**Everything is Solar (or stellar!) Powered\***

Everything around that moves, emits light or sound, or generates heat is, in some fashion, solar powered. This includes all machines, electronics, industrial process, the entire biosphere, and all the weather on the planet.

Do you believe?

Let’s back up a bit. I suppose the first thing we think of when we hear “power” or “energy” is the generation of electricity. The direct production of electricity from solar photovoltaic panels is a small contributor to the [worldwide energy mix](http://environment.nationalgeographic.com/environment/energy/great-energy-challenge/world-electricity-mix/), so I’m not going to discuss it in detail.

Human civilization is primarily dependent on the use of fossil fuels like coal and oil to run our cars and power plants. But what are fossil fuels and where do they come from?

**Fossil Fuels Are Ancient Reservoirs of Solar Power**

As the name suggests, [fossil fuels](https://en.wikipedia.org/wiki/Fossil_fuels) are the remains of ancient organisms. These remains primarily consist of organic matter (carbon-rich matter) that has been altered by extremes of heat and pressure following burial in oxygen-poor conditions. Carbon in the form of organics is relatively rare on Earth (actually carbon itself is pretty rare – [see chemical composition of the Earth](https://en.wikipedia.org/wiki/Earth#Chemical_composition)). Mostly carbon is in the form of carbon dioxide – and most of *that* is locked up in oceanic and continental rocks.

Organic matter, as the utility of fossil fuels illustrates, contains a lot of available energy. Energy is liberated when a catalyst is used to break molecular bonds. New bonds are formed, producing different molecules (with a lower energy state). Forming these new bonds produces energy. An illustration of this is the [combustion](https://en.wikipedia.org/wiki/Combustion) reaction that powers most automobiles, where gasoline is combined with atmospheric oxygen to produce water, carbon dioxide, and heat. The heat causes gas to expand and moves a piston, which produces useful work and drives the engine. A similar reaction is [aerobic respiration](https://en.wikipedia.org/wiki/Aerobic_respiration#Aerobic_respiration), where your body combines organic compounds from your food with oxygen to produce water, CO2, and energy (which is used to generated [ATP](https://en.wikipedia.org/wiki/Adenosine_triphosphate)). Respiration is, in fact, a combustion reaction.

What does this have to do with solar power? Well, something had to create those organic compounds in the first place. Energy-rich matter doesn’t just fall from the sky (well [it does](http://astrogeo.oxfordjournals.org/content/45/2/2.8.full), but not at a [high rate](http://www.tulane.edu/~sanelson/Natural_Disasters/impacts.htm)!). That thing is photosynthesis.

[Photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis) is the process of generating organic matter using carbon dioxide, solar energy (consisting of photons), and a source of electrons. Almost all photosynthesis on the modern Earth proceeds with water as the electron source (or “reductant”). This is known as oxygenic photosynthesis oxygen is a waste product of the reaction.

Photosynthesis allows an organism to achieve a chemical reaction that would not be spontaneous in the absence of biological mediation. The Sun provides a source of “free energy” that allows this reaction to proceed. Organisms can then use this material to build their bodies or recombine the organic material with oxygen to yield energy.

Most of the dead organisms that, after millions of years of geological and geochemical alteration, became fossil fuels were photosynthesizers. Even if they weren’t photosynthesizers, they ultimately got their organic fuel from photosynthesizers. **So fossil fuels are really an enormous time-integrated reservoir of biologically produced solar energy.**

(There is an obvious tie in here with the release of carbon dioxide from fossil fuels and the anthropogenic [climate change](https://en.wikipedia.org/wiki/Climate_change) we are now experiencing. The carbon that constitutes the fossil fuels we burn ultimately came from the atmosphere, but was sequestered into the ground over the course of hundreds of millions of years. We are releasing substantial fractions of that global reservoir in timespans measured in decades – hundreds of thousands of times faster.)

**What about wind, hydro, geothermal, etc.?**

[Wind power](https://en.wikipedia.org/wiki/Wind_power) refers to the collection of energy from turbines that convert the mechanical energy from the movement of the air into electric energy with the use of an [electric motor](https://en.wikipedia.org/wiki/Electric_motor). But where does the mechanical energy of air come from? [Wind](https://en.wikipedia.org/wiki/Wind#Cause) is a consequence of differences in atmospheric pressure between two places. Air will move from areas of high pressure to areas of low pressure in order to reach equilibrium. The pressure differences themselves arise primarily from differences in solar insolation (air expands when heated thus causing higher pressure). On a global scale, the difference in insolation between the poles and the equator is the major factor driving large-scale winds. Therefore the Sun is the source of energy input to winds. This is true on both a global and local scale.

[Hydroelectric power](https://en.wikipedia.org/wiki/Hydroelectricity) is obtained from moving water in much the same way that wind power is extracted from moving air. Water moving down an elevation gradient (from a reservoir to an outflow) has gravitational potential energy that is converted to electricity by moving through a turbine. It’s obvious that the renewable nature of hydroelectric power is predicated on the replenishment of the reservoir with more water and that is achieved ultimately by rainfall. Rainfall is part of the [hydrological cycle](https://en.wikipedia.org/wiki/Hydrological_cycle), which depends on the Sun for evaporation. The Sun provides the energy for evaporation into the atmosphere, allowing rain to fall on high elevation areas, which then drains into hydroelectric reservoirs.

[Geothermal power](https://en.wikipedia.org/wiki/Geothermal) is a bit harder to tie to the Sun. The major contributors to the [internal energy of the Earth](https://en.wikipedia.org/wiki/Earth#Heat) are the decay of radioactive isotopes and the initial heat of formation. It turns out that all radioactive isotopes such as thorium, uranium, and potassium-40 were forged in the crucible of massive dying stars, the [type II supernova](https://en.wikipedia.org/wiki/Type_II_supernova)e. These isotopes can only be formed with massive fluxes of neutrons only achievable by a supernova explosion. Thus, nuclear decay and fission power is really the release of small portions of energy temporarily stored in unstable atomic nuclei by billions-year-old supernova explosions (like little atomic batteries). Clearly this is stellar power if not Solar. The [energy of formation](https://en.wikipedia.org/wiki/Gravitational_binding_energy) is accounted for by the gravitational potential energy that was converted into kinetic energy (heat) billions of years ago as smaller bodies were drawn to our nascent world’s gravitational pull. Of course, the formation of the Earth and the other planets in the Solar System cannot be separated from the same process that formed our Sun. Both are the results of the collapse of a massive molecular cloud (perhaps spurred by a local supernova), but since the Sun contains 99.99% of the mass of the Solar System, the planets can really be thought of as associated byproducts of the Sun’s formation. Perhaps geothermal power is better describes as “stellar-associated” power.

**I heard there’s life not dependent on the Sun. Is that true?**

Kind of, but this has been very exaggerated. Life that uses chemical [redox gradients](https://en.wikipedia.org/wiki/Redox_gradient) for energy (a very small part of the biosphere, but interesting for many reasons) is often heralded as a type of life that is independent of the Sun. A redox gradient is an area where chemicals with different [oxidation states](https://en.wikipedia.org/wiki/Oxidation_states) meet and can release energy. We have to be very careful to exclude redox gradients that are indirect result of the Sun, however, such as chemical gradients that result from photolysis, weathering, or the hydrological cycle. Also, any organism that uses oxygen is dependent on the Sun, as all free oxygen results from oxygenic photosynthesis. The [claim](http://wwf.panda.org/about_our_earth/blue_planet/deep_sea/vents_seeps/) that the entire ecosystems surrounding deep-sea vents are independent of the Sun is demonstrably incorrect, as the animals there require oxygen for respiration. (Let’s also ignore that these ocean depths would freeze if not for the heat from the Sun). There are microorganisms at the [Lost City](https://en.wikipedia.org/wiki/Lost_City_(hydrothermal_field)) hydrothermal vents that get their energy from [serpentinisation](https://en.wikipedia.org/wiki/Serpentinisation) reactions that could occur in the subsurface of extraterrestrial locales such as Mars. The chemical energy that isn’t directly or indirectly created by the Sun was ultimately created by the [nucleosynthesis](https://en.wikipedia.org/wiki/Nucleosynthesis) of evolved stars, so you really can’t escape the dependence on stellar processes.

That was certainly a lot of information. I hope I’ve done a good job tying the role of the Sun and stars in general into many disparate processes that aren’t normally associated with them. The Universe is actually a vastly interconnected web of physics and chemistry, so nothing really exists in isolation.

\*The biggest exception to the “everything is solar powered” thesis is tidal power. Only about 1/3 of the tidal forces the Earth experiences are due to the Sun. The rest are a result of our closest neighbor, the Moon. (Side note: many folks assume the Moon is the only source of tides. In reality we would still have tides even if there was no Moon, but they would be weaker and less variable).