# SAMPLE

## Energy

From Kinetic to Nuclear to Dark Energy

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# Chapter 1: The Discovery of Energy

By photosynthesis, green plants convert solar energy into chemically stored energy, which produces food, wood and the biomass from which fossil fuels are derived.

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 122 PW·year = 3,850,000 exajoules (EJ) per year. In 2002 (2019), this was more energy in one hour (one hour and 25 minutes) than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass.

The potential solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planet because factors such as geography, time variation, cloud cover, and the land available to humans limit the amount of solar energy that we can acquire.

In 2021, Carbon Tracker Initiative estimated the land area needed to generate all our energy from solar alone was 450,000 km2 — or about the same as the area of Sweden, or the area of Morocco, or the area of California (0.3% of the Earth's total land area).

Solar technologies are categorized as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different levels around the world, mostly depending on the distance from the Equator. Although solar energy refers primarily to the use of solar radiation for practical ends, all types of renewable energy, other than geothermal power and tidal power, are derived either directly or indirectly from the Sun.

Active solar techniques use photovoltaics, concentrated solar power, solar thermal collectors, pumps, and fans to convert sunlight into useful output. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternative resources and are generally considered demand-side technologies.

In 2000, the United Nations Development Programme, UN Department of Economic and Social Affairs, and World Energy Council published an estimate of how much of that solar potential humanity could realistically harvest each year. This took into account factors such as insolation, cloud cover, and the land that is usable by humans. It was stated that solar energy has a global potential of 1,600 to 49,800 exajoules (4.4×1014 to 1.4×1016 kWh) per year (see table below).

Solar thermal technologies can be used for water heating, space heating, space cooling and process heat generation. In 1878, at the Universal Exposition in Paris, Augustin Mouchot successfully demonstrated a solar steam engine but could not continue development because of cheap coal and other factors.

In 1897, Frank Shuman, a US inventor, engineer and solar energy pioneer built a small demonstration solar engine that worked by reflecting solar energy onto square boxes filled with ether, which has a lower boiling point than water and were fitted internally with black pipes which in turn powered a steam engine. In 1908 Shuman formed the Sun Power Company with the intent of building larger solar power plants. He, along with his technical advisor A.S.E.

Ackermann and British physicist Sir Charles Vernon Boys, developed an improved system using mirrors to reflect solar energy upon collector boxes, increasing heating capacity to the extent that water could now be used instead of ether. Shuman then constructed a full-scale steam engine powered by low-pressure water, enabling him to patent the entire solar engine system by 1912. Shuman built the world's first solar thermal power station in Maadi, Egypt, between 1912 and 1913.

His plant used parabolic troughs to power a 45–52 kilowatts (60–70 hp) engine that pumped more than 22,000 litres (4,800 imp gal; 5,800 US gal) of water per minute from the Nile River to adjacent cotton fields.

Although the outbreak of World War I and the discovery of cheap oil in the 1930s discouraged the advancement of solar energy, Shuman's vision, and basic design were resurrected in the 1970s with a new wave of interest in solar thermal energy.

In 1916 Shuman was quoted in the media advocating solar energy's utilization, saying: We have proved the commercial profit of sun power in the tropics and have more particularly proved that after our stores of oil and coal are exhausted the human race can receive unlimited power from the rays of the Sun. Solar hot water systems use sunlight to heat water.

In middle geographical latitudes (between 40 degrees north and 40 degrees south), 60 to 70% of the domestic hot water use, with water temperatures up to 60 °C (140 °F), can be provided by solar heating systems. The most common types of solar water heaters are evacuated tube collectors (44%) and glazed flat plate collectors (34%) generally used for domestic hot water; and unglazed plastic collectors (21%) used mainly to heat swimming pools.

Kinetic energy is determined by the movement of an object – or the composite motion of the object's components – while potential energy reflects the potential of an object to have motion, generally being based upon the object's position within a field or what is stored within the field itself.

While these two categories are sufficient to describe all forms of energy, it is often convenient to refer to particular combinations of potential and kinetic energy as its own form.

For example, the sum of translational and rotational kinetic and potential energy within a system is referred to as mechanical energy, whereas nuclear energy refers to the combined potentials within an atomic nucleus from either the nuclear force or the weak force, among other examples. The word energy derives from the Ancient Greek: ἐνέργεια, romanized: energeia, lit. 'activity, operation', which possibly appears for the

first time in the work of Aristotle in the 4th century BC.

In contrast to the modern definition, energeia was a qualitative philosophical concept, broad enough to include ideas such as happiness and pleasure. In the late 17th century, Gottfried Leibniz proposed the idea of the Latin: vis viva, or living force, which defined as the product of the mass of an object and its velocity squared; he believed that total vis viva was conserved.

# Chapter 2: Understanding Energy

As of 2015, the total installed capacity of solar hot water systems was approximately 436 thermal gigawatt (GWth), and China is the world leader in their deployment with 309 GWth installed, taken up 71% of the market. Israel and Cyprus are the per capita leaders in the use of solar hot water systems with over 90% of homes using them.

In the United States, Canada, and Australia, heating swimming pools is the dominant application of solar hot water with an installed capacity of 18 GWth as of 2005. In the United States, heating, ventilation and air conditioning (HVAC) systems account for 30% (4.65 EJ/yr) of the energy used in commercial buildings and nearly 50% (10.1 EJ/yr) of the energy used in residential buildings.

Solar heating, cooling and ventilation technologies can be used to offset a portion of this energy.

Use of solar for heating can roughly be divided into passive solar concepts and active solar concepts, depending on whether active elements such as sun tracking and solar concentrator optics are used. Thermal mass is any material that can be used to store heat—heat from the Sun in the case of solar energy. Common thermal mass materials include stone, cement, and water.

Historically they have been used in arid climates or warm temperate regions to keep buildings cool by absorbing solar energy during the day and radiating stored heat to the cooler atmosphere at night. However, they can be used in cold temperate areas to maintain warmth as well. The size and placement of thermal mass depend on several factors such as climate, daylighting, and shading conditions.

When duly incorporated, thermal mass maintains space temperatures in a comfortable range and reduces the need for auxiliary heating and cooling equipment. A solar chimney (or thermal chimney, in this context) is a passive solar ventilation system composed of a vertical shaft connecting the interior and exterior of a building. As the chimney warms, the air inside is heated, causing an updraft that pulls air through the building.

Performance can be improved by using glazing and thermal mass materials in a way that mimics greenhouses.

Deciduous trees and plants have been promoted as a means of controlling solar heating and cooling. When planted on the southern side of a building in the northern hemisphere or the northern side in the southern hemisphere, their leaves provide

shade during the summer, while the bare limbs allow light to pass during the winter.

Since bare, leafless trees shade 1/3 to 1/2 of incident solar radiation, there is a balance between the benefits of summer shading and the corresponding loss of winter heating.

In climates with significant heating loads, deciduous trees should not be planted on the Equator-facing side of a building because they will interfere with winter solar availability. They can, however, be used on the east and west sides to provide a degree of summer shading without appreciably affecting winter solar gain. Solar cookers use sunlight for cooking, drying, and pasteurization. They can be grouped into three broad categories: box cookers, panel cookers, and reflector cookers.

The simplest solar cooker is the box cooker first built by Horace de Saussure in 1767. A basic box cooker consists of an insulated container with a transparent lid. It can be used effectively with partially overcast skies and will typically reach temperatures of 90–150 °C (194–302 °F). Panel cookers use a reflective panel to direct sunlight onto an insulated container and reach temperatures comparable to box cookers.

Reflector cookers use various concentrating geometries (dish, trough, Fresnel mirrors) to focus light on a cooking container.

These cookers reach temperatures of 315 °C (599 °F) and above but require direct light to function properly and must be repositioned to track the Sun. Solar concentrating technologies such as parabolic dish, trough and Scheffler reflectors can provide process heat for commercial and industrial applications.

The first commercial system was the Solar Total Energy Project (STEP) in Shenandoah, Georgia, US where a field of 114 parabolic dishes provided 50% of the process heating, air conditioning and electrical requirements for a clothing factory.

This grid-connected cogeneration system provided 400 kW of electricity plus thermal energy in the form of 401 kW steam and 468 kW chilled water and had a one-hour peak load thermal storage. Evaporation ponds are shallow pools that concentrate dissolved solids through evaporation. The use of evaporation ponds to obtain salt from seawater is one of the oldest applications of solar energy.

Modern uses include concentrating brine solutions used in leach mining and removing dissolved solids from waste streams.

Clothes lines, clotheshorses, and clothes racks dry clothes through evaporation by wind and sunlight without consuming electricity or gas. In some states of the United States legislation protects the "right to dry" clothes. Unglazed transpired collectors (UTC) are perforated sun-facing walls used for preheating ventilation air. UTCs can raise the incoming air temperature up to 22 °C (40 °F) and deliver outlet temperatures of 45–60 °C (113–140 °F).

The short payback period of transpired collectors (3 to 12 years) makes them a more cost-effective alternative than glazed collection systems. As of 2003, over 80 systems with a combined collector area of 35,000 square metres (380,000 sq ft) had been

installed worldwide, including an 860 m2 (9,300 sq ft) collector in Costa Rica used for drying coffee beans and a 1,300 m2 (14,000 sq ft) collector in Coimbatore, India, used for drying marigolds.

To account for slowing due to friction, Leibniz theorized that thermal energy consisted of the motions of the constituent parts of matter, although it would be more than a century until this was generally accepted. The modern analog of this property, kinetic energy, differs from vis viva only by a factor of two.

Writing in the early 18th century, Émilie du Châtelet proposed the concept of conservation of energy in the marginalia of her French language translation of Newton's Principia Mathematica, which represented the first formulation of a conserved measurable quantity that was distinct from momentum, and which would later be called "energy". In 1807, Thomas Young was possibly the first to use the term "energy" instead of vis viva, in its modern sense.

Gustave-Gaspard Coriolis described "kinetic energy" in 1829 in its modern sense, and in 1853, William Rankine coined the term "potential energy". The law of conservation of energy was also first postulated in the early 19th century, and applies to any isolated system. It was argued for some years whether heat was a physical substance, dubbed the caloric, or merely a physical quantity, such as momentum.

In 1845 James Prescott Joule discovered the link between mechanical work and the generation of heat.

## Chapter 3: Key Characteristics of Energy

Solar distillation can be used to make saline or brackish water potable. The first recorded instance of this was by 16th-century Arab alchemists. A large-scale solar distillation project was first constructed in 1872 in the Chilean mining town of Las Salinas. The plant, which had solar collection area of 4,700 m2 (51,000 sq ft), could produce up to 22,700 L (5,000 imp gal; 6,000 US gal) per day and operate for 40 years.

Individual still designs include single-slope, double-slope (or greenhouse type), vertical, conical, inverted absorber, multi-wick, and multiple effect. These stills can operate in passive, active, or hybrid modes. Double-slope stills are the most economical for decentralized domestic purposes, while active multiple effect units are more suitable for large-scale applications. Solar water disinfection (SODIS) involves exposing water-filled plastic polyethylene terephthalate (PET) bottles to sunlight for several hours.

Exposure times vary depending on weather and climate from a minimum of six hours to two days during fully overcast conditions. It is recommended by the World Health Organization as a viable method for household water treatment and safe storage. Over two million people in developing countries use this method for their daily drinking water. Solar energy may be used in a water stabilization pond to treat waste water without chemicals or electricity.

A further environmental advantage is that algae grow in such ponds and consume carbon dioxide in photosynthesis, although algae may produce toxic chemicals that make the water unusable. Molten salt can be employed as a thermal energy storage method to retain thermal energy collected by a solar tower or solar trough of a concentrated solar power plant so that it can be used to generate electricity in bad weather or at night.

It was demonstrated in the Solar Two project from 1995 to 1999.

The system is predicted to have an annual efficiency of 99%, a reference to the energy retained by storing heat before turning it into electricity, versus converting heat directly into electricity. The molten salt mixtures vary. The most extended mixture contains sodium nitrate, potassium nitrate and calcium nitrate. It is non-flammable and non-toxic, and has already been used in the chemical and metals industries as a heat-transport fluid.

Hence, experience with such systems exists in non-solar applications. The salt melts at 131 °C (268 °F).

It is kept liquid at 288 °C (550 °F) in an insulated "cold" storage tank. The liquid salt is pumped through panels in a solar collector where the focused irradiance heats it to 566 °C (1,051 °F). It is then sent to a hot storage tank. This is so well insulated that the thermal energy can be usefully stored for up to a week.

When electricity is needed, the hot salt is pumped to a conventional steam-generator to produce superheated steam for a turbine/generator as used in any conventional coal, oil, or nuclear power plant. A 100-megawatt turbine would need a tank about 9.1 metres (30 ft) tall and 24 metres (79 ft) in diameter to drive it for four hours by this design.

Several parabolic trough power plants in Spain and solar power tower developer SolarReserve use this thermal energy storage concept.

The Solana Generating Station in the U.S. In Chile, The Cerro Dominador power plant has a 110 MW solar-thermal tower, the heat is transferred to molten salts. The molten salts then transfer their heat in a heat exchanger to water, generating superheated steam, which feeds a turbine that transforms the kinetic energy of the steam into electric energy using the Rankine cycle.

In this way, the Cerro Dominador plant is capable of generating around 110 MW of power. The plant has an advanced storage system enabling it to generate electricity for up to 17.5 hours without direct solar radiation, which allows it to provide a stable electricity supply without interruptions if required. The Project secured up to 950 GW·h per year sale.

Another project is the María Elena plant is a 400 MW thermo-solar complex in the northern Chilean region of Antofagasta employing molten salt technology.

Concentrating Solar Power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then

used as a heat source for a conventional power plant. A wide range of concentrating technologies exists; the most developed are the parabolic trough, the solar tower collectors, the concentrating linear Fresnel reflector, and the Stirling dish. Various techniques are used to track the Sun and focus light.

In all of these systems, a working fluid is heated by the concentrated sunlight, and is then used for power generation or energy storage. Designs need to account for the risk of a dust storm, hail, or another extreme weather event that can damage the fine glass surfaces of solar power plants. Metal grills would allow a high percentage of sunlight to enter the mirrors and solar panels while also preventing most damage.

Sunlight has influenced building design since the beginning of architectural history.

Advanced solar architecture and urban planning methods were first employed by the Greeks and Chinese, who oriented their buildings toward the south to provide light and warmth. The common features of passive solar architecture are orientation relative to the Sun, compact proportion (a low surface area to volume ratio), selective shading (overhangs) and thermal mass.

When these features are tailored to the local climate and environment, they can produce well-lit spaces that stay in a comfortable temperature range.

These developments led to the theory of conservation of energy, formalized largely by William Thomson (Lord Kelvin) as the field of thermodynamics. Thermodynamics aided the rapid development of explanations of chemical processes by Rudolf Clausius, Josiah Willard Gibbs, Walther Nernst, and others. It also led to a mathematical formulation of the concept of entropy by Clausius and to the introduction of laws of radiant energy by Jožef Stefan.

According to Noether's theorem, the conservation of energy is a consequence of the fact that the laws of physics do not change over time. Thus, since 1918, theorists have understood that the law of conservation of energy is the direct mathematical consequence of the translational symmetry of the quantity conjugate to energy, namely time. Albert Einstein's 1905 theory of special relativity showed that rest mass corresponds to an equivalent amount of rest energy.

This means that rest mass can be converted to or from equivalent amounts of (non-material) forms of energy, for example, kinetic energy, potential energy, and electromagnetic radiant energy. When this happens, rest mass is not conserved, unlike the total mass or total energy. All forms of energy contribute to the total mass and total energy.

Thus, conservation of energy (total, including material or rest energy) and conservation of mass (total, not just rest) are one (equivalent) law.

## Chapter 4: The Science Behind Energy

Socrates' Megaron House is a classic example of passive solar design. The most recent approaches to solar design use computer modeling tying together solar lighting,

heating and ventilation systems in an integrated solar design package. Active solar equipment such as pumps, fans, and switchable windows can complement passive design and improve system performance. Urban heat islands (UHI) are metropolitan areas with higher temperatures than that of the surrounding environment.

The higher temperatures result from increased absorption of solar energy by urban materials such as asphalt and concrete, which have lower albedos and higher heat capacities than those in the natural environment. A straightforward method of counteracting the UHI effect is to paint buildings and roads white and to plant trees in the area.

Using these methods, a hypothetical "cool communities" program in Los Angeles has projected that urban temperatures could be reduced by approximately 3 °C at an estimated cost of US$1 billion, giving estimated total annual benefits of US$530 million from reduced air-conditioning costs and healthcare savings. Agriculture and horticulture seek to optimize the capture of solar energy to optimize the productivity of plants.

Techniques such as timed planting cycles, tailored row orientation, staggered heights between rows and the mixing of plant varieties can improve crop yields.

While sunlight is generally considered a plentiful resource, the exceptions highlight the importance of solar energy to agriculture. During the short growing seasons of the Little Ice Age, French and English farmers employed fruit walls to maximize the collection of solar energy. These walls acted as thermal masses and accelerated ripening by keeping plants warm.

Early fruit walls were built perpendicular to the ground and facing south, but over time, sloping walls were developed to make better use of sunlight.

In 1699, Nicolas Fatio de Duillier even suggested using a tracking mechanism which could pivot to follow the Sun. Applications of solar energy in agriculture aside from growing crops include pumping water, drying crops, brooding chicks and drying chicken manure. More recently the technology has been embraced by vintners, who use the energy generated by solar panels to power grape presses.

Greenhouses convert solar light to heat, enabling year-round production and the growth (in enclosed environments) of specialty crops and other plants not naturally suited to the local climate. Primitive greenhouses were first used during Roman times to produce cucumbers year-round for the Roman emperor Tiberius. The first modern greenhouses were built in Europe in the 16th century to keep exotic plants brought back from explorations abroad. Greenhouses remain an important part of horticulture today.

Plastic transparent materials have also been used to similar effect in polytunnels and row covers. Development of a solar-powered car has been an engineering goal since the 1980s. The World Solar Challenge is a biannual solar-powered car race, where teams from universities and enterprises compete over 3,021 kilometres (1,877 mi) across central Australia from Darwin to Adelaide.

In 1987, when it was founded, the winner's average speed was 67 kilometres per hour (42 mph) and by 2007 the winner's average speed had improved to 90.87 kilometres per hour (56.46 mph). The North American Solar Challenge and the planned South African Solar Challenge are comparable competitions that reflect an international interest in the engineering and development of solar powered vehicles.

Some vehicles use solar panels for auxiliary power, such as for air conditioning, to keep the interior cool, thus reducing fuel consumption.

In 1975, the first practical solar boat was constructed in England. By 1995, passenger boats incorporating PV panels began appearing and are now used extensively. In 1996, Kenichi Horie made the first solar-powered crossing of the Pacific Ocean, and the Sun21 catamaran crossed the Atlantic on solar power alone in the winter of 2006–2007. There were plans to circumnavigate the globe in 2010.

In 1974, the unmanned AstroFlight Sunrise airplane made the first solar flight.

On 29 April 1979, the Solar Riser made the first flight in a solar-powered, fully controlled, man-carrying flying machine, reaching an altitude of 40 ft (12 m). In 1980, the Gossamer Penguin made the first piloted flights powered solely by photovoltaics. This was quickly followed by the Solar Challenger which crossed the English Channel in July 1981. In 1990 Eric Scott Raymond in 21 hops flew from California to North Carolina using solar power.

Developments then turned back to unmanned aerial vehicles (UAV) with the Pathfinder (1997) and subsequent designs, culminating in the Helios which set the altitude record for a non-rocket-propelled aircraft at 29,524 metres (96,864 ft) in 2001. The Zephyr, developed by BAE Systems, is the latest in a line of record-breaking solar aircraft, making a 54-hour flight in 2007, and month-long flights were envisioned by 2010.

From March 2015 to July 2016, Solar Impulse, an electric aircraft, successfully circumnavigated the globe.

It is a single-seat plane powered by solar cells and capable of taking off under its own power. The design allows the aircraft to remain airborne for several days. A solar balloon is a black balloon that is filled with ordinary air. As sunlight shines on the balloon, the air inside is heated and expands, causing an upward buoyancy force, much like an artificially heated hot air balloon.

In the 18th century, these had appeared as two seemingly-distinct laws. The first evidence of quantization in atoms was the observation of spectral lines in light from the sun in the early 1800s by Joseph von Fraunhofer and William Hyde Wollaston. The notion of quantized energy levels was proposed in 1913 by Danish physicist Niels Bohr in the Bohr theory of the atom.

The modern quantum mechanical theory giving an explanation of these energy levels in terms of the Schrödinger equation was advanced by Erwin Schrödinger and Werner Heisenberg in 1926. Noether's theorem shows that the symmetry of this equation is equivalent to a conservation of probability. At the quantum level, mass-energy

interactions are all subject to this principle.

During wave function collapse, the conservation of energy does not hold at the local level, although statistically the principle holds on average for sufficiently large numbers of collapses.

Conservation of energy does apply during wave function collapse in H. Everett's many-worlds interpretation of quantum mechanics. In dimensional analysis, the base units of energy are given by: Work = Force × Distance = M L2 T−2, with the fundamental dimensions of Mass M, Length L, and time T. In the International System of Units (SI), the unit of energy is the joule.

# Chapter 5: Observation and Measurement of Energy

Some solar balloons are large enough for human flight, but usage is generally limited to the toy market as the surface-area to payload-weight ratio is relatively high. The Squad Solar is a Neighborhood Electric Vehicle that has a solar roof and can be plugged into a normal 120 volt outlet to be charged. Solar chemical processes use solar energy to drive chemical reactions.

These processes offset energy that would otherwise come from a fossil fuel source and can also convert solar energy into storable and transportable fuels. Solar induced chemical reactions can be divided into thermochemical or photochemical. A variety of fuels can be produced by artificial photosynthesis.

The multielectron catalytic chemistry involved in making carbon-based fuels (such as methanol) from reduction of carbon dioxide is challenging; a feasible alternative is hydrogen production from protons, though use of water as the source of electrons (as plants do) requires mastering the multielectron oxidation of two water molecules to molecular oxygen.

Some have envisaged working solar fuel plants in coastal metropolitan areas by 2050 – the splitting of seawater providing hydrogen to be run through adjacent fuel-cell electric power plants and the pure water by-product going directly into the municipal water system. In addition, chemical energy storage is another solution to solar energy storage. Hydrogen production technologies have been a significant area of solar chemical research since the 1970s.

Aside from electrolysis driven by photovoltaic or photochemical cells, several thermochemical processes have also been explored.

One such route uses concentrators to split water into oxygen and hydrogen at high temperatures (2,300–2,600 °C or 4,200–4,700 °F). Another approach uses the heat from solar concentrators to drive the steam reformation of natural gas thereby increasing the overall hydrogen yield compared to conventional reforming methods. Thermochemical cycles characterized by the decomposition and regeneration of reactants present another avenue for hydrogen production.

The Solzinc process under development at the Weizmann Institute of Science uses a 1

# ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.