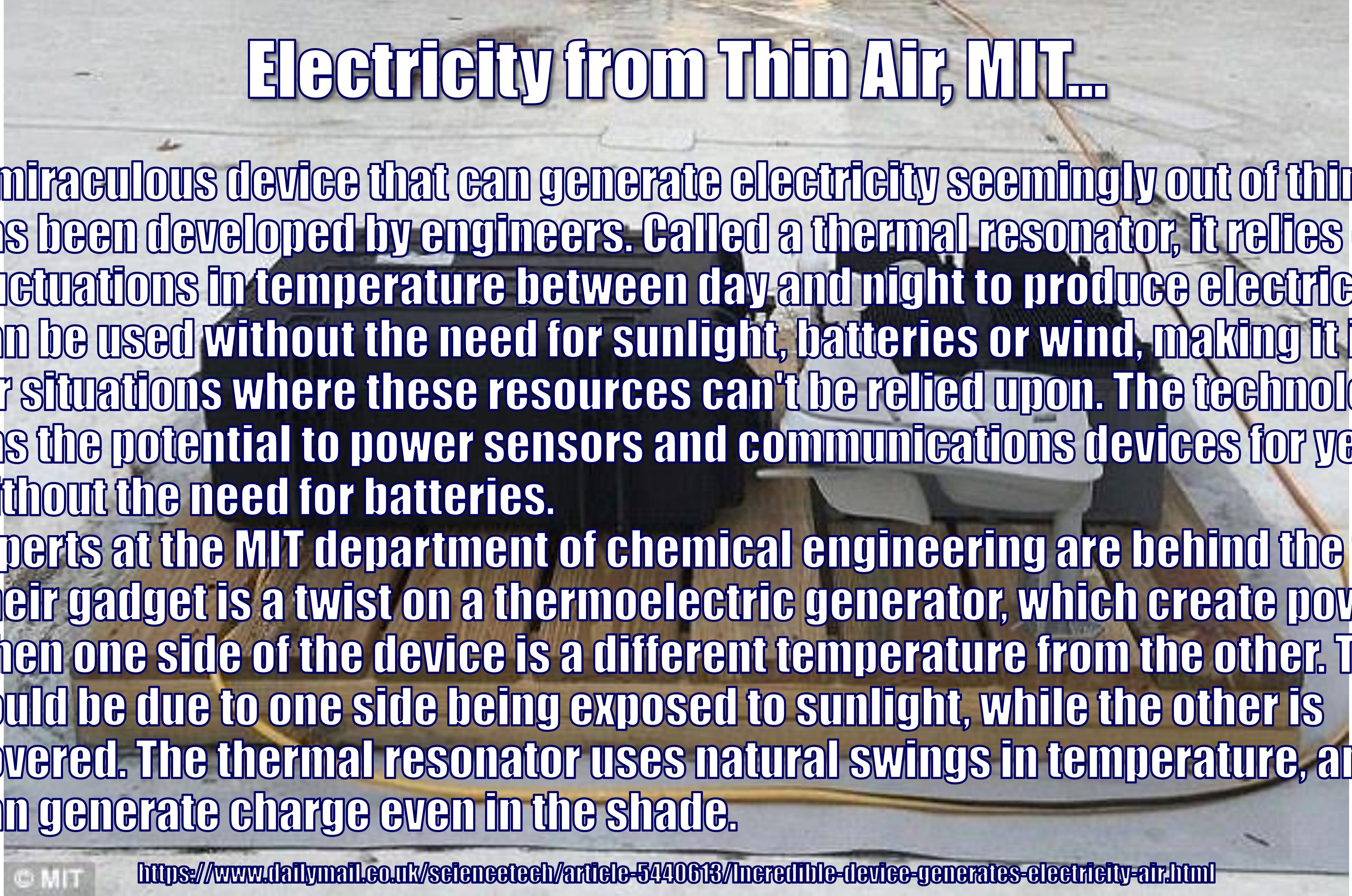
N-Type
Semiconductor
Pellets
Heat Applied
(Hot Side)
https://www.youtube.com/watch?v=YhynSkFIJOs

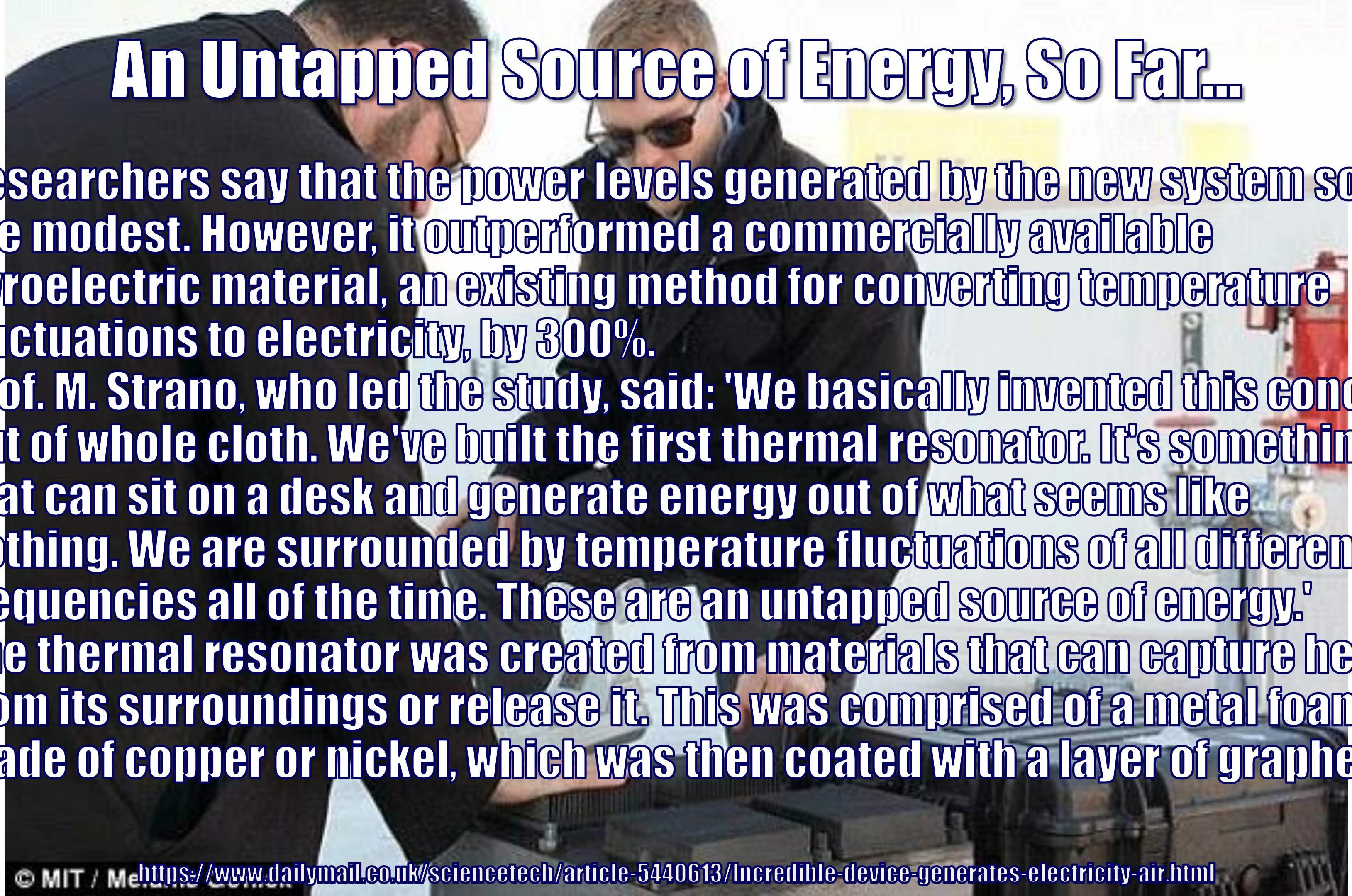
Electricity from Thin Air, MIT...

- A miraculous device that can generate electricity seemingly out of thin air has been developed by engineers. Called a thermal resonator, it relies on fluctuations in temperature between day and night to produce electricity. It can be used without the need for sunlight, batteries or wind, making it ideal for situations where these resources can't be relied upon. The technology has the potential to power sensors and communications devices for years without the need for batteries.
- Experts at the MIT department of chemical engineering are behind the find. Their gadget is a twist on a thermoelectric generator, which create power when one side of the device is a different temperature from the other. This could be due to one side being exposed to sunlight, while the other is covered. The thermal resonator uses natural swings in temperature, and can generate charge even in the shade.



https://www.dailymail.co.uk/sciencetech/article-5440613/Incredible-device-generates-electricity-air.html

An Untapped Source of Energy, So Far...



- Researchers say that the power levels generated by the new system so far are modest. However, it outperformed a commercially available pyroelectric material, an existing method for converting temperature fluctuations to electricity, by 300%.
- Prof. M. Strano, who led the study, said: 'We basically invented this concept out of whole cloth. We've built the first thermal resonator. It's something that can sit on a desk and generate energy out of what seems like nothing. We are surrounded by temperature fluctuations of all different frequencies all of the time. These are an untapped source of energy.'
- The thermal resonator was created from materials that can capture heat from its surroundings or release it. This was comprised of a metal foam, made of copper or nickel, which was then coated with a layer of graphene.

https://www.dailymail.co.uk/sciencetech/article-5440613/Incredible-device-generates-electricity-air.html

Thermal Effusivity

- The new generator relies on thermoelectric power to seemingly create electricity out of thin air. They convert temperature differences directly into electrical energy through a phenomenon called the Seebeck effect. His discovery in 1821 revealed that a thermal gradient formed between two dissimilar conductors can produce electricity. To do so, they rely on specially created materials which take advantage of thermal effusivity.
- This is the combination of thermal conduction and thermal capacity, or how quickly heat can be distributed through a material and how much heat can be stored. One side of the device captures heat, which then slowly radiates through to the other side. One side always lags behind the other as the system tries to reach equilibrium. In most materials one of these properties is high, while the other is low. Ceramics have low conduction but high thermal capacity, for example.

https://www.dailymail.co.uk/sciencetech/article-5440613/Incredible-device-generates-electricity-air.html

Their Findings Archived, Finally…

- This perpetual difference between the two sides can then be harvested through conventional thermoelectrics. The foam was then infused with a kind of wax called octadecane, which changes between solid and liquid within a particular range of temperatures. A proof of concept sample of the material produced 350 mV and 1.3 mW in response to a 10°C change.
- This would be enough to power small environmental sensors or communications systems. Such systems could provide low-power but long-lasting energy sources for landers or rovers exploring remote locations, including other moons and planets. For such uses, much of the system could be made from local materials rather than having to be premade, he says. The findings of the study were published in:
  Nature Communications| (2018) 9:664 |DOI: 10.1038/s41467-018-03029-x|www.nature.com/naturecommunications.

https://www.dailymail.co.uk/sciencetech/article-5440613/Incredible-device-generates-electricity-air.html