The Oil Drum
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The bright future of solar powered factories

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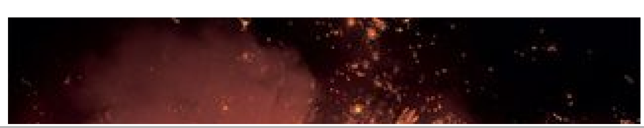
This is a guest post by Kris De Decker, founder and writer at Low-tech Magazine, an internet publication highlighting the need for elegant yet simple old and new sustainable energy technologies

Most of the talk about renewable energy is aimed at electricity production. However, most of the energy we need is heat, which solar panels and wind turbines cannot produce efficiently. To power industrial processes like the making of chemicals, the smelting of metals or the production of microchips, we need a renewable source of thermal energy. Direct use of solar energy can be the solution, and it creates the possibility to produce renewable energy plants using only renewable energy plants, paving the way for a truly sustainable industrial civilization.

A large share of energy consumed worldwide is by heat. Cooking, space heating and water heating dominate domestic energy consumption. In the UK, these activities account for 85 percent of domestic energy use, in Europe for 89 percent and in the USA for 61 percent (excluding cooking).

Heat also dominates industrial energy consumption. In the UK, 76 percent of industrial energy consumption is heat. In Europe, this is 67 percent. I could not find figures for the US and for the world as a whole, but these percentages must be similar (and probably even higher on a worldwide scale because many energy-intensive industries have been outsourced to developing countries). Few things can be manufactured without heat.

Solar panels and wind turbines are no producers of heat energy



The importance of heat in total energy consumption sharply contrasts with our efforts to green the energy infrastructure. These are largely aimed at renewable electricity production using wind turbines and solar panels. Although it is perfectly possible to convert electricity into heat, as in electric heaters or electric cookers, it is very inefficient to do so.

It is often assumed that our energy problems are solved when renewables reach 'grid parity' - the point at which they can generate electricity for the same price as fossil fuels. But to truly compete with fossil fuels, renewables must also reach 'thermal parity'.

Though today in some locations it may be as cheap to produce electricity with wind or solar energy as with gas or coal, it still remains significantly cheaper to produce heat with oil, gas or coal than with a wind turbine or a solar panel. This is because it takes 2 to 3 kWh of fossil fuel thermal energy to create 1 kWh of electricity, so it is at least 2 to 3 times cheaper to make heat by simply burning the fossil fuels directly than to use an electric renewable technology at grid parity.

Manufacturing wind turbines and solar panels requires heat

This means that solar panels and wind turbines will have to become two to three times cheaper than they are today in order to reach thermal parity with fossil fuels. This might sound reasonably possible, especially if you expect fossil fuel prices to rise. But consider this: even though they are intended to replace fossil fuels, renewable energy sources like wind turbines and solar panels are in fact dependent on a continuous supply of fossil fuels.

Solar panels and wind turbines do not need fossil fuels to operate, but they do need fossil fuels for their production. You won't find any factory manufacturing PV solar panels or wind turbines using energy from their own PV solar panels or wind turbines. Why not? Because it is very inefficient (and thus utterly expensive) to convert electricity into heat. Yet to make solar panels and wind turbines, to produce steel and silicon for instance, heat is what is most needed. This means that the production costs of solar panels and wind turbines will be affected negatively by rising fossil fuel prices.

The same goes for batteries, which are an essential element of electric cars and renewable electricity storage, and for many other modern green technologies, like LEDs and heat pumps. They require heat for their production, and this heat can be delivered at least 2 to 3 times cheaper by burning fossil fuels than by using wind turbines or solar panels (cheap electricity from hydropower plants is also an option, but has limited potential). This is a fundamental problem, because we will have to produce new wind turbines and solar panels every 20 to 30 years, and new batteries every 5 to 10 years.

Renewable source of heat energy

The missing element in our sustainable energy strategy is a renewable source of thermal

energy. Geothermal energy produces heat, but for now it is mostly economical in regions that lie on the boundaries of tectonic plates, as there temperatures are higher closer to the surface. Biomass is another option, but it faces many problems. If we were to try to provide an important share of heat demand by burning biomass, we would quickly come up against the limits of what the planet can produce. There is only one source of heat energy left, and it is a powerful and inexhaustible one: solar energy.

We tend to see solar energy as yet another way to generate electricity, using photovoltaic panels or solar thermal power plants. But solar energy can also be applied directly, without the intermediate step of generating electricity. Basically, harvesting direct solar energy can happen in two ways: by means of water-based flat plate collectors or evacuated tube collectors, which collect solar radiation from all directions and can reach temperatures of 120 °C (248 °F), and by means of solar concentrator collectors, which track the sun, concentrate its radiation, and can generate much higher temperatures. These can be parabolic trough systems, linear concentrating Fresnel collectors, parabolic dish systems or solar power towers. Almost all of these technologies were developed at the turn of the 20th century.

Solar thermal power versus solar thermal heat

The problem is that we mostly use this technology for the wrong purpose. In today's solar thermal plants, solar energy is converted into steam (via a steam boiler), which is then converted into electricity (via a steam turbine that drives an electric generator).

This process is just as inefficient as converting electricity into heat: two-thirds of energy gets lost when converted from steam to electricity. This is one of the main reasons why the use of solar thermal energy to produce electricity is only cost-effective in deserts.

If we were to use solar thermal plants to generate heat instead of converting this heat into electricity, the technology could deliver energy 3 times cheaper than it does today and become cost-effective also in less sunny regions. The crucial difference between solar thermal electricity and other renewables producing electricity is that solar thermal actually starts with heat energy. Thus, contrary to other renewables, the cost of heat energy using the technology is far lower than the cost of electricity, and so it can compete with burning fossil fuels at the thermal level.

Low temperature solar heat

This can be demonstrated by flat plate collectors and evacuated tube collectors, which are used for domestic hot water preparation and (to a lesser extent) interior space heating. This technology is used without any conversion losses and is cost-competitive with fossil fuels almost anywhere on Earth. According to the 2011 update (pdf) of the International Energy Agency's Solar Heating and Cooling Programme (IEA-SHC), solar thermal heat is now the second most important renewable energy source following wind, and a much more important energy source than photovoltaics and solar thermal power plants. Almost 60 percent of solar thermal heat capacity can be found in China and another 20 percent is in Europe. The US and Canada (where the main application is to heat swimming pools) account for less than 9 percent.

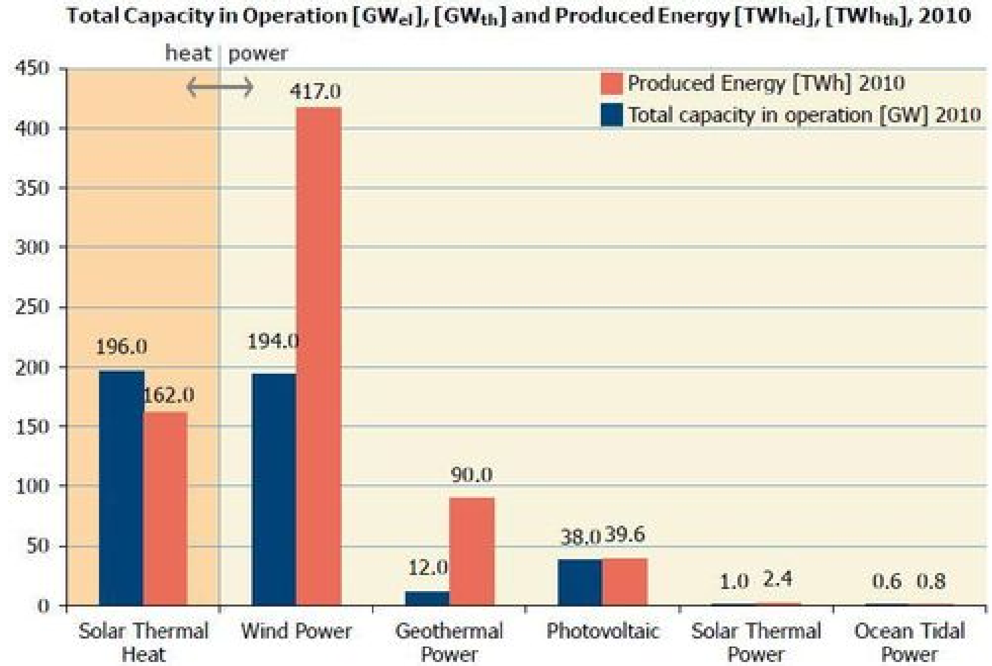


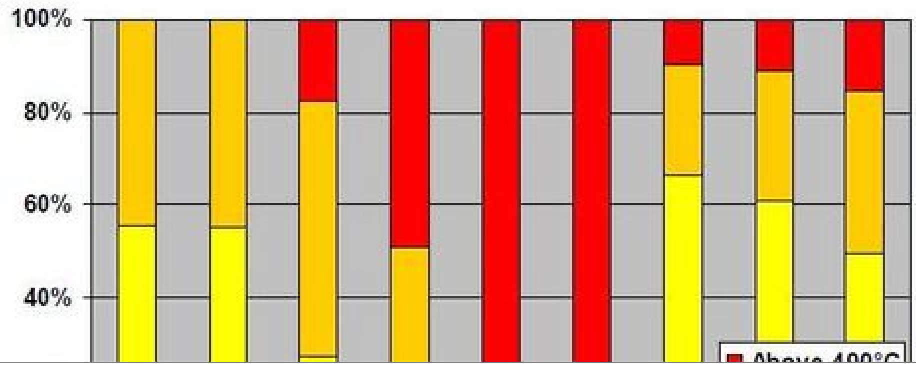
Figure 1. Renewable energies comparison capacity

Sweden, Denmark, Spain, Germany and Austria have the most sophisticated markets for different solar thermal applications, including large-scale plants for district heating and a small but growing number of systems for air conditioning and cooling (using an absorption chiller). By the end of 2009, 115 solar supported district heating networks and 11 solar supported cooling systems were installed in Europe. Canada, Saudi Arabia and Singapore have also built a few large-scale solar heat systems for producing hot water, space heating and cooling.

The potential of solar heat for industrial processes

Without a doubt, solar heat for domestic purposes should continue to be encouraged and a lot of potential remains. But it does not stop there. According to a 2008 report (pdf), which analyses the situation in Europe, the potential for solar heat in industrial processes is even larger than in the domestic market. About 30 percent of industrial heat demand in Europe is below 100 °C (212 °F), which could be delivered by commercially available flat plate collectors (< 80 °C) and evacuated tube collectors (< 120 °C) currently used for domestic purposes.

Another 27 percent of industrial heat demand requires medium temperatures (100 to 400 °C or 212 to 752 °F), which could be reached by improved versions of these collectors (up to 160 °C, see this document) and by commercially available solar concentrator technologies now mostly used for electricity production: parabolic troughs, parabolic dishes and linear concentrating Fresnel collectors.



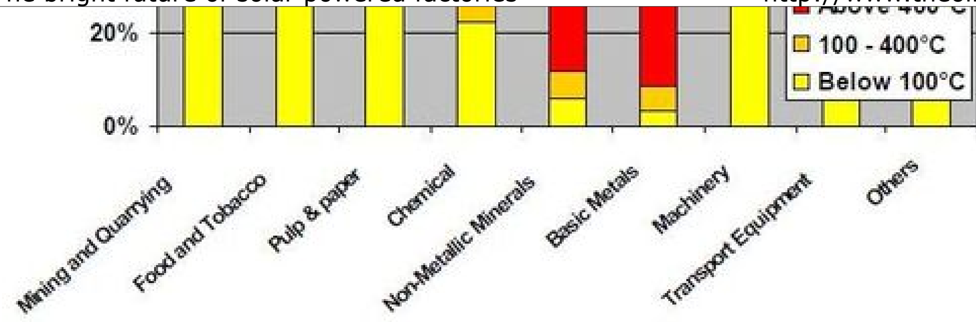


Figure 2. Industrial heat demand

This means that at least 57 percent of heat demand in European industry (or almost 40 percent of total industrial energy demand) could be covered by available and cost-effective technology using an inexhaustible renewable energy source that has no ecological disadvantages whatsoever. The capital costs (and embodied energy) of this would be much less than replacing a similar amount of fossil fuel energy use with solar panels or wind turbines. And of course, it could be done anywhere, not just in Europe.

Solar heat in industry: existing applications

At low and medium temperatures, solar heat can be used for industrial processes in several ways. It can provide warm water for processes like bottle washing or chemical processes. Secondly, it can provide hot air for drying and baking processes, for instance in the food and paper industries. Thirdly, it can generate steam that can be fed into steam heat distribution networks, which are widely used in many industries. The interesting thing is that in all these applications, the existing industrial machinery and distribution infrastructure remains in place. Only the energy source is replaced.

Some manufacturers have started marketing their solar concentrator technologies for the use of heat generation in industry, in addition to their application as electricity generators. Examples are Sopogy (a Hawaian company that sells modular parabolic trough systems - picture above), the Solar Power Group (a German company that sells linear concentrating Fresnel collectors) and HelioDynamics (an American seller offering similar technology - picture below).

Installations for the use of solar industrial process heat are still rare, but they exist. German heating systems manufacturer Viessmann installed 260 m² of its own flat plate collectors on its factory in France to provide hot water for a chemical process, taking a first step towards producing renewable energy using renewable energy. A solar thermal plant based on 1,900 m² of parabolic troughs provides steam for a pharmaceutical plant in Egypt. A similar solar thermal plant was built for a dairy plant in Greece. A food processing facility in California has 5,000 m² of parabolic troughs to produce steam used in the manufacturing process. Several industrial applications of solar heat have been built in India, using both flat plate collectors and concentrator technologies.

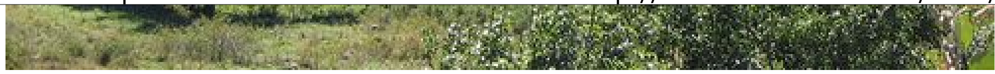
A solar concentrator system called ARUN - a Fresnel parabolic reflector with point focus that delivers temperatures from 80 to 400 °C - has been installed in six industries, ranging from a dairy plant to an automobile manufacturer (picture on the left). India also has several large solar cooking facilities for community kitchens (schools, hospitals, factories, religious centres). The largest one consists of 84 parabolic dish systems reaching temperatures of up to 650 °C and producing up to 38,500 meals per day. The largest solar process heat application to date was recently installed in Hangzhou, China, where 13,000 m² of solar collectors on the roof of a textile factory provide hot water for a dyeing process. The Global Solar Thermal Energy Council is continually updating its list of new industrial applications of solar heat.

Renewables building renewables

The remaining 43 percent of industrial heat demand in Europe is above 400 °C (752 °F). These include many of the industrial processes that we need to manufacture renewable energy sources (wind turbines, solar panels, flat plate collectors and solar concentrators) as well as other green technologies (like LEDs, batteries and bicycles). Examples include the production of glass (requiring temperatures up to 1,575 °C) and cement (1,450 °C), the recycling of aluminum (660 °C) and steel (1,520 °C), the production of steel (1,800 °C) and aluminum (2,000 °C) from mined ores, the firing of ceramics (1,000 to 1,400 °C) and the manufacturing of silicon microchips and solar cells (1,900°C).

These temperatures can be achieved by solar concentrator technology. Linear reflectors (parabolic trough systems and linear concentrating Fresnel collectors) are limited to temperatures of about 400 °C, but point concentrators can reach higher temperatures. These include parabolic dish systems, solar power towers, and solar furnaces - which are basically a combination of power towers and parabolic dish systems.

Solar furnaces can produce temperatures up to 3,500 °C (6,332 °F), enough to manufacture microchips, solar cells, carbon nanotubes, hydrogen and all metals (including tungsten which has a melting point of 3,400 °C). These temperatures can be achieved in just a few seconds - see this short video of a solar furnace melting steel. The most powerful solar furnace is the one at Odeillo in France, built in 1970, which concentrates the light of the sun 10,000 times and has a power output of 1 MW.



More than 60 heliostats (only one is seen on the picture above, in the lower righthand corner) direct the rays of the sun onto a parabolic mirror of more than 1,800 square metres, from which they are concentrated on a focal point with a diameter of only 40 centimetres in the tower in front of it. A [similar solar furnace stands in Uzbekistan](), built in 1976, but it is slightly less powerful due to lower solar insolation in the region. The picture on the right shows it in action, melting metal.

You don't need such an enormous structure to achieve high temperatures. Several smaller solar furnaces have been built, often using only one heliostat. They reach similar or only slightly lower temperatures (usually between 1,500 and 3,000 °C) than the giants pictured above, though at significantly lower power outputs (between 15 and 60 kW). They can perform most of the same processes as the large solar furnaces, but processing smaller amounts of materials or chemicals.

Examples of smaller solar furnaces can be found at the Paul Scherrer Institute in Switzerland (pictured below right), the National Renewable Energies Laboratory in the USA, the Plataforma Solar de Almería in Spain, the German Aerospace Center in Germany, and the Weizmann Institute of Science in Israel (a solar power tower). They have concentration ratios between 4,000 and 10,000. In solar concentration, the temperature is proportional to the degree of concentration, whereas power will be proportional to size and efficiency (which is mostly determined by temperature).

Solar energy improves product quality

Solar furnaces not only have the potential to replace fossil fuels for the energy-intensive production of construction materials, chemicals, and high-tech products like microchips and solar cells, but they also offer additional benefits because of their pure combustion and selective heating capacities. A 1999 research paper describes the manufacturing of silicon solar cells using a solar furnace, concluding that "solar furnace processing of silicon solar cells has the potential to improve cell efficiency, reduce cell fabrication costs, and also be an environmentally friendly manufacturing method. We have also demonstrated that a solar furnace can be used to achieve solid-phase crystallization of amorphous silicon at very high speed."

As opposed to low and medium temperature processes in industry, where only the energy source is replaced and the machinery and distribution infrastructure can remain in place, most high temperature solar heat applications require new machinery. Furnaces and kilns have to be rebuilt. Some efforts have been made. The Paul Sherrer Institute in Switzerland designed several solar powered lime and cement kilns (pdf), and research concluded that they could become cost-competitive with a fossil fuel powered kiln (pdf) following some further technological improvements. Again, the quality of the product turned out to be better using solar energy, eliminating combustion by-products.

Low-tech, open source solar concentrators

Though existing solar funaces prove that anything could be produced using direct solar heat instead of fossil fuels, this is not yet possible in a cost-effective way (it is cheaper to use fossil fuels). However, since solar furnaces could produce all materials needed to build more solar furnaces, they might become cost-effective even without technical improvements if fossil fuels become more expensive.

Moreover, the capital costs of solar concentrators are decreasing quickly following some recent innovations aimed at simplifying the technology. These might not only lead to cheaper high temperature solar heat concentrators in the future, but they also make the use of solar heat for medium temperatures more affordable and competitive today.

The most spectacular example is the Solar Fire P32 (picture above and pictures below), a solar concentrator developed in 2010 by the French NGO the Solar Fire Project. It is an open source design (joining forces with the Open Source Ecology project), but the machine can also be bought for 7,500 euro - less than the price of an urban wind turbine.

The Solar Fire P32 is built using simple, abundant and non-toxic materials. Contrary to most other modern green technologies, there is no need for rare earth metals or advanced tools that are not found in an average metal workshop. Essentially, this is a renewable source of heat energy analogous to home made windmills used to produce mechanical energy.

The machine can deliver up to 15 kW and can reach a focal temperature of 700 °C (1,292 °F), enough to melt (and thus recycle) aluminum, the material that is used to make its reflectors. This means that you could use a Solar Fire P32 to make another Solar Fire P32. Or almost. The receiver and the supporting structure are made of steel, which requires a higher melting temperature to recycle. However, the structure could as well be made of wood, bamboo, organic fibre or aluminum, and the steel receiver could easily be scavenged material. The use of glass improves the workings of the device, but is not strictly necessary.

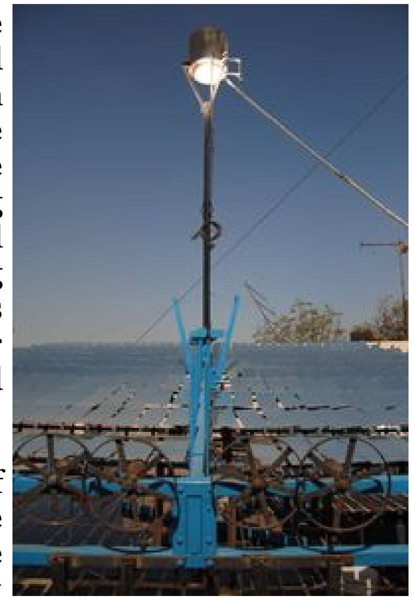
The Solar Fire P32 is composed of 360 small mirrors with a total surface of 32 square metres, focusing sunlight on a steam boiler above them. The steam can be used directly to purify large quantities of water, boil milk, produce edible oils, make charcoal, bake bricks, make paper, and so on.

Increasing energy autonomy

The steam can also drive a steam engine to directly power a water pump, oil and grain mills, cotton spinning, or any other stationary application requiring mechanical power. Connected to a steam generator, the machine can also generate electricity (up to 3 kW). These two last applications involve conversion losses, but they are interesting additions for those who want to achieve energy independence, especially in regions where there is lots of sun but no wind. The machine can produce heat, electricity and direct mechanical energy.

The Solar Fire P32 is - in the first place - aimed at developing countries and designed to be cost-effective compared to burning coal and wood, reducing deforestation and pollution, increasing energy autonomy, and providing an energy source at the scale of traditional practices and small industries. It has been built in Mexico, Cuba, Burkina-Faso, Mali, India and Kenya, but also in Texas, France and Canada. Obviously, the design could also be useful in the developed world, where the supply of fossil fuels might not remain as easily accessible as it is today.

Simplifying technology



Apart from the additional equipment that is required to generate electricity, conventional solar concentrator technologies demand heavy capital investments for several reasons. Parabolic trough systems and parabolic dish systems require curved mirrors that are expensive to produce. Moreover, these mirrors cannot be manufactured locally and often have to be transported over long distances, increasing costs further. In both systems the curved mirrors are large and heavy, requiring rigid frames, strong foundations, powerful hydraulics and sophisticated tracking systems to follow the sun. In parabolic dish systems, the heat engine or steam boiler is part of the moving structure, increasing weight and thus making things even worse.

Solar power towers - which were invented in 1878 - solve some of these issues: they use nearly flat mirrors and all mirrors share one stationary receiver. But, they require the construction of a large tower building. Last but not least, all of these systems have very high land requirements because of overshadowing issues. Linear Fresnel concentrators use (mostly) flat mirrors, have simpler tracking systems and are more compact, but they can only reach temperatures of 250 °C (using relatively low-tech materials) or 450 °C (using sophisticated technology).

The Solar Fire is a Fresnel parabolic reflector with point focus, just like ARUN - but unlike that machine it is placed horizontally and the receiver does not have to be turned together with the mirrors, resulting in light weight and high wind resistance. The machine uses slightly curved mirrors, achieved by mechanical bending which can be done on the spot. Sun tracking of the mirrors is done by hand, eliminating the need for electronics and electric motors altogether (multiple mirrors can be turned at once using hand operated wheels). This might sound crude, but for industrial applications the machine has to be supervised anyway.

And because it is open source, it can be further improved by anyone. Eerik Wissenz, the designer of the machine, thinks this is the only way: "Companies pursuing patents for solar collectors have fallen into a complexity trap. Since solar energy is free it is far simpler to add 5 percent more surface area instead of creating complex machines too expensive to be commercially viable. Solar fire concentration is so simple it cannot be patented."

Low-tech solar furnaces

High temperature solar furnaces can be low-tech autonomous systems, too. One example is the large magnifying glass used by [Sundrop Jewelry](), which reaches high enough temperatures to melt coloured bottle glass into handcrafted jewelry. Of course the power output is low, making this installation useless if you want to produce industrial quantities of glass. But it shows that solar heat can be used on any scale.

Another example is the Solar Sinter Project by Markus Kayser, in which glass is produced using only sunlight and desert sand. I would like to quote the artist here: "Whilst not providing definitive answers, this experiment aims to provide a point of departure for fresh thinking".

Storage

How can you power factories using an energy source that is not always available? Solar insolation varies throughout the day and the seasons, and there is no sun at night. Moreover, solar concentrator technologies only work with unscattered sunlight, which means that a passing cloud stops energy production. This raises two questions. Some industrial processes work fine with intermittent energy supply, but how do you guarantee an uninterrupted supply of energy to a process that requires it? And what do you do when there is no sun at all for a week?

There are three ways to deal with the intermittency of solar power. The first solution is to design hybrid systems: make solar and already existing energy sources work together. This is how most of today's solar thermal power plants work. In this scenario, which offers a solution for both short and long term storage, industrial processes are powered by solar heat whenever it is available. When it is not, solar energy is instantly replaced by fossil fuels or electricity. It is not an ideal solution, but it could save large amounts of energy. And we don't need new technology to make it work.

The second strategy is to store solar energy so that it can be used to smooth out industrial processes (analogous to a flywheel for smoothing out mechanical processes) and to guarantee energy supply on cloudy days or at night. Storage of heat is much cheaper and more efficient than storage of electricity. The most low-tech way is to store heat in well-insulated water reservoirs - another technology that is more than 100 years old. The disadvantages are that you need quite a lot of space, and that water storage only works up to a temperature of 100 °C (212 °F). There are more compact ways to store heat at higher temperatures, for example by using ceramics or phase-changing materials (certain salts). These storage media are already used in one solar thermal power plant, but they would be even more efficient if used in a thermal only system. Innovative technology could further improve heat storage.

Storing work instead of energy

The third way to deal with the intermittency of solar heat is to store *work* instead of *energy*. We let our factories work when the sun shines, and only when the sun shines. Just like we wait for a sunny day to do the laundry, we could wait for a sunny day to bake bricks, recycle metal or produce smartphones. Industrial production would be concentrated in summer months. Of course, there is a price to pay. Industrial production would be lower. But considering the fact that our energy and environmental problems are largely caused by overproduction and overconsumption of goods, this is not as far-fetched as it might seem.

Combining all three strategies could be a solution. In that scenario we would run part of our factories only when the sun shines (and when the wind blows), using heat storage, fossil fuels, biomass or electricity to smooth out industrial processes if necessary. Critical goods could be produced continuously combining solar heat and heat storage, fossil fuels, or biomass. Of course, not all climates are blessed with enough sun to make solar heat a viable option to power the whole industry. But since many people are now talking about outsourcing electricity production to desert regions, we could just as well move our factories to regions where there is plenty of sun. It is much more efficient to transport manufactured goods over large distances than to transport electricity.

Solar powered enhanced oil recovery

As always, a sustainable technology can be used for unsustainable purposes. Solar heat is a great way to get more oil out of fields that are now considered exhausted. Getting that remaining oil out using gas would cost more money and energy than the oil could return, but using a free source of energy changes everything.

At least one company specializes in this application. Glasspoint, a US firm originally founded to use solar heat for drying gypsum wall board, has seen remarkable growth promoting "Solar Enhanced Oil Recovery".

This has been tried before, but they use an innovative technology: parabolic trough mirrors suspended from the ceiling of enormous glasshouse structures that are equipped with robotic cleaning systems. Because they are protected from wind, sand and dust by the greenhouse, the mirrors can be made extremely light and without protective glass layers - lowering their costs and increasing their efficiency. The steam that is generated by the solar heat is pumped into the oil reservoir. The more sun there is, the more oil will come to the surface. Only 20 to 40 percent of an oil field can be recovered using standard techniques, but as much as 60 to 80 percent can be recovered using solar heat. In the end, solar heat could thus increase fossil fuel production and CO2-emissions.

Kris De Decker (edited by Rachel Meyer)

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