a field guide to renewable energy technologies

land art generator initiative

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ABOUT THIS GUIDE

The Land Art Generator Initiative provides a platform for innovative ways of thinking about what renewable energy generation looks like and how it relates to the overall fabric of our constructed and natural environments. It calls on interdisciplinary teams to conceive of large scale site-specific artworks that provide renewable electricity to the city at a utility-scale (equivalent to the demand of hundreds of homes). Once constructed, these public infrastructure artworks will offset thousands of tons of CO_2 and provide iconic amenities that will serve to educate and inspire the communities in which they are built.

As a part of the Land Art Generator Initiative, we have put together this field guide of renewable energy generation technologies as a useful resource for all designers, homeowners, urban planners, students, artists, architects and landscape architects, engineers, and anyone else interested in a clean energy future.

There is a lot more out there than what we see in the everyday. In fact, you will see in this guide that there are dozens of proven methods of harnessing the power of nature in sustainable ways. Some of the more interesting examples that may be applicable as a medium for public art installations are the organic thin films which are flexible and offer interesting hues and textures, piezoelectric generators that capture vibration energy, and concentrated photovoltaics, which allow for interesting play with light. But the possibilities are endless, and new designs that can be artistically integrated into residential and commercial projects are coming into the market all the time.

It is our hope that this field guide will get you thinking creatively about ways to use technologies in innovative contexts—and that a clear understanding of the wealth of possibilities that are out there will help designers to conceive of the most creative net zero energy constructions.

solar

THERMAL

DIRECT NON-CONCENTRATING

CONVERSION EFFICIENCY $= \frac{\text{energy output}}{\text{energy input}} =$ 45%–75%
Depending on system type & operating temperature

Solar thermal collectors can be mounted on the roof or the wall of a building, or in another location that has exposure to the sun.

Solar combisystems: solar thermal is often used in combination with other energy-saving techniques such as ground source heat (geosolar systems), and solar thermal cooling (absorption refrigeration).

One large installation can be used for "district heating" of multiple buildings.

EVACUATED TUBE SYSTEM
Photo provided by Lumen Solar, courtesy of Apricus Solar Hot Water.

Solar thermal is any installation in which solar radiation is used to heat a medium such as water or air.

Water can be for direct use in the domestic plumbing system of a building and for radiant floor heating (instead of relying on natural gas or grid source electricity that is most likely generated from fossil fuels to heat the water). These systems typically utilize either flat plate or evacuated tube collection systems.

Solar heated water can serve as an energy storage mechanism to create thermal heat lag within occupied space such as with a trombe wall.

Other systems that can help heat occupied space rely on air rather than water. The air is circulated through a cavity that is exposed to direct sunlight on the exterior of a building.

A very simple example of thermal energy is a greenhouse where the entire building acts as the solar energy collection device.

solar

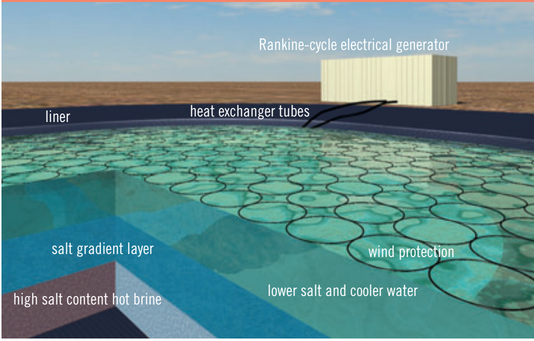
THERMAL

SOLAR POND (SALTWATER)

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 10\%$$

A defining characteristic of a highly saline body of water is that it naturally stratifies into three layers of salinity. At the surface is a layer of low salinity and at the bottom is a layer of very high salinity. In between there is an intermediate insulating layer that keeps a heat exchange convention cycle from forming.

When exposed to solar radiation, heat is trapped in the bottom of the salt water pond where temperatures can reach nearly 100°C while water at the surface is 30°C.



SOLAR POND

The heat that is trapped at the bottom of a saltwater pond can be harnessed to power an organic Rankine cycle turbine or a Stirling engine, both of which convert heat into electricity without steam (does not require temperatures in excess of H_2O boiling point).

Via the Organic Rankine Cycle (ORC), water is piped to an evaporator coil that heats a low-boiling-point fluid to pressurized vapor, driving a turbine. The vapor then passes to a condenser, where water from the top layer of the pond is used to cool the fluid back into liquid form after which it is then pumped back to the evaporator (with energy from a PV panel on-site).

Because salt water is an excellent thermal heat sink, the solar pond produces electricity 24 hours per day regardless of weather conditions.

Efficiency is greater in climates that receive higher average solar irradiance.

solar

THERMAL CONCENTRATED (CSP)

PARABOLIC TROUGH

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 25\%$$

As of 2010, CSP (concentrated solar power) plants in operation in the USA met the needs of over 350,000 people and displaced the equivalent of 2.3 million barrels of oil annually.

Utility-scale CSP typically requires large tracts of land, but "Micro CSP" systems can be designed for installation on building rooftops.

SEGS POWER PLANT AT KRAMER JUNCTION IN THE MOJAVE DESERT
Owned and operated by FPL Energy. Image via Desertec-UK.

The concentrated parabolic trough design is one of the most common types of solar power systems in application for utility-scale electricity generation. It consists of a series of long, highly polished parabolic reflecting surfaces that focus sunlight onto an absorber tube running along the focal point of the parabola.

A heat transfer fluid (typically an oil) runs through the tube and is heated to approximately 400°C to provide the thermal energy required to run a steam turbine.

The parabolic shape of the reflector allows the troughs to be oriented on a north-south axis and track the sun in only one rotational axis from east to west each day.

Highly polished metals are often used as the reflector material since parabolic curved mirrors can be complex to manufacture.

solar

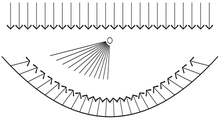
THERMAL CONCENTRATED (CSP)

LINEAR FRESNEL REFLECTOR (LFR OR CLFR)

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 20\%$$

Fresnel geometry allows flat surfaces to act in a way that mimics convex or concave mirror or lens optics.

It was originally developed by French physicist Augustin-Jean Fresnel for use in lighthouses.



In a Fresnel reflector, a parabolic mirror is simulated in a segmented or “Fresnel” arrangement of flat mirrors.

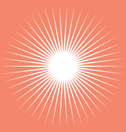
KIMBERLINA POWER PLANT IN BAKERSFIELD, CALIFORNIA
Image courtesy of AREVA Solar.

Linear Fresnel Reflectors (LFR) use long, thin segments of flat mirrors to focus sunlight onto a fixed absorber located at a common focal point of the reflectors. Absorbers in LFR often contain multiple heat transfer tubes.

Similar to the more common parabolic trough, this single-axis tracking concentrated reflector system heats up a transfer fluid which in turn heats water to run a steam turbine (in the case of LFR, temperatures in the transfer fluid can reach 750˚C although 300˚C is more common). One advantage of LFR is that the reflector mirrors are flat rather than parabolic in shape, which makes for a simpler mirror manufacturing process.

Systems can be set up to focus sunlight onto a single absorber (LFR) or onto multiple absorbers which is referred to as a Compact Linear Fresnel Reflector (CLFR) system. CLFR design is obtained by alternating the angle of each reflector. This can lead to greater energy conversion efficiency of the overall system.

solar



THERMAL CONCENTRATED (CSP)

DISH STIRLING

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 31.25\%$$

The Stirling Engine is a type of external combustion engine of the reciprocating piston variety. It is named after Robert Stirling, who in 1816 invented the closed-cycle air engine.

The engine works on the principle that gas expands as its temperature increases. Expansion and contraction cycles will move a piston back and forth within a closed chamber. A magnetic piston moving through an electromagnetic field becomes a linear alternator, thus producing electric current.

STIRLING ENERGY SYSTEMS
At the Sandia National Laboratories in Albuquerque, New Mexico.

Dish type collectors look sort of like television satellite receivers in their shape. They are parabolic, but unlike a linear parabola that concentrates along an axis, these are dish parabolas that concentrate light onto a single point. They can be one large dish, or an array of smaller reflectors as in the photo above.

They must rotate on a dual-axis to track the sun's position in the sky. At the single focal point is typically situated a Stirling Engine which converts heat into mechanical energy with high efficiency. The mechanical energy is then converted to electricity with a dynamo.

This type of concentrated solar thermal electricity installation rivals the best efficiencies of concentrated photovoltaic systems per similar land area and relies on more simple mechanical technologies as opposed to semiconductors and microelectronics.

Some CPV installations also utilize dish type collectors (refer to page 18).

solar

THERMAL CONCENTRATED (CSP)

SOLAR POWER TOWER

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 25\%$$

Solar power towers require a large amount of land in order to achieve sufficient operating temperature (500°C–1000°C) in the central receiver. The overall efficiency of the system can rise as receiver temperature increases.

Higher receiver temperature can allow for thermal storage, making it possible for this type of CSP power plant to generate consistent energy for baseload supply 24 hours a day (up to 17 hours of continuous electrical generation without solar feed).

GEMASOLAR POWER PLANT IN SPAIN
Owned by Torresol Energy (joint venture of SENER and MASDAR). Image courtesy of Torresol Energy.

In this type of concentrated solar thermal power, an array of mirrors at the ground level tracks the sun's location in the sky and focuses sunlight onto a single collector positioned high atop a central tower pylon structure. The temperatures reached at the collector can become extremely high and create efficiencies of scale. By using a high heat capacity material such as molten salt in the collector (which transfers heat to water to run a steam turbine) energy can be stored to produce electricity even after the sun has set.

Another variation, the beam-down tower, was recently demonstrated by Masdar in Abu Dhabi. Beam-down design allows the entire heat transfer loop to be located at ground level, potentially increasing the overall efficiency of the system.

Other design variations include a pit-power tower for a stadium mirror array (University of Queensland), and integrated applications on buildings such as those by Studied Impact Design (10MW Tower for Dubai).

solar

PHOTOVOLTAICS

ALL TYPES

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 3\%\text{–}42.5\%$$

The photovoltaic effect, first recognized by A. E. Becquerel in 1839, is the ability of a material (a semiconductor) to produce direct current electricity when exposed to solar radiation. It is related to the photoelectric effect, which is the ejection of an electron from a material substance by electromagnetic radiation incident on its surface. However, in the photovoltaic effect, the electrons remain within the material, creating positive and negative bands which can be harnessed by an electrical circuit.

MONOCRYSTALLINE SILICON PHOTOVOLTAIC ARRAY
Image courtesy of Siemens AG, Munich/Berlin.

Although the photovoltaic (PV) effect was demonstrated in various laboratory applications throughout the 19th century, it was not until 1954 that the first commercially viable application of the technology was demonstrated by Bell Laboratories.

Throughout the PV section we will discuss conversion efficiency. A good rule of thumb is that one square meter surface area (at sea level and perpendicular to the sun on a clear day) will typically receive 1000 watts of solar radiation energy (insolation = 1000W irradiance/square meter). This measure will vary slightly according to latitude, time of day, and season. The conversion efficiency is how many of those 1000 watts can be converted to electrical energy. A 20% efficient solar panel will have a 200W(p) capacity. The (p) stands for peak, nameplate, or rated capacity, and the panel will not always reach this level of output during field operation. The ratio between the rated capacity and the real measured output is the "capacity factor."

Many environmental factors such as heat build-up, humidity, surface dust, and airborne particulates can contribute to a lower capacity factor in field applications.

solar

PHOTOVOLTAIC

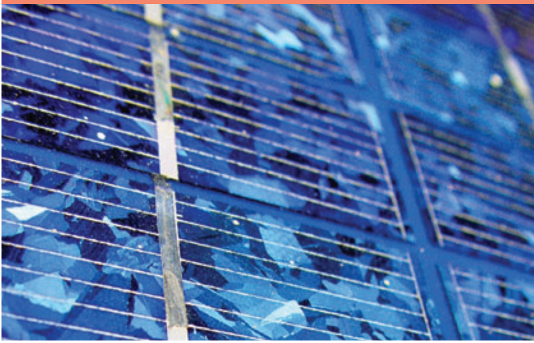
CRYSTALLINE SILICON WAFER

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 18\%–23\%$$

Silicon is the most common metalloid found in nature. It is typically found as silica (SiO_2) in sands rather than in its pure elemental form. Silicon makes up 27.7% of the earth's crust by mass.

Molten salt electrolysis can create pure silicon from silica with low energy input and without CO_2 emissions.

More commonly, high temperature furnaces (1,900°C) create the condition in which silica is converted via reaction with carbon into pure silicon.
$SiO_2 + 2\,C \rightarrow Si + 2\,CO$



POLYCRYSTALLINE SILICON SOLAR PANEL
Photo by Scott Robinson.

Silicon (Si) is a semiconductor material that displays the photovoltaic effect. It was the first material to be employed in solar cells and is still the most prevalent. It can be applied for use in either a crystalline (wafer) form, or in a non-crystalline (amorphous) form.

There are two types of crystalline silicon (c-Si): monocrystalline and polycrystalline (aka multicrystalline).

Monocrystalline is expensive to manufacture (because it requires cutting slices from cylindrical ingots of silicon crystals that are grown with the Czochralski process) but it is the most efficient crystalline silicon technology in terms of energy conversion.

Polycrystalline is easier to manufacture and can be cut into square shaped slices, but has slightly lower efficiency (approximately -5%). It is comprised of small crystals or crystallites.

solar

PHOTOVOLTAIC

THIN FILM SILICON

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 12\%$$

The efficiencies that are gained in the manufacturing process of thin film photovoltaics often times more than offset the reduced conversion efficiency of the panels when figured over the life-cycle of the system.

PHOTOVOLTAIC INSTALLATION
REAL GOODS SOLAR LIVING CENTER IN HOPLAND, CALIFORNIA
Photo by Cris Benton.

Amorphous silicon (a-Si) is less expensive to produce than either mono or poly-crystalline silicon. It is non-crystalline, meaning that the atomic structure is more randomized. While it operates at a lower efficiency than crystalline structures (about half the efficiency of monocrystalline Si), it can be placed in much thinner applications which can lead to a lower cost per watt capacity of the solar cell design.

Other types of thin film silicon are protocrystalline and nanocrystalline (aka microcrystalline). Some variations that combine layers of different types of thin film silicon have been referred to as micromorph (a combination of the terms MICROcrystalline and aMORPHous).

solar

PHOTOVOLTAIC

THIN FILM NON-SILICON

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 16\%\text{–}20\%$$

The levelized cost of energy for non-silicon systems when compared to silicon-based PV depends greatly on the global market cost of silicon at the time of manufacture.

Silicon is more abundant in nature than CIGS or CdTe raw materials. However, during periods of high global demand, silicon can sometimes cost more as a raw material.

Each semi-conductor material captures light energy most efficiently across a limited wavelength spectrum.

SEMPRA GENERATION'S CDTE COPPER MOUNTAIN SOLAR FACILITY
Image courtesy of Sempra U.S. Gas & Power, LLC.

As an alternative to silicon (Si), other semiconductor materials can be used for thin film solar cells. They have been proven to have greater efficiency than thin film amorphous silicon.

Copper-Indium Gallium Selenide (CIGS) has a conversion efficiency of about 20%. It can be manufactured to be very thin due to its high absorption coefficient.

Cadmium Telluride (CdTe) has a conversion efficiency of about 16% and potentially offers cost advantages over CIGS.

The company Nanosolar has developed a method of printing CIGS onto thin foil substrates with nanoparticle inks and roll-to-roll manufacturing, which allows for flexible thin film panels while reducing production costs.

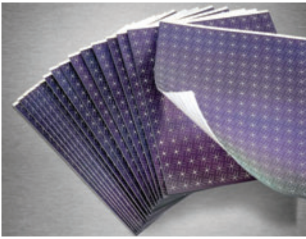


Image courtesy of Nanosolar.

solar

PHOTOVOLTAIC

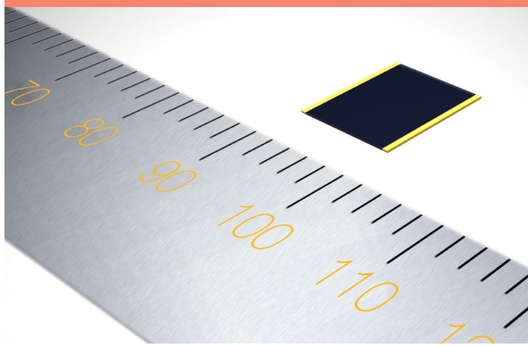
MULTIJUNCTION

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 25\%\text{–}45\%$$

Also called “tandem cells,” these specialized type of solar cells have been limited to use in aerospace, CPV, or other unique applications due to their complexity and expense.

Multijunction cells are capable of achieving high conversion efficiencies because they are able to capture electrons within multiple wavelengths of light.

Single junction cells are limited to the energy within a partial spectrum, the remaining light either reflecting off or being lost to heat energy.



MULTIJUNCTION CELL

Multijunction cells take advantage of multiple materials, each of which best capture a particular light wavelength (color spectrum) for solar-to-electricity conversion. This can lead to very high conversion efficiencies, even above 40%.

The technology was first developed for use in space explorations such as the Mars rover missions, and is still used for space applications. Because of the manufacturing expense, terrestrial commercial application has been generally limited to CPV systems (refer to page 18).

Different techniques use different substrate materials and can be either two-junction or three-junction. Some substrate materials that are used are: Gallium arsenide, Germanium, and Indium phosphide. Because the thin film is deposited (epitaxially) onto a monocrystalline substrate, the applied layers take on the lattice structure of the substrate crystal while maintaining thin film properties.

solar

PHOTOELECTROCHEMICAL CELL (PEC)

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 10\%$$

One of the technical obstacles to greater proliferation of PEC-type electrolysis for hydrogen generation is the corrosive effect of the electrolyte solution on the semiconductor anode.

PROOF-OF-CONCEPT BY PROFESSOR MICHAEL STRANO ET AL.
Image courtesy of MIT. Photo by Patrick Gillooly.

These are solar cells that transform solar energy directly into electrical energy. Instead of using a solid-state semiconductor as the light absorbing material, PECs use a electrolyte material (typically a fluid). A circuit is created via a semiconducting anode and a metal cathode which are both in contact with the electrolyte.

One type of PEC is the DSSC (dye-sensitized solar cell). More about DSSC can be found on page 13.

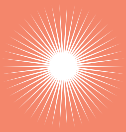
Other types of PEC can be used to harness solar energy directly for purposes of electrolysis to create hydrogen—a stored fuel. In this system, water acts as the electrolyte solution. Hydrogen and oxygen form around the anode when exposed to sunlight. The resulting hydrogen can be stored and used to generate electricity in fuel cells. An example of this technology in action is the work by Rose Street Labs Energy (RSLE) scientists in Phoenix, Arizona.

Because of the existence of liquid electrolyte within the DSSC cells, the temperature must be maintained within certain bounds.

The liquid also acts as a solvent over time. This, and the volatility of the dyes under UV light, mean that details of the material housing assembly are critical.

Research is underway to replace the liquid with a solid material.

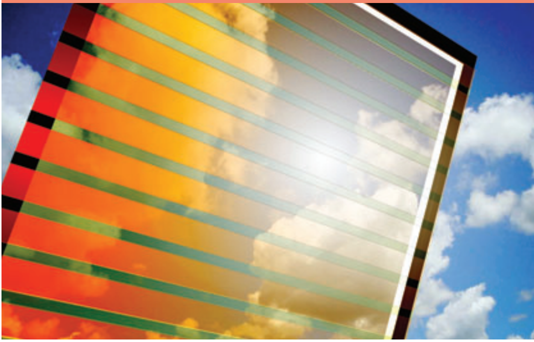
solar



PHOTOVOLTAIC

THIN FILM
DYE-SENSITIZED (DSSC)

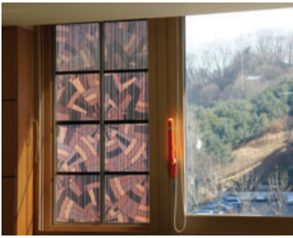
$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 9\%\text{–}11\%$$



DSSC MODULE

Techniques for creating dye-sensitized solar cells (DSSC) are simple and the materials are very low cost, but the conversion efficiency is also below that of solid-state semiconductor technologies (DSSC is the most efficient of the "third generation" thin films). This technique was invented in 1991 by Michael Grätzel and Brian O'Regan at EPFL. The DSSC solar cell is alternatively known as the Grätzel cell.

They have the characteristic of being semi-transparent, flexible, and are very durable. They also function comparatively better than other PV technologies in low light levels and indirect light. Because they are relatively inexpensive to produce they have one of the lowest price/performance ratios, and despite their lower conversion efficiency are therefore competitive with conventional energy in terms of levelized cost (price per KWh over the lifetime of the installation).



The Dye Solar Cell (DSC) modules (tiles) used in the window systems installed at Seoul City's Human Resource Development Centre, were produced and supplied by Dyesol Limited's Korean joint venture partner, Timo Technology, using Dyesol DSC materials.

solar

PHOTOVOLTAIC

THIN FILM ORGANIC PHOTOVOLTAIC CELL (OPVC) OR POLYMER SOLAR CELL

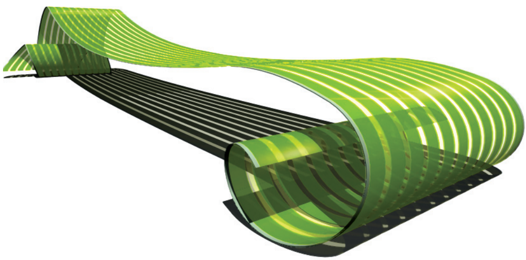
$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 5\%\text{–}10\%$$

Organic thin film has some advantages over silicon or other semi-conductor type solar cells.

Its organic and plastic nature means that it can be easily fabricated into flexible shapes and adhered to fabrics.

It functions well under low light conditions and at non-perpendicular angles to the sun such as vertical walls.

Its translucency means that it can also be applied to windows and other light transmitting surfaces.



ORGANIC PHOTOVOLTAIC PLASTIC SHEET
Similar to that produced by Heliatek, Solarmer, Eight19, and Disasolar.

OPVC (or OPV) uses organic polymers to absorb sunlight and transmit electrical charges. Organic PV can be manufactured in solutions that can be painted or rolled onto proper substrate materials. They can be produced at a very low cost in comparison to other PV technologies because they can take advantage of roll-to-roll production techniques in which the organic photovoltaic system is "printed" onto a continuous sheet of substrate material. Current OPVC technology has a conversion efficiency of up to 10%. Its low cost of production, its flexibility, and its good performance in lower level and indirect light make it an attractive option for some applications.

Examples of small-scale uses for OPVC can be seen sewn into fabric such as in backpacks, laptop cases, tents, and jackets. The energy generated by a backpack utlizing this technology, for example, is sufficient to charge portable electronic devices and to provide power to one or two lights. OPV is finding interesting applications in developing countries. A great example is the IndiGo 2.5KW system by Eight19 that is being provided to off-grid communities, financed via mobile phone SMS credit codes. Larger-scale applications, such as building integrated OPV in façade systems are also being implemented.

solar

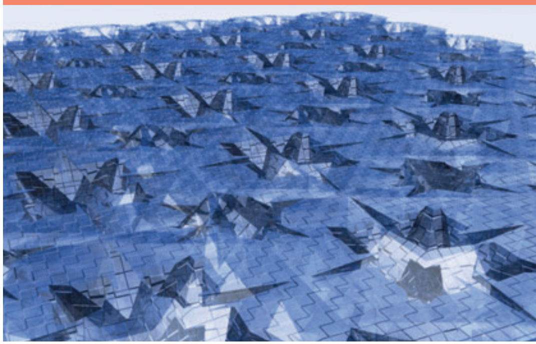
PHOTOVOLTAIC 3D CELLS

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 26\%\text{–}50\%$$

STILL IN THE RESEARCH STAGE OF DEVELOPMENT

One application of 3D photovoltaics is the research that is being done at Georgia Tech. They are coating optical fibre cable with dye-sensitized solar cells in an effort to increase the amount of light transmission to photovoltaic material over any given surface area exposed to the sun.

A project at CalTech also shows promise with a flexible array of light-absorbing silicon microwires and light-reflecting metal nanoparticles embedded in a polymer.



3D SOLAR CELL

These solar cells can utilize any of the various PV material designs. The initial focus by the company 3D Solar has been on integrating conventional silicon-based PV as the photovoltaic material. The technological innovation lies in the initial capture of light at the surface of the solar panel.

Whereas a standard panel solar cell will typically reflect 20%–30% of the light that strikes its surface, a 3D cell relies on a geometric structure that can recapture the reflected light onto adjacent PV surfaces, thus increasing the efficiency of the entire system over the same surface area of installation.

Use of multijunction technology in combination with 3D solar cell geometry has the potential to see applications in CPV systems with an energy conversion efficiency of 50% or greater.

Plasmonic solar cells (PSC) use nanoparticles on the surface of a solar cell to scatter and trap more light within the cell.

solar

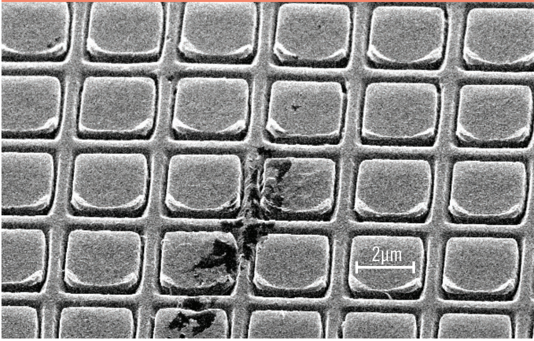
PHOTOVOLTAIC INFRARED AND UV

CONVERSION EFFICIENCY = $\frac{\text{energy output}}{\text{energy input}}$ = UP TO 90%

STILL IN THE RESEARCH STAGE OF DEVELOPMENT

Because infrared and ultraviolet light is outside of the spectrum of human sight, these type of photovoltaic panels could function very well as window surfaces, while still letting in the entire visible spectrum and reducing internal building heat gain at the same time.

This technology is still mostly in the research stage and is not yet commercially available.



NANOANTENNA STRUCTURE CAPTURES IR SPECTRUM RADIATION
Image courtesy of Idaho National Laboratory.

Experimental research is ongoing to develop methods of converting infrared and UV light into electrical power.

Since infrared solar radiation energy is radiated back from the earth during the night, a system to capture it could potentially provide energy 24 hours a day. A team of researchers at Idaho National Laboratory, the University of Missouri, and the University of Colorado are working to develop nanoantennas (nantenna) that can collect both solar heat energy and industrial waste heat energy. The flexible film would be able to convert up to 90% of available light across multiple spectrums.

Since UV and infrared light is beyond the visible spectrum, solar panels that focus on these spectrums can let visible light through while still harnessing solar energy. Japan's National Institute of Advanced Industrial Science and Technology has shown proof of concept applications of this type of technology.

solar

THERMOPHOTOVOLTAIC (TPV)

Potential exists with TPV to see significant increases in the overall efficiency of solar power systems by converting residual heat energy that is otherwise wasted.

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{Greater than 50\% PV + TPV (theoretical)}$$

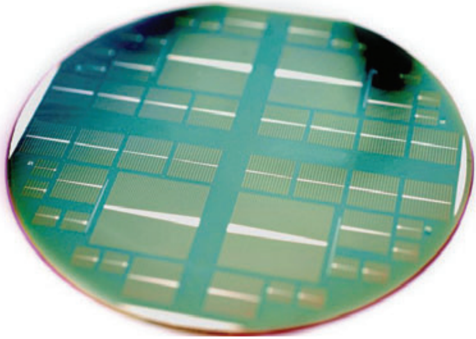
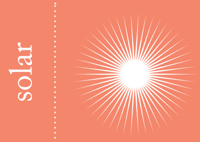


Image courtesy of IMEC.

TPV converts heat energy directly into electricity via photons. A TPV system consists of a thermal emitter and a photovoltaic diode. For the most efficient operation, the temperature of the thermal emitter should be about 1000˚C above the temperature of the photovoltaic diode cell, but some amount of energy could be created from smaller differences in temperature.

TPV employs photovoltaic technology but does not necessarily rely on the sun as the emitter of the photon energy.



PHOTOVOLTAIC

CONCENTRATED PV (CPV)
LOW (LCPV) = 2–100 SUNS
HIGH (HCPV) = 300–1000 SUNS

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{UP TO 42\%}$$

Some CPV systems employ parabolic troughs that direct sunlight onto a linear solar cell.

Another design is the Total Spectrum Collector which separates light with a prism into different spectrums best suited to different solar cell types.

Still another variation is the mylar balloon design developed by Cool Earth in which a CPV solar cell at the upper side of a clear hemisphere receives concentrated sunlight from the lower hemisphere which is highly reflective on the inside surface.

CONCENTRATED PV
Image courtesy of SolFocus, Inc.

CPV employs photovoltaic cells, but rather than rely on the standard intensity of naturally occurring solar radiation energy, the CPV system concentrates the sunlight and directs a magnified beam onto a smaller area solar cell specifically designed to handle the greater energy and heat.

Because the solar cell can be much smaller, the amount of semiconductor material required is far less for the same watt capacity output when compared to non-concentrated PV systems. This can greatly reduce the construction cost per watt capacity of the overall system. Because of the increased heat on the solar cell, CPV installations often require the integration of heat sinks or other cooling apparatus.

The magnification of the sunlight can be accomplished by a number of methods, the most common of which is a Fresnel lens. Other designs, such as that of SolFocus and Cool Earth, utilize reflectors. Nearly all CPV systems must track the sun's movement across the sky in order to function properly. CPV can reach the greatest installed efficiencies of existing PV installations for utility-scale applications.

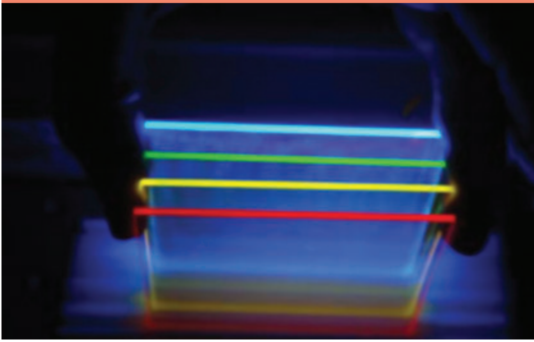
solar

LUMINESCENT SOLAR CONCENTRATOR (LSC)

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 7\%$$

STILL IN THE RESEARCH STAGE OF DEVELOPMENT

While this technology has not had commercial application yet, there is some potential for building integration in windows. The LSC panels allow most visible light to pass through them while still generating some power at the luminescent edges from a very defined spectrum.



EXAMPLE OF LUMINESCENT SOLAR CONCENTRATORS
Image courtesy of MIT and researchers: Marc Baldo, Michael Currie, Jon Mapel, and Shalom Goffri. Photo by Donna Coveney.

The application of special dyes to the surface of a pane of glass or plastic can cause a certain spectrum of light to be diverted at concentrated levels directly to the edges of the glass, where it can then be collected by a solar cell that is calibrated specifically for that wavelength. All other light wavelengths continue uninterrupted through the glass pane, which appears completely transparent.

Research continues to improve efficiency of transmission and stability of dye treatment. Advances in OLED technology and laser technology have portability to LSC applications.

Commercial application is being pursued by Covalent Solar, Inc.

solar

CONCENTRATED PV & THERMAL (PVT) INTEGRATED SYSTEM

(COMBINED HEAT AND POWER)

CONVERSION EFFICIENCY $= \frac{\text{energy output}}{\text{energy input}} =$ UP TO 75%

Combined Heat and Power (CHP) systems use concentrated solar power, which can be achieved by various methods such as parabolic trough, parabolic dish, or linear Fresnel reflector.

Heated water can be used directly in domestic systems or can be heated again to produce steam (lowering the input energy required of the parallel system).

PARABOLIC TROUGH CHP INSTALLATION
Image courtesy of Cogenra Solar.

Known by a variety of names, such as Concentrated Photovoltaic Thermal (CPVT), or Combined Heat and Power Solar (CHAPS), or most simply Combined Heat and Power (CHP), these integrated systems capture the wasted heat energy from the inefficiency of the photovoltaic system, and store it in a heat transfer fluid such as water for direct use.

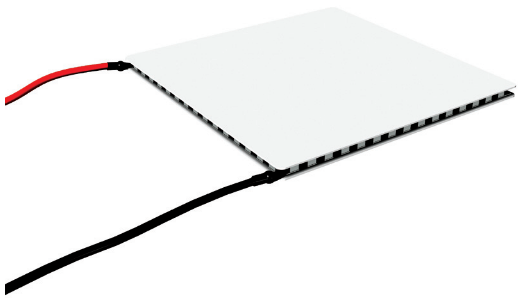
CHP systems help to cool the operating temperature of the PV cell (which increases its conversion efficiency to electrical power) while providing hot water for domestic consumption at temperatures of approximately 80°C. This water would otherwise require external energy (most likely derived from fossil fuels) to heat it.

solar

THERMOELECTRIC

CONVERSION EFFICIENCY $= \dfrac{\text{energy output}}{\text{energy input}} =$ 6%–10%

Thermoelectric systems have the potential to increase the overall efficiency of photovoltaic panels by harnessing the heat energy that would otherwise be wasted, and at the same time increasing the operating efficiency of the PV panels.



THERMOELECTRIC GENERATOR (TEG)

Thermoelectric systems convert heat (temperature differences) directly into electrical energy, using a phenomenon called the "Seebeck effect" (or "thermoelectric effect"). This is where an electric current is created between two different metals that are at different temperatures.

The voltage generated can be as high as 41 microvolts per degree kelvin difference using the right combination of metals.

Thermoelectric cooling takes advantage of the reverse effect, wherein an electric current is provided to a similar device, thus creating a difference in temperature between the two sides of the device. Known as the Peltier Effect, this can be used to remove heat from an object or space.

solar

UPDRAFT TOWER

SOLAR CHIMNEY

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{APPROX. 2\%}$$

The stack effect is the natural property of air within a closed space to rise vertically with buoyancy when heated in relation to ambient air temperature. The greater the heat differential the faster the resulting air movement.

This differential is made as great as possible in the updraft tower by 1) heating the air at ground level via a greenhouse with thermal storage, and 2) building the tower tall enough so that the ambient temperature of the air is naturally lower by a few degrees at the mouth.

CROSS CUT DIAGRAM OF SOLAR UPDRAFT TOWER
Image created by Robert Ferry based on design by EnviroMission.

A solar updraft tower combines the stack effect with wind turbines located at the base of a very tall tower. The tower is surrounded by a large greenhouse at ground level where air is constantly being pulled in by convection and heated.

With a sufficiently tall chimney tower structure, the convection current moves air from the greenhouse area into the bottom of the tower and up to the open mouth at the top. As air passes into the base of the tower, it drives wind turbines located there.

A theoretical variation would replace the tower with a controlled cyclonic atmospheric updraft vortex.

The application of the updraft tower principle to double-skinned skyscrapers has been proposed by Studied Impact Design.

A theoretical inverse is the solar downdraft tower in which water vapor is misted at the top of the tower causing the air to cool and fall down the tower.

solar

SOLAR CHEMICAL

ARTIFICIAL PHOTOSYNTHESIS

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{UP TO 60\%}$$

Since the photosynthetic process removes CO_2 from the atmosphere, a highly efficient system in wide commercial application could help to bring down atmospheric levels of CO_2 while at the same time producing clean energy.

Image via Wikimedia Commons.

Some direct-to-hydrogen processes (refer to PEC technology on page 12) are referred to as artificial photosynthesis, but they can also be more accurately described as photoelectrolysis.

There are other types of technologies that closely mimic photosynthesis by using carbon dioxide and water along with sunlight in order to produce hydrogen using ruthenium as a chlorophyll substitute. Other systems using cobalt oxide aim to create synthetic fuels such as methanol or methane.

Cyanobacteria (blue-green algae) can also be used to create hydrogen directly from sunlight, though the efficiency is lower.

Researchers Andreas Mershin and Shuguang Zhang of MIT's Center for Biomedical Engineering have shown how the actual molecules responsible for photosynthesis in plants (PS-I) can be inexpensively put to work in solar panels. Work continues to increase efficiency (presently 0.1%).

Photodimerization and Photoisomerization are two other processes that are being investigated as methods of storing solar energy in usable forms.

DIRECT TO FUEL OR SUNLIGHT TO PETROL (S2P)

The Counter Rotating Ring Receiver Reactor Recuperator (CR5) at Sandia National Laboratories is demonstrating the conversion of solar energy directly into fuels such as ethanol that are combustible in existing gas engines without modification. The Sandia Solar to Petrol (S2P) system works by converting atmospheric CO_2 into oxygen and carbon monoxide which can then be converted into liquid fuels. Although the process takes CO_2 from the atmosphere, because the combustion of the fuel that comes from these technologies most likely produces CO_2 again as a by-product, a complete system could be seen as carbon neutral.

Another example is the work being done by Joule Unlimited in Massachusetts. One of their technologies, called Helioculture™ uses photosynthetic organisms to create fuel from sunlight and carbon dioxide.

DIRECT TO HYDROGEN

Usually via photoelectrochemical (PEC) technology, the conversion of solar energy directly into hydrogen can be used as a stored fuel. An example of this technology in action is the work by RoseStreet Labs Energy (RSLE) scientists in Phoenix, Arizona.

RADIOMETER

Also called a Light Mill or a Solar Engine, the somewhat mysterious phenomenon of the radiometer has not been investigated as of yet for its potential to run electrical turbines, but perhaps this will have application in the future.

wind

HORIZONTAL AXIS WIND TURBINE (HAWT) ONSHORE

CONVERSION EFFICIENCY = $\frac{\text{energy output}}{\text{energy input}}$ = Varies with wind speed typically up to 40%

The energy available in the wind for conversion by a wind turbine is equal to:
$\frac{1}{2} pAv^3$ where p=air density, A=swept area of the rotor, and v=velocity of the wind.

In 1920, Albert Betz published the discovery (also made by Frederick Lanchester in 1915) that it is possible to extract 59.3% of the wind energy that passes through the swept area of the rotor. This is now known as the Betz Limit.

Typically HAWTs are able to operate at 70% of the Betz Limit, or at about 40% overall efficiency.

WILD HORSE WIND FARM, PUGET SOUND ENERGY
Photo by Robert Ferry.

Perhaps the most commonly recognizable icon of the renewable energy industry, the horizontal axis wind turbine has come a long way from its historic origins in milling grains and pumping water.

Early wind turbines typically had at least four blades, and sometimes many more. The first megawatt capacity turbine, built in Vermont in 1942, had only two large blades. There are some interesting modern examples of single-blade turbines as well. Standard contemporary utility-scale models typically have three blades and can have capacities as high as 10 megawatts.

The capacity of the modern HAWT is a function mostly of the overall outside diameter as measured from tip to tip, with some larger models exceeding 100 meters.

Smaller units can be designed to rotate with assistance of a vane on the downwind side. Larger models must be turned more slowly by computer guided gears.

wind

HORIZONTAL AXIS WIND TURBINE (HAWT) OFFSHORE

CONVERSION EFFICIENCY = $\frac{\text{energy output}}{\text{energy input}}$ = Varies with wind speed typically up to 40% wind speed is more consistent offshore = greater overall output

HAWTs must be placed far apart from one another in order to minimize the shadow effect of air wake disturbance on the efficient operation of downwind turbines.

Offshore arrays can take advantage of the large open area of the sea to ensure the most proper placements and maximize overall efficiency.

Without topographic ground features to cause air disturbance, offshore installations also can take advantage of more consistent and higher velocity winds.

NYSTED WINDFARM (72 WINDMILLS, 165.6MW CAPACITY)
Image courtesy of Siemens AG, Munich/Berlin.

There are two types of off-shore turbines—those mounted on pylons in shallow waters and those that are designed to float in deep water. Both types typically employ variations on the standard three-blade designs for the turbine itself.

Floating models can be designed to use this feature as a method of rotation to follow the wind direction. Also, floating models can take advantage of higher and more consistent wind speeds in the open ocean.

Floating HAWTs deal with the issue of aesthetics in that their location more than 12 miles from land makes them completely disappear beyond the horizon as viewed from shore.

Pylon-mounted shallow water turbines are less expensive and easier to maintain. Their power transmission lines are also shorter.

It is important to consider all possible impacts that offshore turbines can have on marine ecosystems.

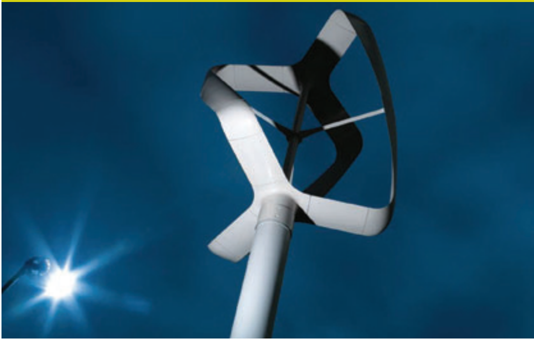
wind

VERTICAL AXIS WIND TURBINE (VAWT)

CONVERSION EFFICIENCY $= \frac{\text{energy output}}{\text{energy input}} =$ Varies with wind speed typically up to 40%

The earliest recorded use of wind power is with vertical axis wind turbines used to mill grains as long ago as 200 BCE. They were very common in 7th century Persia.

These typically employed four vertical flags of fabric or woven grasses connected with wooden beams to a central column.



REVOLUTIONAIR WT1KW (GHT TYPE DESIGN)
Image courtesy of PRAMAC. Design by Philippe Starck.

Vertical axis wind turbines are generally either Darrieus or Savonius in type (named after their early 20th century inventors). A simple distinction is that Darrieus-type turbines use aerofoil blades and Savonius-type turbines use wind scoops. Gorlov helical turbine (GHT) is a variation on a standard Darrieus type (invented by Professor Alexander M. Gorlov of Northeastern University in the 1990's).

Typically VAWTs have lower cut-in speeds (the wind speed at which they begin to produce electricity) than HAWTs and can be positioned lower to the ground than can HAWTs.

Another advantage of VAWTs is that they can be located in closer proximity to each other than can HAWTs. Some studies have shown that dense configurations can actually increase efficiency of the overall installation with turbines picking up wake energy from the rotations of adjacent turbines.

wind

CONCENTRATED WIND

COMPACT WIND ACCELERATION TURBINE (CWAT), ALSO KNOWN AS DIFFUSER AUGMENTED WIND (DAWT), OR DUCTED TURBINE

CONVERSION EFFICIENCY $= \dfrac{\text{energy output}}{\text{energy input}} =$ Varies with wind speed 56%–90% (as measured against non-ducted turbine with equal rotor diameter)

CWAT is a new acronym that encompasses the class of machines formerly known as DAWTs as they were known in the 1970's and 1980's.

Comparison on wind energy conversion efficiency is often made between ducted and non-ducted rotor diameter. A more accurate comparison would be between non-ducted rotor diameter and ducted diffuser diameter. In the former comparison, increases are as high as 2x. Using the latter comparison, the increase is closer to 1.4x.

CROSS-CUT ILLUSTRATION OF A TYPICAL CWAT
Image created by Robert Ferry.

This type of horizontal axis wind turbine uses a cone—or series of cones—to concentrate the wind, increase the velocity of the wind as it passes through the rotor's swept area, and thus increase the efficiency of the overall system. They are also referred to as ducted turbines.

This technology has recently (after a long history of attempts) proven some measure of improvement over non-ducted HAWTs. As these systems require more material (the ducting cone) their application to utility-scale installations may be limited.

For now, companies such as Arista and Enflo-WindTec are bringing small and medium size turbines to the market with excellent energy output efficiencies and reduced noise levels.

Ducted turbine manufacturers often refer to standard HAWTs as "free-running" turbines to distinguish the two types.

wind

BLADE TIP POWER SYSTEM

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{Varies with wind speed up to 56\%}$$

The Blade Tip design has a low cut-in speed that allows for the generation of energy at wind speeds as low as 0.5 miles per hour or 2 meters per second.

Current models measure approximately 6 feet in diameter and are capable of generating 1500 KWh per year. Ideal operation is at wind speeds of 12.5 mph (5.6 meters per second).

BLADE TIP WIND TURBINES INSTALLED ON A ROOF
Image courtesy of WindTronics/Honeywell.

This wind turbine has the appearance of a horizontal axis wind turbine with a concentrator ring. However, with the Blade Tip design, the outside tips of the rotating blades carry the magnets that generate electrical current when they pass the copper coil banks on the inside of the perimeter diffuser.

This reduces the resistance as compared to the mechanics of a centrally located gearbox and it captures the power at the place where the rotation speed is highest.

The Blade Tip Power System™ design is patented by WindTronics and manufactured by Honeywell.

wind

HIGH ALTITUDE WIND POWER (HAWP) AND AIRBORNE WIND TURBINES (AWT)

CONVERSION EFFICIENCY $= \frac{\text{energy output}}{\text{energy input}} =$ Varies with wind speed up to 40% high altitude wind is very constant, leading to high annual energy output

Douglas Selsam conceived of the ladder mill in 1977 to make use of high altitude winds. It is a series of kites arranged like a ladder in a loop formation. The shape of the individual kites changes based on their location in the loop so that they are either fully harnessing the wind or creating minimum drag resistance on their return journey. In this way, the loop can be designed to constantly rotate. With kite-type HAWP, the conversion of energy is done at the ground level by harnessing the movement of the tether cable.

HIGH ALTITUDE WIND POWER
Image courtesy of Joby Energy.

The power of the wind at high altitudes is much stronger and more consistent than what is typically available nearer to the ground. However, getting access to this excellent source of energy and harnessing it for electrical use presents obvious challenges.

HAWP has the potential to be a cheap and consistent source of energy. There are a wide number of HAWP technologies that are presently being developed. The electricity generation can either occur in the sky or at ground mooring, depending on the design type.

Some designs, such as the KiteGen system, are derivative of kite and sailing technologies. Other types of HAWP devices (airborne turbines, or AWT) use lighter-than-air balloons (aerostats) that rotate between two cables. One example of this is the Magenn AWT.

Yet another design is comprised of small glider-like machines that are designed to fly in a constant circle or figure-eight such as the systems by Joby or Makani.

wind

WINDBELT

CONVERSION EFFICIENCY = $\frac{\text{energy output}}{\text{energy input}}$ = UNKNOWN

The Windbelt works on the aerostatic flutter effect.

Aerostatic flutter is created when a feedback loop occurs between an object's natural mode of vibration and an aerodynamic flow of energy passing over that object.

The effect is similar to that of an aeolian harp which is used to create musical notes from the wind.

EXAMPLE OF A WINDBELT IN OPERATION
Image created by Robert Ferry based on design by Humdinger Wind Energy.

This type of wind generator uses a belt secured between two fixed points set within a rectangular housing. The belt oscillates rapidly creating a rocking motion at the two ends. This motion is harnessed by small kinetic energy generation devices employing magnets at the ends of the belt which move rapidly back and forth between metal coils.

The invention is patented by Shawn Frayne who has founded the company Humdinger Wind Energy LLC to develop and market the device.

OTHER EXPERIMENTAL / THEORETICAL

SELSAM MULTIROTOR WIND TURBINE

This invention by Douglas Selsam uses multiple rotors on a single drive shaft. There are two main variations on the technology. One type supports the system at a pylon located at about the midpoint of the driveshaft. This type can accommodate approximately seven rotors and provides a power output equivalent of up to six rotors of the same size (but using only one shaft and generator). The other type, called the Sky Serpent, is supported from one end at the ground (location of the generator) and (like its name) is free to wave in the wind. It is supported at the other end by a balloon.

VANELESS ION

This concept requires no moving parts. Rather, the device is in appearance similar to a fence that allows the wind to pass through it. By introducing water mist with small differing charges and allowing the wind to carry the charge between electrodes, electrical power can be produced, potentially on a large scale. It is similar in operational principal with Lord Kelvin's Thunderstorm where two bodies of water with small charge difference can create high voltage current by using the force of gravity. The vaneless ion generator uses the wind to move the water rather than gravity.

Two prototypes were patented by Alvin Marks in the late 1970's.

water

HYDROELECTRICITY

DAMMED RESERVOIR

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 80\%\text{–}95\%$$

Turbine efficiency

Generating approximately 20% of the world's electrical energy, hydroelectricity is by far the most established form of renewable energy.

It accounts for more than 80% of all renewable energy installed capacity.

HOOVER DAM
Image via Wikimedia Commons.

Conventional hydroelectricity uses dam structures to limit the flow of existing rivers. By selectively releasing water through turbines in the dam, the tremendous pressure of the water is converted to electrical energy.

There are many ecological side effects of interrupting the flow of existing rivers. This has led to the deconstruction of many hydroelectric dams and has resulted in a decrease in construction of new hydroelectric facilities.

The damming of a river causes the upstream side to flood large areas of land, disrupts fish spawning activities, and changes the characteristics (temperature, oxygen content, and silt content) of the downstream water.

Dams also come with the risk of structural failure and the resulting severe downstream flooding.

water

HYDROELECTRICITY

RUN-OF-THE-RIVER (DAMLESS HYDRO)

CONVERSION EFFICIENCY = $\frac{\text{energy output}}{\text{energy input}}$ = 80%–95% Turbine efficiency (limited by the amount of water that is diverted)

In some installations a penstock pipe is placed in the river in order to regulate the flow of water. At the mouth of the penstock a constant water pressure is formed and is transferred to the turbine downstream.

Other installations simply place a water turbine in a strong current area of a river without any additional damming or piping. While this type of installation has the most minimal ecological impact, it is most susceptible to fluctuations in the flow rate of the river.

FISH LADDER AT THE COLUMBIA RIVER JOHN DAY DAM
Image courtesy of the Army Corps of Engineers.

While not entirely without ecological side effects, run-of-the-river type hydroelectricity plants offer an alternative to large flooding reservoirs. In these installations, only a portion of the river is diverted to the generators and the rest of the river is left to flow naturally.

Since no land is flooded, existing forests and natural habitats are not adversely affected.

Since there is very little storage capacity, this technology requires a river with a constant flow rate. While conventional hydro facilities can generate in the 10,000MW capacity and above, run-of-the-river type plants typically are limited to around a 1,000MW range or below.

water

HYDROELECTRICITY

MICRO AND PICO HYDRO

CONVERSION EFFICIENCY $= \dfrac{\text{energy output}}{\text{energy input}} =$ 50%–85% (varies)
Smaller turbines are sometimes less efficient

Many micro and pico-hydro installations use a penstock pipe to divert water from the natural flow of an existing river or stream.

This pipe then flows to a small turbine generator, after which the water is channeled to rejoin the river at some point downstream.

PICO HYDRO PROJECT (PRACTICAL ACTION SRI LANKA) IN KALAWANA, SRI LANKA Photo by Janani Balasubramaniam.

Classified as hydroelectric installations of less than 100KW capacity for micro-hydro and less than 5KW capacity for pico-hydro, these installations are in smaller rivers and streams. They can be either dammed reservoir type or run-of-the-river type but are usually the latter, especially for pico installations.

These types of installations are an excellent method of providing energy to small communities in developing countries that do not have access to grid source power. Because the required output is small, the elevation drop (hydraulic head) of the water can be small, in some cases as little as one meter.

Pico-hydro can be very do-it-yourself and inexpensive. For example, Sam Redfield of the Appropriate Infrastructure Development Group (AIDG) has developed a pico-hydro generator that can be built for less than $150, made from PVC pipe, a modified Toyota alternator, and a five gallon bucket.

water

HYDROELECTRICITY (HYDROKINETIC)

VORTEX POWER

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{UNKNOWN}$$

Vortex Hydro Energy is a spin-off of the University of Michigan's Engineering Department and owns the rights to the VIVACE converter, which was invented in 2004 by Michael Bernitsas, a professor in the school's Department of Naval Architecture and Marine Engineering.

The VIVACE converter is inspired by the way that fish use water vortex energy to propel themselves.

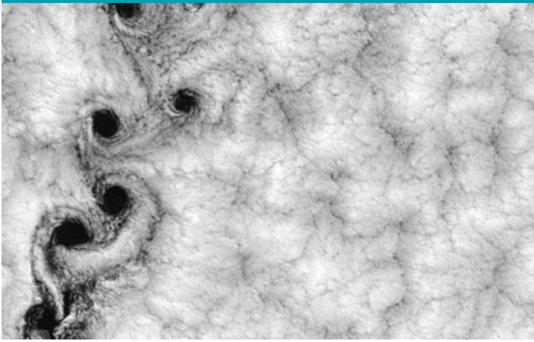


IMAGE OF CLOUDS OFF THE CHILEAN COAST NEAR THE JUAN FERNANDEZ ISLANDS (VON KARMAN VORTEX)
Image courtesy of NASA/GSFC/Landsat.

When you place obstacles in the path of flowing water, it creates vortices or small turbulent spinning movements within the fluid. Recent research into harnessing these vortices has made some very rapid progress. This is perhaps the hydro power least damaging to the environment since the installations are no more impactful to wildlife than natural obstacles along the path of water in a riverbed or ocean floor.

By placing fins in sequence, the vortex energy that is created by the wake of one fin is transferred to up and down mechanical motion by the next fin downstream. This in turn generates a sustained feedback loop and maximizes the efficiency of the system. The vortex power converter functions in flowing water with a speed as slow as two knots.

Some micro-hydro designs are referred to as "vortex gravity turbines" when they are placed on a vertical axis within a water channel and use a controlled vortex to run a turbine.

water

OCEAN TIDAL (HYDROKINETIC)

TIDAL STREAM GENERATOR (TSG)

CONVERSION EFFICIENCY $= \frac{\text{energy output}}{\text{energy input}} =$ UP TO 40%

Five main types of TSG:

1. Axial: most similar to HAWT designs adapted to water application.

2. Vertical and Horizontal Axis Crossflow: similar to Darrieus-type VAWTs. They are often oriented horizontally in TSG applications.

3. Flow Augmented: uses a shroud to increase the flow to the turbine.

4. Oscillating: do not have a rotating component, but instead employ hydrofoil sections that move back and forth.

5. Venturi: a duct generates differential pressure which is used to run a turbine.

SEAGEN TIDAL POWER PLANT, STRANGFORD, COUNTY DOWN, NORTHERN IRELAND (BLADES RAISED FOR MAINTENANCE)
Image via Wikimedia Commons, user Ardfern.

Similar to how a wind turbine harnesses the flowing kinetic energy of the wind, tidal stream generators harness the similar power of the water as tides flow in and out of coastal inlets by transferring the flow of the water to a rotating turbine. In outward appearance, they typically resemble a horizontal axis or vertical axis wind turbine. Since this is a relatively new technology, there are many approaches that are currently being tried and tested.

Tidal is an interesting form of energy. Whereas other forms of ocean energy (wave, thermal, ocean currents) can trace their energy origin to the wind or the sun, tidal energy is caused by the gravitational forces of the moon and the sun and the rotation of the earth. Depending on the body of water, tides can be either semidiurnal (two high waters and two low waters each day), or diurnal (one tidal cycle per day).

water

OCEAN TIDAL (HYDROKINETIC)

BARRAGE

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{UP TO 85\%}$$

Five main types of barrage:

1. Ebb Generation: A natural tidal basin is filled through sluice gates until high tide. At low tide, gates are opened to run turbines.

2. Flood Generation: Turbines operate while the tide is rising.

3. Pumping: Ebb Generation + excess grid power pumps additional water into the tidal basin.

4. Two Basin: An additional barrier wall across the basin provides nearly continuous generation.

5. Tidal Lagoon: A circular wall structure that has built-in basin(s). Surrounding water is free to flow around the lagoon.

RANCE RIVER TIDAL POWER PLANT IN BRETAGNE, FRANCE
Image via Wikimedia Commons, user Dani 7C3.

Tidal Barrage Generators typically span the width of a tidal inlet or estuary and impede the entire tidal flow. Similar to dammed reservoir hydroelectricity in rivers, they can have negative effects on the marine ecosystems of the inlet due to the nearly complete separation of the estuary from the open ocean.

Changes to water salinity, water turbidity (opacity due to suspended solids), sediment disturbance, and fish kills in turbines also lead to negative environmental impacts. These effects can be mitigated with studied design strategies (the tidal lagoon type is the lease damaging design), but there will always be greater impact from barrage-type tidal power than from TSG systems.

water

OCEAN MARINE CURRENT (HYDROKINETIC)

CONVERSION EFFICIENCY = energy output / energy input = UP TO 85%

There are three types of Ocean Marine Current designs: sea bed mounted systems, floating moored systems, and hybrid combinations of these two.

Sea bed mounted systems can be designed with similar engineering to tidal stream generators, but must be located in relatively shallow waters where ocean currents are not at their strongest.

Floating moored systems offer the greatest energy potential but require engineering solutions to transmission and mooring.

ILLUSTRATION OF THE GULF STREAM FROM BENJAMIN FRANKLIN'S PHILOSOPHICAL AND MISCELLANEOUS PAPERS, 1787
Image courtesy of Smithsonian Institute Libraries.

This type of ocean power would harness the streaming currents that exist in the world's oceans such as the powerful Gulf Stream in the Atlantic Ocean. These currents are so powerful that explorers sailing the Atlantic in the 16th century such as Ponce de Leon noted that often the stream of the water was more powerful than the wind, causing their ships to be still or even to move backward.

No installation has yet successfully been implemented to harness the oceans currents. While the available energy is quite vast, the difficulties for engineering systems in deep ocean water are also great.

Marine current energy is indirectly a form of solar power since the currents of the ocean are created by the heat energy of the sun.

water

OCEAN WAVE (HYDROKINETIC)

SURFACE FOLLOWING OR ATTENUATOR

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 70\%$$

Broad wave surface area

Wave energy converters (WEC) harness the local surface energy of large bodies of water.

If you think about it, wave energy is (very indirectly) a form of solar energy. Waves are caused by the movement of wind over the surface of water, and the wind is caused by changes in air temperature created by the energy of the sun.

In 2004 Pelamis Wave Power first transmitted electricity to the land grid. Each Pelamis machine is currently rated at 750KW.

SECOND GENERATION P2 PELAMIS MACHINE IN OPERATION AT THE EUROPEAN MARINE ENERGY CENTRE (EMEC) IN ORKNEY
Owned by E.ON UK. Image courtesy of Pelamis Wave Power Ltd.

Wave energy offers another vast potential for harnessing the power of the oceans. Waves are generated by winds over large expanses of ocean area and travel immense distances with minimal energy loss. Because of this fact, the energy embodied in local waves is often out of phase with local wind conditions and can therefore act as a complement to off-shore wind power generation.

Surface following type wave generation uses long, hinged serpentine devices that create pressure in chambers of oil as the segments of the device change their orientations with the action of the waves. The release of the oil pressure drives hydraulic motors within the floating machine.

water

OCEAN WAVE (HYDROKINETIC)

BUOY OR POINT ABSORBER

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 80\%$$

Limited wave surface area

There have been attempts made to harness wave energy since the late 18th century.

The ocean surface is a harsh environment for the continuous operation of mechanical devices.

BUOY TYPE WEC OFF THE COAST OF HAWAII
Image courtesy of Ocean Power Technologies, Inc.

Buoy type wave generators use the up and down motion of the waves at a single point. Some use the up and down motion to transfer liquids within chambers to spin turbines.

Some types installed in more shallow conditions use a piston that extends to the sea floor to drive a hydraulic motor, a linear generator, or to fill compressed air chambers that run small internal air turbines.

Deeper water provides longer period waves and more regular wave energy without as much potential for damage to equipment from cresting waves. But the logistics of electrical transmission and equipment maintenance must be weighed against this.

water

OCEAN WAVE (HYDROKINETIC)

OSCILLATING WAVE SURGE CONVERTER

CONVERSION EFFICIENCY = energy output / energy input = 65%
(capture factor: 20m wide flap)

The Oyster Wave Energy Converter employs a fin perpendicular to the wave propagation direction.

The first successful demonstration is a 315KW version installed in 2009 off the coast of the Orkney Islands in Scotland by a joint project of SSE Renewables and Aquamarine Power.

The joint venture has recently installed a 800KW version and has secured sea bed leases for many tens of megawatts in capacity to be installed over the coming years in Ireland and the US Pacific coast.

OYSTER WEC IN OPERATION
Image courtesy of SSE and Aquamarine Power.

The oscillating wave surge energy converter is installed in nearshore locations of approximately 10 meters depth and is secured to the sea bed.

A mechanical flap at the surface is hinged to allow it to move with the waves. This movement drives hydraulic pistons that create high pressure water. The pressure from the pistons drives a constant flow through a series of pipes to the shore where the pressurized water runs a turbine to generate electricity.

water

OCEAN WAVE (HYDROKINETIC)

WING REFLECTOR OR OVERTOPPING

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{UNKNOWN}$$

Testing began on the Wave Dragon WEC in 2003 at which time the device was connected to the land grid.

A 1.5MW demonstrator project was launched in the North Sea in 2011.

Once scaled up, the potential exists to deploy overtopping WECs in series. Such an installation would be on scale with conventional utility power generation facilities.

OVERTOPPING TYPE WEC IN OPERATION
Image courtesy of Wave Dragon.

This type of wave energy converter consists of a long floating armature containing a reservoir that is at a higher elevation than the surrounding ocean wave troughs. The crests of the waves gradually fill this reservoir by overtopping the sides. The reservoir, once filled, releases the water back into the ocean to run a series of low head hydraulic turbines.

The device is designed to be heavy for stability against rolling and is constructed with thick ship-like steel plates. It is slack moored to the sea bed to anchor it permanently in place.

See page 47 for additional methods of wave energy conversion.

water

OCEAN

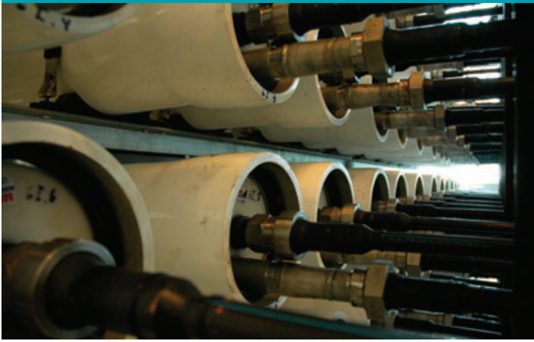
OSMOTIC POWER OR SALINITY GRADIENT POWER

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = \text{UNKNOWN}$$

The Norwegian company Statkraft opened the world's first facility for osmotic power generation in 2009 with a limited capacity of 4KW, using the technology of pressure-retarded osmosis.

A full-scale commercial osmotic power plant could be ready by 2015.

The negative environmental impacts of discharging brackish water (by-product of osmotic power) in large quantities into surrounding waters should be carefully mitigated.



OSMOTIC MEMBRANES ARE COILED INSIDE PRESSURE VESSELS
Photo courtesy of Statkraft.

In locations where freshwater mixes with saltwater there is an opportunity to take advantage of an interesting characteristic of water which is its strong tendency towards equalization of salinity levels. Therefore, if two containers of water are separated by a semi-permeable membrane, water will pass from the freshwater side to the saltwater side thus increasing the pressure on the saltwater side. This increased pressure can then be released to turn a turbine and generate electricity in a continuous cycle.

Methods of energy conversion include: pressure-retarded osmosis (used in commercial production); reversed electrodialysis (experimental); and capacitive (experimental).

These methods could theoretically be applied in combination with a solar pond (refer to page 2) where salinity gradients exist between water layers within the pond.

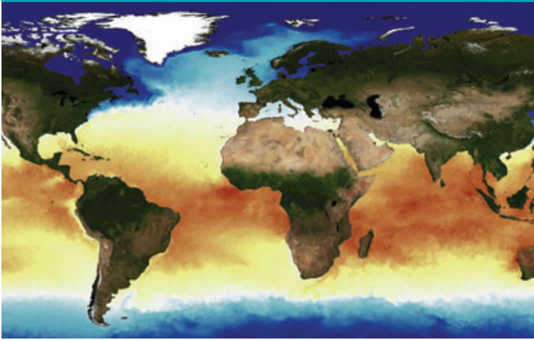
water

OCEAN THERMAL ENERGY CONVERSION (OTEC)

$$\text{CONVERSION EFFICIENCY} = \frac{\text{energy output}}{\text{energy input}} = 10\%$$

OTEC can also supply quantities of cold water which can be used for air conditioning and refrigeration.

Some open-loop OTEC designs can also create desalinated water as a by-product.



SATELLITE COMPOSITE SHOWING OCEAN THERMAL ENERGY
Image courtesy of the National Oceanic and Atmospheric Administration.

Water in the deep ocean is many degrees cooler than surface temperature water. The difference in temperature can be used to run a heat engine either using the water itself in an open-loop (placing warm ocean water in a low pressure system causes it to boil), or by transferring the heat energy to a closed-loop system with a heat exchanger and a low-boiling point liquid such as ammonia.

The technology for energy conversion is similar to that employed in solar pond systems (refer to page 2), such as Rankine cycle low pressure turbines.

Cool deep water from oceans or deep lakes (typically at a constant 4°C or 40°F) can also be used as heat sinks, reducing the demand side electrical loads of buildings that are sited to take advantage of this. A similar (though less efficient) effect can be utilized in almost any location via ground source heat sink loops.

water

GEOTHERMAL

CONVERSION EFFICIENCY = $\frac{\text{energy output}}{\text{energy input}}$ = 10%–25%
Natural steam is at a lower temperature than that produced by a boiler

There are three geothermal power generation methods:

1. Dry steam: directly uses geothermal steam of 150°C or greater to run turbines.

2. Flash steam: requires natural geothermal temperatures of 180°C or more. High pressure steam is pulled into a low pressure separator which creates a powerful flash steam.

3. Binary cycle: can operate with water temperatures as low as 57°C. This moderate heat is used to generate steam in a secondary fluid with a low boiling point.

NESJAVELLIR GEOTHERMAL POWER PLANT, ÞINGVELLIR, ICELAND
Image courtesy of Gretar Ivarsson.

Geothermal power harnesses the natural force of thermal energy from deep underground which comes both from residual heat from the formation of planet Earth and from heat that is constantly generated by radioactive decay.

The ability to harness the earth's geothermal energy is somewhat limited by site dependency (located near thermal plumes in the earth's crust), though recent technological advancements in drilling have extended the range. Advanced drilling technologies may have the potential to trigger seismic events by creating new fissures where tectonic pressure has built up over time.

The overall efficiency of the plant can be increased if exhaust heat from the turbine is captured and used for other purposes.

The earth's natural insulation can be used in any location as part of a ground source heat pump. While not actively generating electricity, this is a great method of energy conservation.

OTHER TECHNOLOGIES

DYNAMIC TIDAL POWER (DTP)

This is an untested technology that could theoretically produce large amounts of power in the range of 10,000MW capacity by creating extremely large artificial jetties into the ocean that would be shaped like a "T" as viewed from the sky. The top of the "T" would serve to separate tidal action on either side of the long leg that connects to the land. Computer simulation models have shown that the length of the system would have to be in the area of 30km to be viable, which would require an extremely large capital expense. There may be negative impacts to marine habitat by building such a extensive structure out into the ocean.

OTHER WAVE ENERGY CONVERTERS (WEC)

Experiments are being done on a wide range of technologies to convert wave energy to electricity. In addition to the surface-following, buoy, oscillating wave surge, and overtopping varieties, there are also those that use an oscillating water column at the shoreline and other techniques to convert the kinetic energy of waves to electricity.

Each of these mechanical systems can use a variety of electric energy conversion technologies. These include: hydraulic ram, elastomeric hose pump, pump-to-shore, hydraulic turbine, air compression with air turbine, and direct linear generator.

HYDROELECTRIC BARREL (HEB)

Mike Lowery has developed a floating waterwheel that spins on the surface of a river or stream. The treading of the outer surface keeps the barrel from sinking (counteracts the Coanda effect).

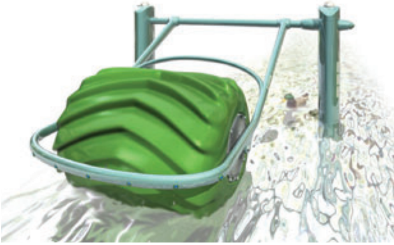


Image created by Paul Price and used with permission of HEB.

bio

BIOMASS

BIOGAS AND LANDFILL GAS

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

Biomass is considered a sustainable energy resource because it is a product of organic processes which naturally regenerate at a rapid cycle (as opposed to fossil fuel energy sources which take millions of years to form naturally).

Biomass can be combusted directly as a solid fuel or converted to liquid or gas biofuels. These biofuels can be used in either a combustion engine (conversion to mechanical energy) or in a fuel cell (conversion to electrical energy).

LANDFILL GAS INFRASTRUCTURE AT FRESHKILLS PARK, THE FORMER FRESH KILLS LANDFILL, NEW YORK CITY
Photo by Robert Ferry.

Biogas is created through the breakdown of any organic material (biomass) in an oxygen-poor environment. The resulting gas by-product is mostly methane and carbon dioxide. Biogas is similar in composition to conventional natural gas and as such can be compressed or fed into a municipal gas grid. It can be used for many different purposes including cooking, heating, lighting, transportation, and electricity production.

It can be either tapped from the underground activity in a landfill site, or it can be produced in specially constructed anaerobic digester tanks.

Farms with such tanks can process manure into biogas reducing the amount of nitrous dioxide and methane that would otherwise enter the atmosphere. These two gases have a far greater atmospheric warming effect than does carbon dioxide (nitrous dioxide = 310 times greater, and methane = 21 times greater).

bio

BIOMASS ALCOHOL BIOFUEL

ETHANOL

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

Alcohol biofuels like ethanol are produced through the fermentation of sugars from high carbohydrate content plants such as corn, potato, beet, wheat, or sugarcane.

Other (more costly) processes can use wood product waste and fibrous grasses such as switchgrass that grow very quickly.

Ethanol can be used as an additive to gasoline or it can be used in a majority ethanol mix such as "E-85" (ethanol 85%) in engines that have been appropriately modified.

Some concerns over the proliferation of "first generation" ethanol type biofuels include:

FOOD VS. FUEL: with the world frequently experiencing food shortages and people suffering from starvation, it is not wise to convert useful food resources into fuels if other alternatives are available. Ethanol use has been promoted by the agricultural industry lobby because higher corn prices result from increased demand.

CONVENTIONAL OIL PRICE DEFLATION: the abundant use of biofuels has kept oil prices below where they would otherwise be. Some estimates put the deflation at as much as 25%. The price deflation of oil may contribute to a greater and longer lasting reliance on conventional fossil fuels.

LOSS OF BIODIVERSITY AND DEFORESTATION: with more demand for sugarcane and high sugar corn, fields are dedicated to monoculture.

POLLUTION: the combustion of ethanol produces carcinogenic by-products such as formaldehyde and acetaldehyde.

WATER: crops that most easily produce the best performing biofuels require significant irrigation resources.

As a response to these issues, new methods have evolved as second, third, and fourth generation biofuel technologies (see subsequent pages).

bio

BIOMASS ALCOHOL BIOFUEL

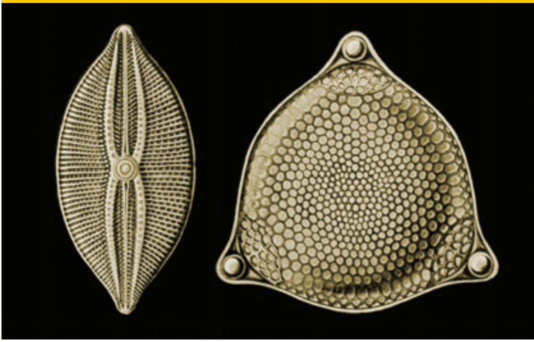
BIOBUTANOL FROM DIATOM OR ALGAE (SOLALGAL FUEL)

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

Diatoms or algae can be used as the raw organic material (feedstock) for butanol production instead of agricultural crops like corn or sugar cane.

The biobutanol conversion process can be powered (catalyzed) entirely by solar energy.

When algae is used as the feedstock and solar power as the energy source, the resultant biobutanol from this process is known as Solalgal fuel.



DRAWING OF DIATOMS
From Ernst Haeckel's Kunstformen der Natur (Artforms of nature) (1904).

Butanol can be used in gasoline engines without engine modification. The exact same fuel can be produced from fossil fuels or biomass. Biobutanol is that made from biomass. The process is similar to the way that ethanol can be formed via (anaerobic) fermentation processes. Butanol production uses a specialized bacteria, clostridium acetobutylicum, instead of yeast.

Clostridium acetobutylicum is also known as the Weizmann organism. Chaim Weizmann first used this bacteria in 1916 for the production of acetone from starch. The butanol was a large by-product of this fermentation (twice as much butanol was produced as was acetone).

The process also creates a recoverable amount of H_2 and a number of other by-products: lactic and propionic acids, acetic, isopropanol, and ethanol.

bio

BIOMASS BIOFUEL

BIODIESEL

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

The process of methanolysis that creates biodiesel fuel from biomass has its origins in experiments to produce glycerine for explosives during World War II.

The chemical processes that go into transesterification, and the reliance on the availability of glycerol, sodium hydroxide and other compounds, make this type of biodiesel production relatively expensive.

Production costs can be in the range of $2 per gallon (using soybean oil)[§] or $84 per barrel.

A SUNFLOWER FIELD IN FARGO, NORTH DAKOTA
Image courtesy of the Agricultural Research Service of the US Department of Agriculture. www.ars.usda.gov

Using a process known as transesterification, naturally occurring oils or fats (biolipids) are transformed into liquid diesel fuel that can be used in most diesel engines. The raw material, or feedstock, can be animal fat, vegetable oil, soy, rapeseed, jatropha, mahua, mustard, flax, sunflower, palm, hemp, field pennycress, pongamia pinnata, or algae.

The specific chemical process (type of transesterification) when applied to biodiesel production is called methanolysis. It requires the addition of alcohol to the biolipid in the presence of an acid or base catalyst. While complicated chemically, the process does not require added heat. The same process can be used for plastic recycling.

[§] Michael J. Haas, Andrew J. McAloon, Winnie C. Yee, Thomas A. Foglia (US Department of Agriculture). A process model to estimate biodiesel production costs. Bioresource Technology 97 (2006). 671–678

bio

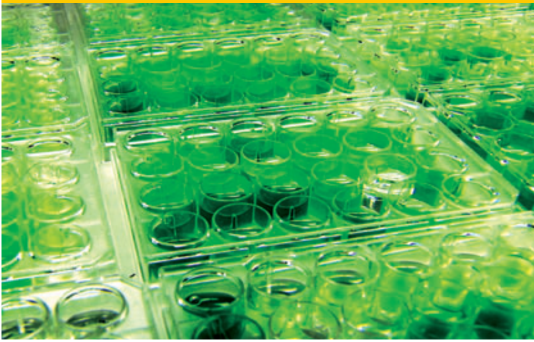
BIOMASS BIOFUEL

GREEN DIESEL OR RENEWABLE DIESEL

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

The fractional distillation process required to produce green diesel from biolipid feedstock requires heating the feedstock to very high temperatures (approximately 600°C). This is usually done by combusting fossil fuels.

The vaporized feedstock rises up a distillation column where it is separated into its constituent parts and cooled.



ALGAE GROWING IN SUSAN GOLDEN'S LAB AT UC SAN DIEGO
Image courtesy of UC San Diego.

Green diesel uses naturally occurring oils (biolipids) to produce diesel fuel. Natural oils can be extracted from canola, algae, jatropha, salicornia, or tallow. It differs from biodiesel in that it uses traditional fractional distillation methods to process the oils rather than transesterification.

This type of green diesel should not be confused with fossil-fuel based diesel that has been dyed green to distinguish its quality.

The benefit of algae cultivation as feedstock is that it can be produced using ocean water or wastewater (it does not require fresh water resources) and that it is biodegradable and relatively harmless to the environment if spilled. Algae costs somewhat more to produce per unit of feedstock mass (compared to soybean) due to the complexity of cultivation, but it can be converted into much more fuel energy per unit of feedstock mass, which more than makes up for this difference.

bio

BIOMASS BIOFUEL

SYNGAS

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

Syngas is combustible and can be used in internal combustion engines, but it contains less than half of the energy density when compared to natural gas.

It can also be used in the creation of synthetic natural gas or synthetic petroleum by a technique known as the Fischer–Tropsch process.

Syngas is a mixture of carbon monoxide and hydrogen that is created by partially combusting (in a medium-low oxygen environment) any material rich in carbon content including biomass and even plastic waste. It can also be produced from coal gasification, but that particular method is not recommended by this guide.

The name "syngas" comes from its use as an intermediate in the production of synthetic natural gas (SNG) and for producing ammonia or methanol. Syngas can also be used as an intermediate in producing synthetic petroleum for use as a fuel or lubricant.

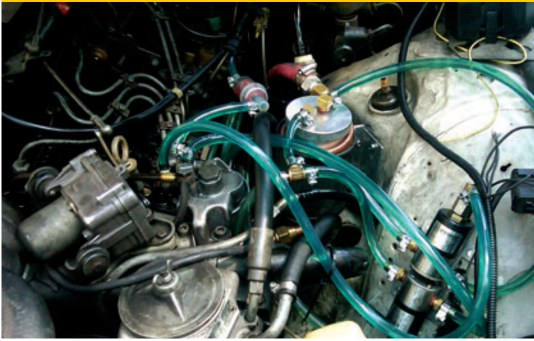
Syngas production has been shown to be possible using solar energy as the single source of heat in the process.

bio

BIOMASS
BIOFUEL
VEGETABLE OIL

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

Vegetable oil used as fuel can be either waste vegetable oil (WVO) left over from its first use such as food frying, or it can be straight vegetable oil (SVO) also known as pure plant oil (PPO).



WASTE VEGETABLE OIL CONVERSION
Image courtesy of Dr. Dave's Automotive.

Vegetable oil can be used in some older diesel engines or in newer engines that are modified. Modifications typically incorporate systems to preheat the oil to allow for proper atomization of the fuel.

In many cases, there is a greater wear and tear on the engine parts from 100% vegetable oil use due to its high viscosity. This can be mitigated by burning conventional diesel at the beginning and the end of the cycle and/or by cutting the vegetable oil with conventional diesel.

Vegetable oil can also be blended with gasoline, diesel, or kerosene, to reduce viscosity, but this has had generally poor results in sustained practical use.

bio

BIOMASS
BIOFUEL
HYDROCARBON PLANTS AND BIOGASOLINE

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

A list of hydrocarbon plant families:

- Euphorbiaceae
- Apocynaceae
- Asclepiadaceae
- Sapotaceae
- Moraceae
- Dipterocarpaceae
- Compositae (sunflower)
- Leguminosae

Some algae also produce hydrocarbons.

Dr. M. Calvin (1979) was the first to collect the hydrocarbons from plants of the Euphorbiaceae family.

EUPHORBIUM RESINIFERA (EUPHORBIACEAE)
Image from Franz Eugen Köhler's Medizinal-Pflanzen, 1887.

Hydrocarbon plants, such as Euphorbia lathyris and Euphorbia tirucalli, produce terpenoids in sufficient quantities through their metabolic processes that it is possible to convert them directly into gasoline-like fuels.

Biogasoline is usually produced from algae using complex industrial conversion processes such as deoxygenation/reforming or hydrotreating. The resulting fuel is very similar to conventional gasoline but with higher octane levels. It is not an alcohol fuel like ethanol.

bio

BIOMASS
BIOFUEL

PYROLYSIS DERIVED FUELS

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

Pyrolysis is the same process that occurs when you roast vegetables, bake a pie, or grill a cheese sandwich. In dry conditions, the carbohydrates present on the surface of these foods undergo pyrolysis and leave behind the darkened brown crust or black residue of charcoal. Controlled pyrolysis of sugar (170°C) results in caramel.

Pyrolysis is a different process than combustion, occurring generally below ignition temperature.

BIOCHAR RESEARCH AT UPPSALA UNIVERSITY
Photo by Tor Kihlberg.

Pyrolysis is a high temperature and high pressure thermochemical decomposition process that differs from anaerobic digestion or fermentation and requires very little water.

The process requires pressure and temperatures of over 430°C. It can be used in controlled conditions and with biomass feedstock to produce bio-oils which resemble light crude oil.

Flash pyrolysis, in which feedstock is heated quickly for two seconds to between 350°C and 500°C, is the most efficient method.

Pyrolysis can also be used to create biochar from organic waste and charcoal from wood feedstock. Biochar is useful as a fertilizer, and both can be combusted for energy.

bio

BIOMASS BIOFUEL

SOLIDS

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

IMPORTANT:
The by-products of solid biofuel combustion are very hazardous to human health and include high quantities of the greenhouse gases that are directly responsible for global climate change.

A strong reliance on solid biomass energy in the developing world is responsible for highly elevated rates of respiratory diseases, especially among women who are exposed to the toxic fumes for extended periods every day during cooking activities.

This category includes combustion of any renewable solid organic material such as wood or charcoal. We must include this category in this guide because it is technically a renewable energy source. However the combustion of solid biomass contributes heavily to greenhouse gases and the harvesting of wood for this purpose increases deforestation.

Conversion to mechanical, heat, or electrical energy is generally inefficient, and the environmental and human health costs are too high for biomass energy to be used on a large scale.

Solid biomass was the predominant form of energy prior to the advent of coal mining. This transition began to occur in the late medieval period (around 1500) in Europe, when unsustainable use of wood as fuel had led to massive deforestation[§].

[§]Norman F. Cantor (1993). The Civilization of the Middle Ages: The Life and Death of a Civilization. Harper Collins. p. 564.

bio

BIOMASS

WASTE TO ENERGY (WTE)

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

WtE is generally preferable to landfill waste disposal even though WtE results in emissions of CO_2 and other greenhouse gases.

Limestone scrubbers can greatly reduce the emission of harmful chemicals from incineration, and while there is CO_2 released, the effect of this is less than the more toxic greenhouse gases that are produced by landfill offgassing of methane, even if much of that methane is captured.

TREZZO SULL'ADDA 3 WASTE TO ENERGY PLANT IN MILAN, ITALY
Image courtesy of Falck Renewables SpA.

WtE is the use of non-recyclable waste for combustion (incineration) to generate electricity, or (in a small number of cases) for processing into methane or similar fuel.

There are some emerging WtE technologies which do not require incineration (some of which have been discussed above):

GASIFICATION (produces hydrogen, synthetic fuels)
THERMAL DEPOLYMERIZATION (produces synthetic crude oil)
PYROLYSIS (produces combustible tar, bio-oil, and biochars)
PLASMA ARC GASIFICATION, PGP (produces syngas)

Non-thermal technologies:

ANAEROBIC DIGESTION (biogas rich in methane)
FERMENTATION PRODUCTION (ethanol, lactic acid, hydrogen)
MECHANICAL BIOLOGICAL TREATMENT (MBT)

bio

BIOMASS MICROBIAL FUEL CELLS (MFC)

Conversion efficiency is determined by the method used to convert the biofuel into mechanical or electrical energy

The University of Queensland, Australia, completed a prototype MFC in partnership with Foster's Brewing.

The prototype converts brewery wastewater into carbon dioxide, clean water, and 2KW of power.

The idea of using microbial cells in an attempt to produce electricity was first conceived at the turn of the nineteenth century. M.C. Potter was the first to perform work on the subject in 1911.

MICROBES
Image courtesy of Rocky Mountain Laboratories, NIAID, NIH.

Microbial Fuel Cells produce electricity by harnessing the natural bio-electrical systems that convert chemical energy into electrical energy in anaerobic microbial ecosystems. The by-products of the electricity production are water and carbon dioxide (CO_2 emissions may be minimal).

There are two types of MFC:

MEDIATOR MICROBIAL FUEL CELL

Most of the microbial cells are electrochemically inactive. The electron transfer from microbial cells to the electrode is facilitated by mediators such as thionine, methyl viologen, methyl blue, etc., which are expensive and toxic.

MEDIATOR-FREE MICROBIAL FUEL CELL

Mediator-free microbial fuel cells do not require a mediator but use electrochemically active bacteria to transfer electrons to the electrode. Mediator-less microbial fuel cells can run on wastewater and derive energy directly from certain aquatic plants.

other

KINETIC ENERGY HARVESTING

There are many different ways that kinetic energy (natural or man-made) can be harvested and converted to electrical energy.

Conversion efficiency varies by technology

PAVEGEN SYSTEMS PAVER IN A LONDON SIDEWALK
Image courtesy of Pavegen Systems Ltd. www.pavegen.com

PIEZOELECTRIC GENERATORS convert mechanical strain into electrical energy. They can be inserted into shoes or in walkway pavers to harvest the energy of walking or jumping.

AMBIENT RADIATION from radio transmitters could potentially be collected and converted into usable electricity.

PYROELECTRIC EFFECT converts temperature change into electric current.

THERMOELECTRICS was discussed in the Solar section as it referred to the use of the device to harness heat energy that is generated by the sun. Other applications of the technology could be used to harvest heat energy from sources that would otherwise be wasted.

ELECTROSTATIC devices can harvest vibration energy and convert it into electricity. One example is the regenerative shock absorber that is planned for use in electric vehicles.

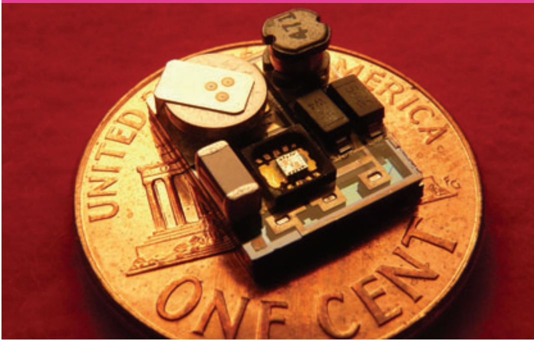
other

MICROHARVESTING

Conversion efficiency varies by technology

Microharvesting is the process by which low levels of natural energy that would otherwise be dissipated or wasted is captured and converted into electrical energy. The natural energy can be in any form (e.g., solar power, mechanical vibrations, thermal energy, wind energy, salinity gradients).

The harvested micropower can be stored and/or used to power small, wireless autonomous devices,such as those used in wearable electronics, wireless sensor networks, and biomedical devices.



PIEZOELECTRIC MICROHARVESTER
Image courtesy of Ethem Erkan Aktakka, Ph.D. and the University of Michigan. www.eecs.umich.edu/~aktakka

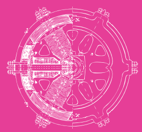
There are various technologies in use that harvest energy from blood sugar and tree sugars for conversion into electricity to power very small biological devices and monitoring equipment. Other advanced technologies include electroactive polymers, nanogenerators, and noise harvesting devices.

Energy harvesters provide a very small amount of power for low-energy electronics. While the input fuel to some large-scale generation costs money (oil, coal, etc.), the energy source for energy harvesters is present as ambient background and is free.

For example, temperature gradients exist from the operation of a combustion engine, and in urban areas there is a large amount of electromagnetic energy in the environment because of radio and television broadcasting.

Output is measured in: milliwatts (10^{-3} W), microwatts (10^{-6} W), and nanowatts (10^{-9} W).

other



ENERGY STORAGE

CHEMICAL: BATTERY, HYDROGEN, AND SYNTHETIC GAS

Conversion efficiency varies by technology

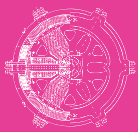
Since some forms of renewable energy do not produce consistent power twenty-four hours a day (base load power), it is important to develop methods of energy storage that are in themselves ecological and do not cause more harm in their production and disposal than the old forms of electrical generation that renewable energy is replacing.

1MW SODIUM SULFUR (NaS) BATTERIES FOR GRID STABILITY
Image courtesy of Younicos.

While there are great transitional applications for lithium-ion, nickel-metal hydride, sodium-sulphur, and other electrochemical batteries, especially as it pertains to transportation, these may not be the best long term solution for utility-scale energy storage since the metals that go into their production are not in themselves entirely renewable. There are however some successful applications of high capacity battery storage such as the 1MW units used in the Younicos Island Systems.

Electrical power can be used to produce hydrogen gas which can then be used to power hydrogen fuel cells with water as the only product required during production and the only by-product output during consumption.

Biofuels and methane gas can be considered a type of energy storage. If renewable energy is the power used in the processing of these fuels then the energy that is embodied in them can be considered entirely renewable.



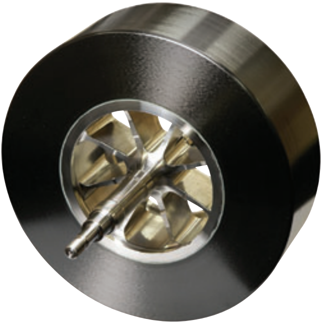
ENERGY STORAGE

MECHANICAL

Conversion efficiency varies by technology

Flywheels can provide continuous (regulated) energy output in any situation where the energy input is not continuous.

The use of the flywheel for efficient use of mechanical energy dates back to the Neolithic spindle.



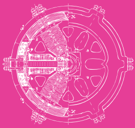
EXAMPLE OF A FLYWHEEL FROM A HYBRID AUTO ENGINE
Image courtesy of Ricardo.

Compression of gas or water can be used during times of peak capacity. Then the pressure can be released during times of lower production to augment power. This can be accomplished in very large quantities with the use of underground cavities.

Mechanical Flywheels can be used to store energy. They consist of heavy weighted round cylinders which are designed to rotate on a central axis with as little friction as possible. Electrical energy can be put into the flywheel causing it to rotate up to very high rotations per minute speeds. Then when energy is required at a later time, the rotational energy is extracted from the flywheel, slowing its rotation down.

Hydroelectrical Pumped Storage uses conventional dammed hydroelectrical technology to fill a reservoir with water while there is access to inexpensive electrical power. The water is then released to power turbines when electricity is required (during times of day when the cost per KWh is higher).

other



ENERGY STORAGE

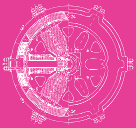
THERMAL

Conversion efficiency varies by technology

GEMASOLAR PLANT
Image courtesy of Torresol Energy.

Thermal energy storage is storage of energy in the form of heat. Some concentrated solar power plants use liquid sodium or other thermal storage mediums that store heat for long periods and allow for the operation of steam turbines for as many as 17 hours after the sun has set. These systems have the potential to provide base load power from the sun.

Alternatively, energy can be stored by cooled liquids during off-peak hours (and when temperatures are cooler) that can then be used for air conditioning purposes in the daytime.



ENERGY STORAGE

UPDATED GRID

ELECTRICAL TRANSMISSION PYLONS
Photo by Robert Ferry.

With a large enough, well interconnected, and technologically sophisticated power grid, intermittent energy generation can be managed within limits by allowing peak electrical generation capacity in some locations to make up for lower capacity in other locations.

other

ENERGY CONSERVATION

DEMAND SIDE MANAGEMENT

If the end use of electricity can be managed through energy efficient architecture and through the application of smart meters, smart appliances, and smart grids, peaks and valleys in demand can be minimized. A widespread application of intelligent energy infrastructure will serve to mitigate the problem of renewable energy source intermittency.

Smart grid technology allows end users to monitor in real time the amount of energy available in the grid at any point in time and plan their use patterns accordingly. Appliance control technologies can be designed to perform this function automatically (you load your washing machine and press the start button, but it instead informs you that it will be waiting for two hours before beginning its operation because it senses a demand peak at the moment).

Fully realized systems will price consumer energy consumption according to KWh spot prices as they fluctuate with demand.

Over the past 200 years non-renewable energy resources have helped to bring about great advancements. But their consumption has also brought great blight upon the health of the planet and her inhabitants, and our easy access to them is soon running out. But change is just around the corner...

Right now is a great time to help contribute to this change. The more we can increase public awareness and acceptance of renewable energy and local applications, the more direct our path will be to a truly sustainable world.

a field guide to renewable energy technologies

solar
wind
water
bio
other

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www.landartgenerator.org

EDITION
February 2012 1st edition

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A project of Society for Cultural Exchange &
Land Art Generator Initiative

THANK YOU to all of the institutions, companies, and individuals who have generously allowed the use of their images.

BACK COVER IMAGE

THE WINDMILL, HAMMERSTEIN'S PARADISE GARDENS, NEW YORK (1900–1906)
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