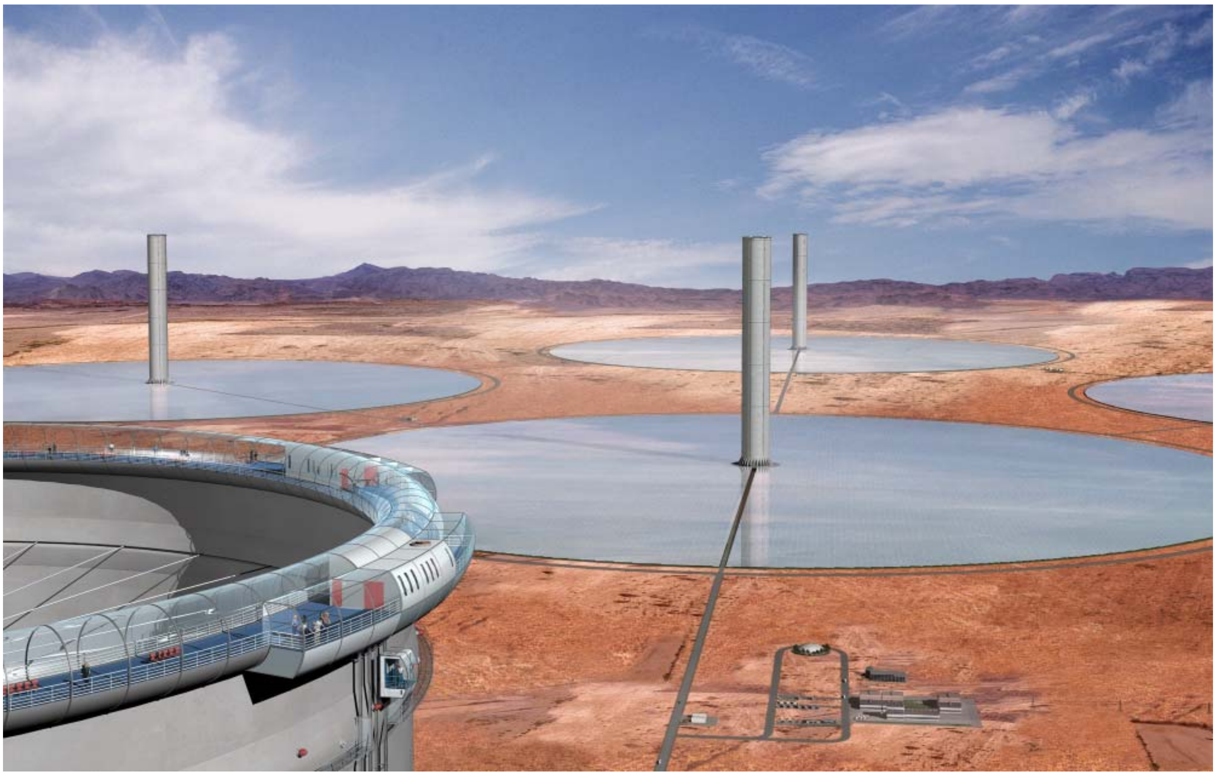
Schlaich Bergermann Solar GmbH

Solar Updraft Tower



Schlaich Bergermann Solar GmbH, Stuttgart
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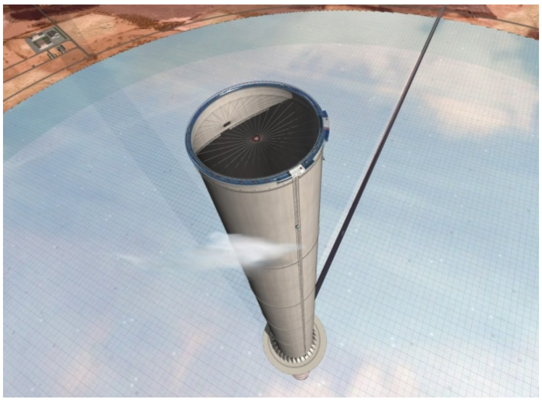
0 EXECUTIVE SUMMARY

Electricity from the sun: Clean, economical, unlimited.

Solar Updraft Towers will have a share already in the near future in solving one of today's dominant challenges: The global, sustainable, inexhaustible and affordable supply of energy.

The principle of this technology is rather simple: under a large glass roof the sun warms up the air (greenhouse effect) which is sucked in by the central vertical cylindrical tube (chimney effect). The updraft wind, thus created, drives turbines/generators and so generates electricity.

Due to the soil under the collector working as a natural heat storage system, Solar Updraft Towers can operate 24 h on pure solar energy, at reduced output at night time. Simple water tubes, placed on the ground, increase the storage capacity and can yield a uniform 24 h electricity generation, if desired.



Solar Updraft Towers, mainly suitable for large-scale energy production in units of 100 MW or more, can be erected by local labor force and to a high degree with locally available materials.

Solar Updraft Towers can be built in desert countries either to cover regional demand resp. to save oil reserves, or to contribute to the energy supply of e.g. Europe, since the electricity produced by Solar Updraft Towers in the sunny countries can be transported and sold to any place either by transmission lines or – as liquid hydrogen – by ships without substantial losses.

Solar Updraft Towers are particularly reliable. Turbines and generators are the plant's only moving parts. This simple and robust structure guarantees operation that needs little maintenance and of course no combustible fuel.

Unlike conventional oil / gas fired and also other solar-thermal power plants, Solar Updraft Towers do not need cooling water. This is a key advantage in many sunny countries that already have major problems with water supply.

Electricity from Solar Updraft Towers is the cheapest when compared with other solar power plants. Nevertheless its energy production costs are still somewhat higher than those of "conventional" coal or gas-fired power plants. However, the approaching shortfall of fuel reserves in combination with dramatically increasing demand will soon balance the cost difference of today and later even reverse it. We expect this "break-even-point" already at a value of 60 to 80 $/barrel of crude oil. Therefore it is time now to build large-scale solar power plants and also large-scale Solar Updraft Towers.

The know-how is available with us.

1 INTRODUCTION

Current electricity production from coal, oil and natural gas is damaging the environment, is non-sustainable and many developing countries cannot afford these energy sources. Nuclear power stations are an unacceptable risk in most locations. But inadequate energy supply leads to or maintains poverty, which commonly is accompanied by population explosion: a vicious circle.

Sensible technology for the wide use of renewable energy must be simple and reliable, accessible to the technologically less developed countries that are sunny and often have limited raw material resources, it should not need cooling water or produce waste and should be based on environmentally sound production from renewable or recyclable materials.

The solar updraft tower meets these conditions and makes it possible to take the crucial step towards a global solar energy economy. Economic appraisals based on experience and knowledge gathered so far have shown that large scale solar updraft towers ($\geq$ 100 MW) are capable of generating energy at costs close to those of conventional power plants. This is reason enough to further develop this form of solar energy utilization, up to large, economically viable units. In a future energy economy, solar updraft towers could thus help assure the economic and environ–mentally benign provision of energy in sunny regions.

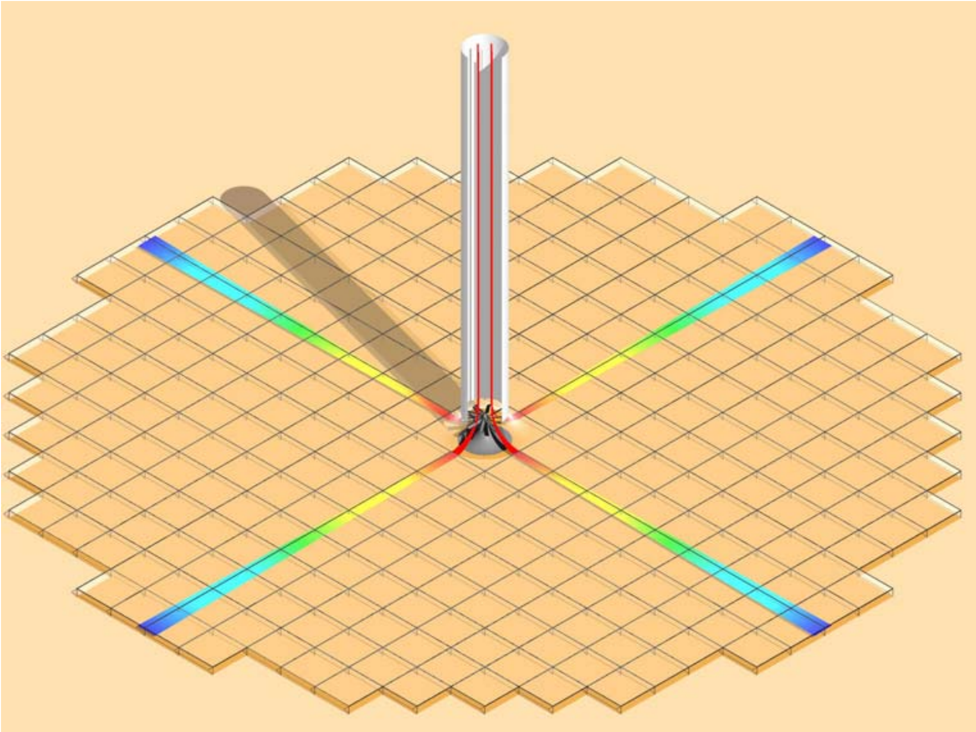


Figure 1. Solar Updraft Tower Principle

Although invented by others already 100[1] years ago, **Schlaich Bergermann** has taken up the solar updraft tower concept about 30 years back and developed it to the present stage of technical and economical feasibility. Thermodynamic behaviour has been investigated and tested in a pilot plant in Manzanares in Spain, forming the basis for the layout of large plants.

Extensive research work and detailed analyses by **Schlaich Bergermann** have proven the constructibility of huge towers in general and have resulted in an economically optimised structural concept for tower and collector.

[1] In 1903, Spanish Army Colonel Isidoro Cabanyes first proposed a solar chimney power plant in the magazine *La energía eléctrica*. One of the earliest descriptions of a solar chimney power plant was written in 1931 by a German author, Hanns Günther. He already described the Desertec concept, too.

2 THE SOLAR UPDRAFT TOWER TECHNICAL CONCEPT

2.1 Principle

Man learned to make active use of solar energy at a very early stage: greenhouses helped to grow food, chimney suction ventilated and cooled buildings and windmills ground corn and pumped water.

The solar updraft tower's three essential elements – solar air collector, chimney/tower, and wind turbines – have thus been familiar for centuries, but are combined now in a novel way.

The principle is shown in Figure 1: Air is heated by solar radiation under a low circular transparent roof open at the periphery; the roof and the natural ground below form an air collector. In the middle of the roof is a vertical tower with large air inlets at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter.

Thus solar radiation causes a constant updraft in the tower. The energy contained in the updraft is converted into mechanical energy by pressure-staged turbines at the base of the tower, and into electrical energy by conventional generators.

Continuous 24 hours-operation can be achieved by placing tight water-filled tubes or bags under the roof (Figure 3 and Figure 4). The water heats up during day-time and releases its heat at night. These tubes are filled only once, no further water is needed.

2.2 Power Output

Electrical output of a solar updraft tower is proportional to the volume included within the tower height and collector area (Figure 2.). The same output may result from a larger tower with a smaller collector area and vice versa.

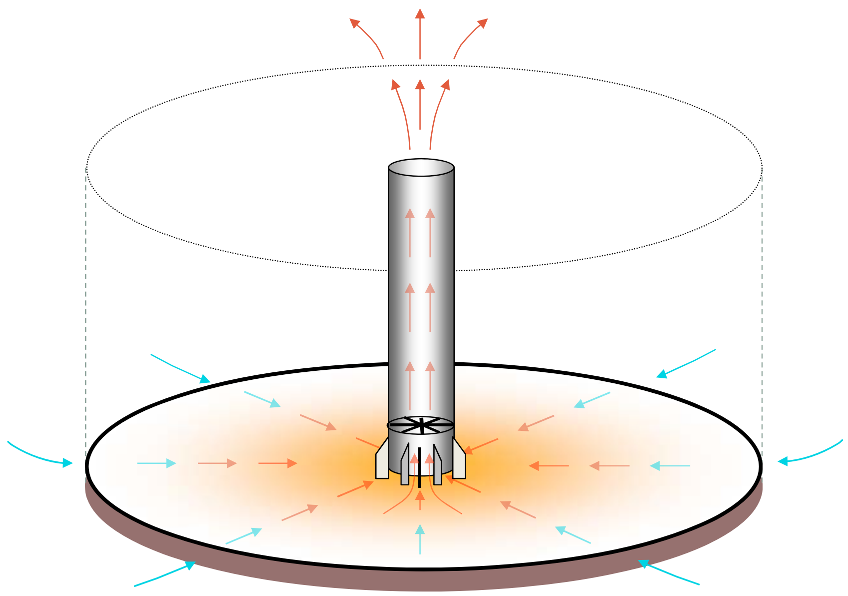


Figure 2. Electricity generation of a solar updraft tower is in proportion to the volume defined by tower height and collector diameter

2.3 Components

2.3.1 Collector

Hot air for the solar updraft tower is produced by the greenhouse effect in a simple air collector consisting of a glass or plastic film glazing stretched nearly horizontally several meters above the ground. The height of the glazing increases towards the tower base, finally the air is diverted from horizontal into vertical movement with minimum friction loss. This glazing admits the shortwave solar radiation to penetrate and retains longwave re-radiation from the heated ground. Thus the ground under the roof heats up and transfers its heat to the air above flowing radially from the outside to the tower.

2.3.2 Storage

If additional thermal storage capacity is desired, water filled black tubes or bags are laid down side by side on the radiation absorbing soil under the collector.

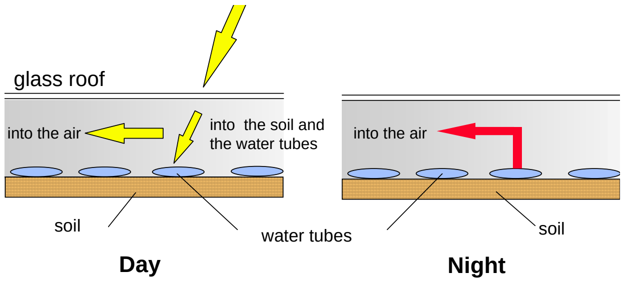


Figure 3: Principle of thermal energy storage with water-filled tubes

The tubes are filled with water once and remain closed thereafter, so that no evaporation can take place (Figure 3). The volume of water in the tubes is selected to correspond to a water layer with a depth of 5 to 20 cm depending on the desired power output characteristics (Figure 4).

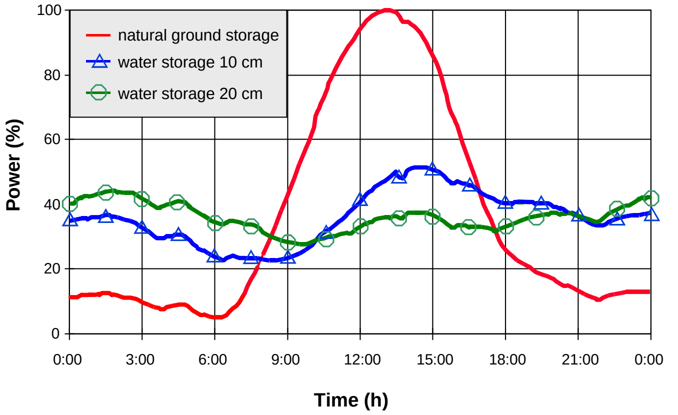


Figure 4. Effect of heat storage underneath the collector roof using water-filled black tubes.

Since the heat capacity of water (4.2 kJ/kg) is much higher than that of soil (0.75 – 0.85 kJ/kg) the water inside the tubes stores a part of the solar heat and releases it during the night when the air in the collector cools down. This enables the plant to run for 24h per day on pure solar energy.

2.3.3 Tower

The tower itself (Figure 5) is the plant's actual thermal engine. It is a pressure tube with low friction loss (like a hydro power station pressure tube or pen stock) because of its favorable surface-volume ratio. The updraft of the air heated in the collector is approximately proportional to the air temperature rise (ΔT) in the collector and to the height of the tower. In a large solar updraft tower the collector raises the air temperature by about 30 to 35 K. This produces an updraft velocity in the tower of about 15m/s at full load. It is thus possible to enter into an operating solar tower power plant for maintenance without danger from high air velocities.

2.3.4 Turbines

Using turbines, mechanical output in the form of rotational energy can be derived from the air current in the tower. Turbines in a solar updraft tower do not work with staged velocity like a free-running wind energy converter, but as a shrouded pressure-staged wind turbo generator, in which, similarly to a hydroelectric power station, static pressure is converted to rotational energy using a cased turbine. The specific power output (power per area swept by the rotor) of a shrouded pressure-staged turbine in the solar updraft tower is roughly one order of magnitude higher than that of a velocity staged wind turbine. Air speed before and after the turbine is about the same. The output achieved is proportional to the product of volume flow per time unit and the pressure differential over the turbine. With a view to maximum energy yield the aim of the turbine control system is to maximize this product under all operating conditions.

Figure 5. Tower tube of a solar updraft tower power plant.

To this end, blade pitch is adjusted during operation to regulate power output according to the altering airspeed and airflow. If the flat sides of the blades are perpendicular to the airflow, the turbine does not turn. If the blades are parallel to the air flow and allow the air to flow through undisturbed there is no drop in pressure at the turbine and no electricity is generated. Between these two extremes there is an optimum blade setting: the output is maximized if the pressure drop at the turbine is about 80 % of the total pressure differential available, depending on weather and operating conditions as well as on plant design.

3 HISTORY – MANZANARES AND THEREAFTER

Based on detailed theoretical preliminary research and a wide range of wind tunnel experiments Schlaich Bergermann has designed, constructed and operated an experimental plant with a peak output of 50 kW on a site made available by the Spanish utility Union Electrica Fenosa in Manzanares (about 150 km south of Madrid) in 1981/82 (Figure 6), with funds provided by the German Ministry of Research and Technology (BMFT).

Figure 6. Prototype of the solar updraft tower at Manzanares, Spain

The aim of this research project was to verify, through field measurements, the performance projected from calculations based on theory, and to examine the influence of individual components on the plant's output and efficiency under realistic engineering and meteorological conditions.

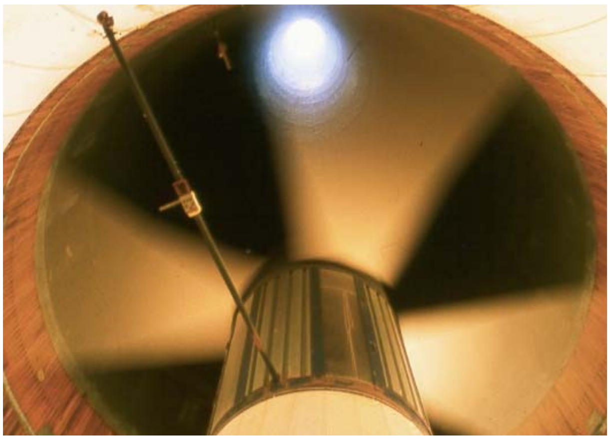


Figure 7. Turbine of the prototype plant

Figure 8. Glass roof of the prototype plant

Figure 9 presents a comparison between the measured and calculated average monthly energy outputs, showing that there is good agreement between the theoretical and measured values. Overall, it may be said that the optical and thermodynamic processes in a solar updraft tower are well understood and that models have attained a degree of maturity so that they accurately reproduce plant behavior under given meteorological conditions.

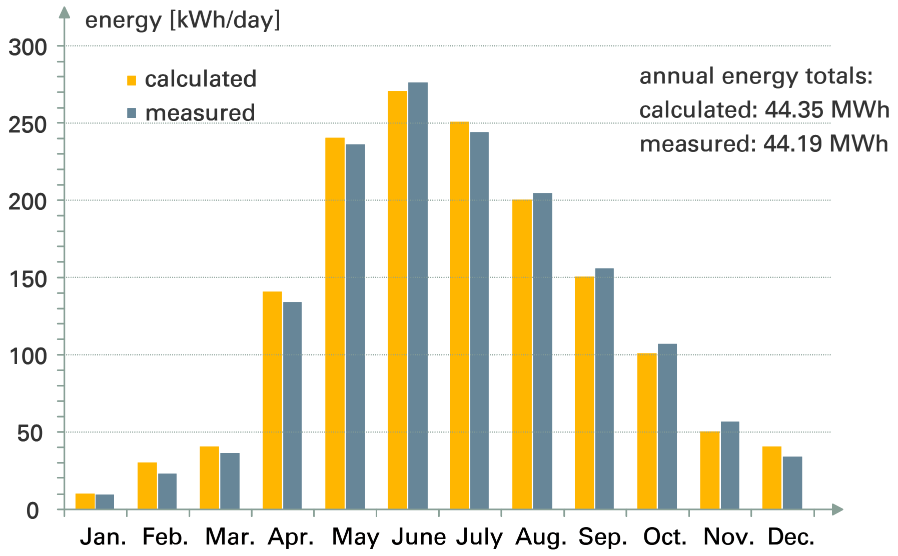


Figure 9. Comparison of measured and calculated monthly energy outputs for the Manzanares plant.

4 COMMERCIAL SOLAR UPDRAFT TOWER POWER PLANTS

4.1 General system advantages

Apart from working on a very simple principle, solar updraft towers have a number of special features:

1. The collector can use all solar radiation, both direct and diffuse. This is crucial for tropical countries where the sky is frequently overcast.

2. Due to the soil under the collector working as a natural heat storage system, solar updraft towers will operate 24 h on pure solar energy, at reduced output at night time. If desired, additional water tubes or bags placed under the collector roof absorb part of the radiated energy during the day and release it into the collector at night. Thus solar updraft towers can operate as base load power plants. As the plant's prime mover is the air temperature difference (=air density difference) between the air in the tower and ambient air, lower ambient temperatures at night help to keep the output at an almost constant level even when the temperature of natural and additional thermal storage also decreases without sunshine, as the temperature *difference* remains practically the same.

3. Solar updraft towers are particularly reliable. Turbines and generators - subject to a steady flow of air - are the plant's only moving parts. This simple and robust structure guarantees operation that needs little maintenance and of course no combustible fuel.

4. Unlike conventional power stations (and also some other solar-thermal power station types), solar updraft towers do not need cooling water. This is a key advantage in the many sunny countries that already have major problems with water supply.

5. The building materials needed for solar updraft towers, mainly concrete and glass, are available everywhere in sufficient quantities. In fact, with the energy taken from the solar tower itself and the stone and sand available in the desert, they can be reproduced partly on site.

6. Solar updraft towers can be built now, even in less industrially developed countries. The industry already available in most countries is entirely adequate for solar updraft tower requirements. No investment in high-tech manufacturing plants is needed.

7. Even in less developed countries it is possible to build a large plant without high foreign currency expenditure by using local resources and work-force; this creates large numbers of jobs while significantly reducing the required capital investment and thus the cost of generating electricity.

Nevertheless, solar updraft towers also have some features that make them less suitable for some sites: They require large areas of flat land. This land should be available at low cost, which means that there should be no competing usage, like e.g. intensive agriculture for the land. The siting of the solar updraft tower has to be carefully considered in extremely earthquake prone areas.

4.2 Scale-Up

Detailed investigations, supported by extensive wind tunnel experiments, show that thermodynamic calculations for collector, tower and turbine are very reliable for large plants as well.

Despite considerable area and volume differences between the Manzanares pilot plant and a projected 100 MW facility, the key thermodynamic factors are of similar size in both cases. Using the temperature rise and air velocity in the collector as examples, the measured temperature rise at Manzanares was a daily average of 8 K, wind speed was average 4 meters per second, while the corresponding calculated average figures for a 100 MW facility are 11 K and 9 meters per second.

Therefore measurements taken from the experimental plant in Manzanares and solar updraft tower thermodynamic behavior simulation codes are used to design large plants with an output of up to 200 MW.

In this way the overall performance of the plant, by day and by season, given the pre-scribed plant geometry and climate, considering all physical phenomena including single and double glazing of the collector, heat storage system, and pressure losses in collector, tower and turbine, can be calculated rather accurately.

4.3 Optimisation

Electricity yielded by a solar updraft tower is in proportion to the intensity of global solar radiation, collector area and tower height. There is in fact no optimum physical size for such plants. Optimum dimensions can be calculated only by including specific component costs (collector, tower, turbines) for individual sites. And so plants of different optimum key dimensions will be built for different sites - but always at optimum cost: if collector area is cheap and concrete expensive then the collector will be large and the tower relatively small, and if the collector is expensive there will be a smaller collector and a tall tower.

To give an overview, typical dimensions for selected solar updraft tower capacities are given in Table 1. The numbers are based on typical material and construction costs.

Table 1. Typical Dimensions and Electricity Output

Capacity		50 MW	100 MW	200 MW
tower height	m	750	1000	1000
tower diameter	m	90	110	120
collector diameter	m	3750	4300	7000
electricity output at 2300 kWh/(m²yr)[A]	GWh/a	153	320	680
electricity output at 1800 kWh/(m²yr)[B]	GWh/a	120	250	532

[A] Annual global horizontal solar radiation of 2300 kWh/(m²a), a value found at the best sites worldwide
[B] Annual global horizontal solar radiation of 1800 kWh/(m²a), a typical value for Spain

Table 2. Investment Cost and Electricity Cost

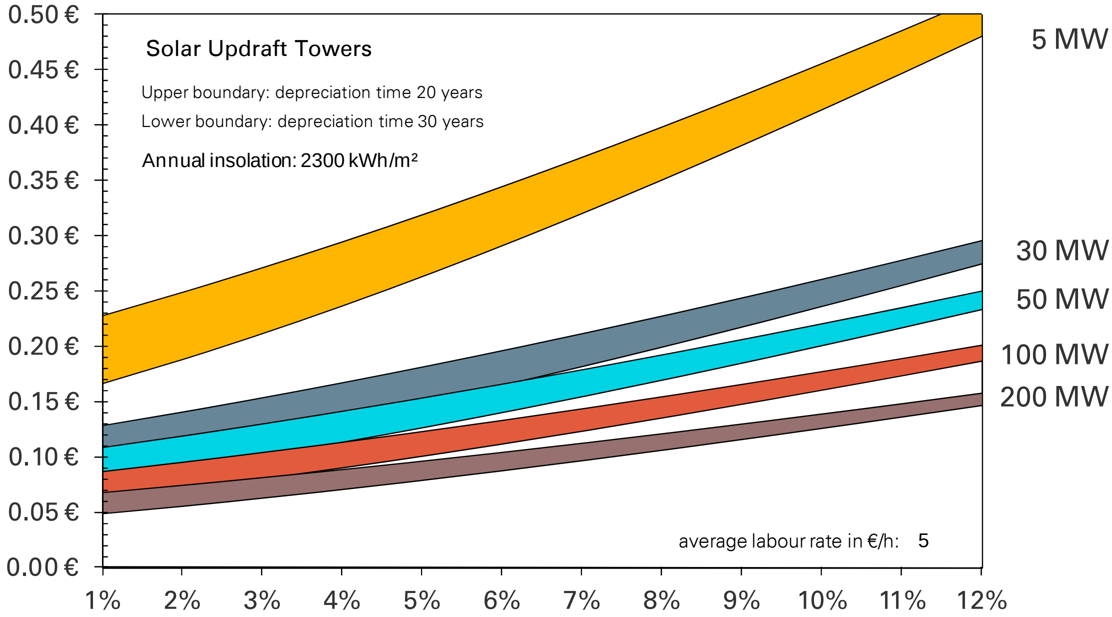
Capacity		50 MW	100 MW	200 MW	
Tower cost	Mio. €	72	176	192	192
Average labor cost for collector construction		18 €/h	18 €/h	18 €/h	5 €/h
Collector cost	Mio. €	142	189	474	390
Turbine cost incl. housing	Mio. €	56	83	146	146
Engineering, tests, misc.	Mio. €	32	51	53	53
Total investment cost	Mio. €	302	499	865	781
Annuity on investment	Mio. €/a	28.3	46.7	81	73.2
Annual operation & maintenance cost	Mio. €/a	1.6	2.3	3.8	3.2
Electricity cost at 2300 kWh/(m²yr) [A]	€/kWh	0.19	0.15	0.12	0.11
Electricity cost at 2300 kWh/(m²yr) [B]	€/kWh	0.15	0.12	0.10	0.09
Electricity cost at 1800 kWh/(m²yr) [A]	€/kWh	0.25	0.20	0.16	0.14
[A] assuming weighted average cost of capital of 8 % and a depreciation time of 25 years [B] assuming weighted average cost of capital of 5 % and a depreciation time of 25 years					

4.4 Electricity Generation Costs

Based on specific costs and the dimensions from Table 1, investment costs were calculated. For the 50 MW solar updraft tower investment costs of 302 M€ are estimated (see Table 2).

With the respective annual energy outputs from simulation runs, electricity costs (EC) are calculated using weighted average cost of capital (WACC) of 8% and a depreciation time of 25 years. Results are shown in Table 2 for a 50 MW, a 100 MW and a 200 MW power plant. For all plants two generic reference sites are considered with an annual insolation of 1800 and 2300 kWh/(m²yr) respectively, to show the effect of this important site characteristic (bottom rows of Table 1 and Table 2). For the 200 MW solar updraft tower there is an additional column to the very right with data assuming average labor cost of 5 €/h, as compared to the value of 18 €/h being used before. An average labor cost for collector construction of 5 €/h, or even significantly below, can be expected in low wage countries like, e.g., in North Africa, India, Mexico or China (cf. chapter 4.5 'The Market for Solar Updraft Towers').

From Table 2 and Figure 10 it becomes obvious that with increasing plant size, a significant reduction of electricity generation cost is associated, leading to EC of 0.12 €/kWh for a 200 MW plant at a high-insolation site, with a further reduction in low wage countries of about one €-Cent (see examples given in Table 2).



Non-energy revenues are not included.

Figure 10. Levelized Electricity Costs vs. weighted average cost of capital for solar updraft towers (high insolation, low labor cost country)

The financial parameters 'weighted average cost of capital' (WACC) and depreciation time are varied to illustrate their influence (Figure 10). The upper boundary was calculated for a depreciation time of 20 years, the lower boundary for 30 years. As expected, electricity generating costs of the capital intensive solar updraft towers are dominated by WACC. Depreciation time has a significant influence, too. Assuming WACC of, e.g., 12 % and a depreciation time of 20 years leads to EC of 0.16 €/kWh for the 200 MW system at a location with 2300 kWh/(m²yr) of global solar radiation and average collector labor costs of 5€/h. When, e.g. by clever financial engineering, WACC of 5% and a depreciation time of 30 years are achieved, EC drop to 0.8 €/kWh, i.e. half the formerly calculated value.

4.5 The Market for Solar Updraft Towers

According to the reference scenario of the latest IEA World Energy Outlook, world electricity demand will grow at an average annual rate of 2.5% to 2030. Hence about 4800 GW of new capacity between now and 2030 are needed to meet the projected increase in electricity demand and to replace ageing infrastructure[2]. In this gigantic market, Solar Updraft Towers have to compete against conventional power plants and against other types of solar power plants as well. According to the reference scenario, the use of non-hydro modern renewable energy technologies (including solar) sees the fastest rate of increase until 2030: The share of non-hydro renewables in total power output rises from 2.5% in 2007 to 8.6% in 2030.

4.5.1 Areas with sufficiently high solar radiation

Many areas and countries in the sun belt of the earth, i.e. the zone about 35° north and south of the equator, are suitable for solar updraft towers. As a rule of thumb, annual global horizontal radiation should equal or be higher than 1800 kWh/m². Thus all areas marked in orange, yellow or magenta on the map in Figure 11 are suitable.

[2] See IEA World Energy Outlook 2009 Executive Summary, page 4

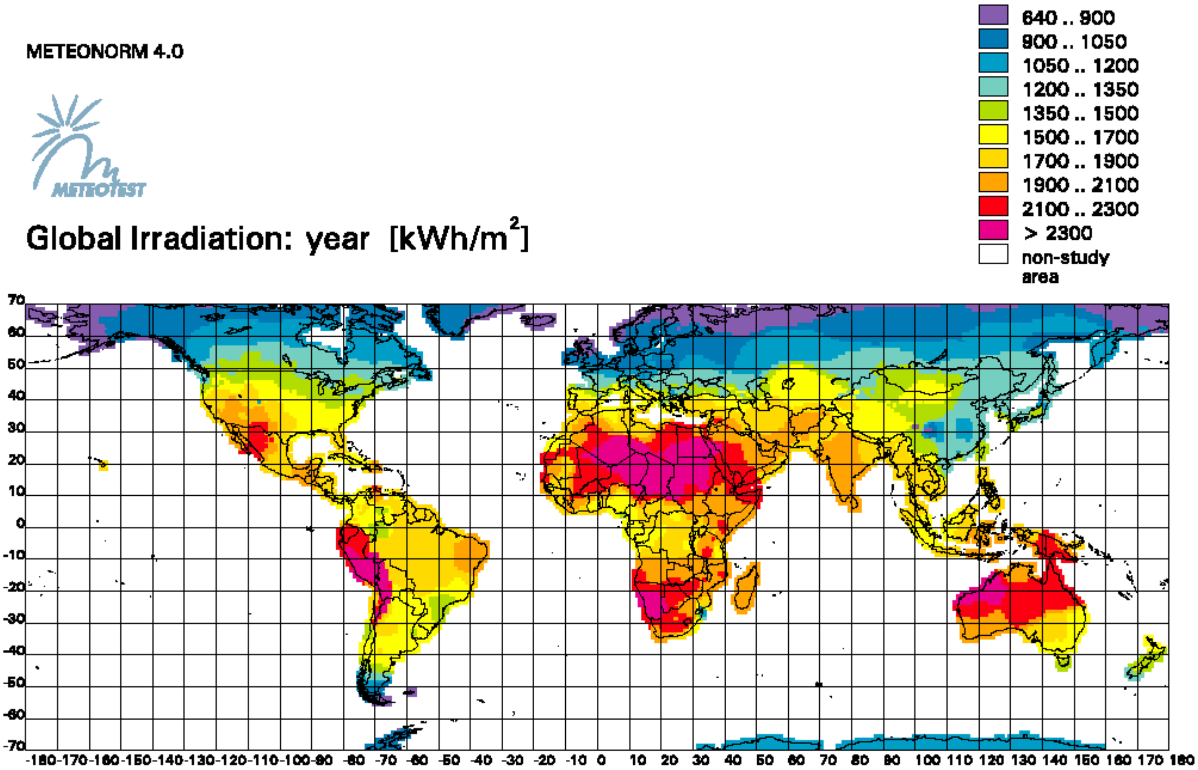


Figure 11: Solar radiation world map (Source: Meteotest, Switzerland)

4.5.2 Conventional Competitors: Fossil-fuelled power plants

Today, most of world electricity is produced in power plants utilizing fossil fuels. Increasing demand and the fact that fossil resources are limited result in rising, unstable, and often unpredictable fossil fuel prices. Moreover, due to growing concern about the consequences of carbon dioxide emissions, renewable energies play an increasingly important role in current energy policy.

Still, fossil fuels remain the dominant sources of primary energy worldwide in the IEA reference scenario, accounting for more than three-quarters of the overall increase in energy use between 2007 and 2030. Even though its share drops, oil remains the single largest fuel in the primary fuel mix in 2030.

4.5.2.1 Oil-Fired Power Plants

Figure 12 shows electricity generation costs for oil-fired power plants as a function of oil price and plant efficiency. Not quite surprisingly, electricity costs rise linearly with oil price. Even for moderate oil prices of, say, 70 US$/barrel and a plant efficiency of 35%, electricity costs for the oil fired power plants are about the same as for a 200 MW Solar Updraft Tower at a very sunny location, even at average labor cost of 18€/h. In other words, compared to an oil-fired power plant, **the 200 MW Solar Updraft Tower is competitive even today**.

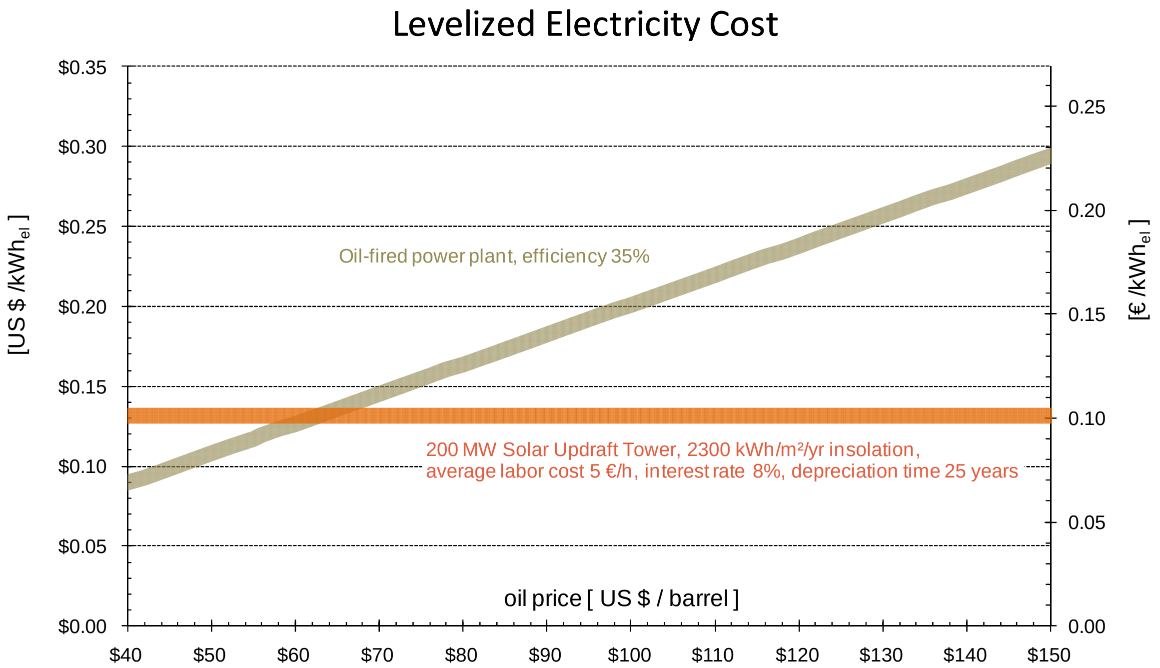


Figure 12: Electricity Cost for Oil-Fired Power Plants and Solar Updraft Towers

4.5.3 Renewable Competitors: Parabolic Trough Power Plants, Power Towers and Linear Fresnel Systems

Current Situation. In the US, parabolic trough power plants operate successfully since the 1980ies. Installed capacity in the Mojave desert in California is 354 MW. Additional plants have been constructed in Nevada (64 MW) and Arizona (1 MW) lately, while new projects with individual capacities in the 200MW range have been announced.

Power tower systems are being promoted by Brightsource and eSolar: In June 2008, BrightSource has commissioned a 4 to 6 MW pilot plant in the Negev desert in Israel. Currently it is developing its first commercial solar power complex, located in Ivanpah, approximately 50 miles northwest of Needles, California. Planned final capacity is up to 440 MW.

ESolar realized the 5 MW Sierra Sun Tower in California, the only operating power tower plant in the US, and now plans to deploy its technology worldwide.

Ausra is promoting linear Fresnel systems in the US. The 5 MW Kimberlina power plant has already been built and is operational, and an application for certification (AFC) has been filed for the 177 MW Carizzo Energy Solar Farm.

Dish/Stirling systems are being developed and promoted by Tessera Solar and Infinia. Both companies built first demonstration units. Infinia announced to start large-scale series production in 2011.

As of today, in Spain about 2.3 GW of solar thermal power plant capacity have been approved under the favorable feed-in tariff and are under construction, or already operational (~700 MW). The majority of these plants are of the parabolic trough type with a capacity of 50 MW each. Two Power Tower systems, PS-10 and PS20, with a combined capacity of 31 MW, are already operational, a third power tower, Gemasolar, is under construction. One linear Fresnel pilot plant, Puerto Herrado I developed by Novatec-Biosol, is operational. It has a capacity of 1.4 MW; the next step for this technology will be the 30 MW system Puerto Herrado. Moreover, a small number of Dish/Stirling systems is being operated in Spain. A 10 kW EuroDish-system designed by Schlaich Bergermann was the first to generate electricity under the successful Spanish feed-in tariff.

Assessment. Parabolic Trough systems are a proven technology. This is a prerequisite for support by the Global Environmental Facility (GEF). The GEF, established in 1991, is an independent financial organization that provides grants to developing countries for projects and programs that benefit the global environment. The GEF supports solar thermal power generation projects in Brazil, Egypt, India, Mexico and Morocco[3], all of the parabolic trough type.

Power Towers have been of scientific interest throughout the last decades. Now they are poised on the verge of commercialization. The important step of first smaller scale systems has been taken in Spain and in the US. Different approaches are being followed. The next years will be critical. It remains to be seen if power towers can achieve the commercial breakthrough that has been prophesized for many years due to their potentially high thermodynamic efficiency.

Promoters of Linear Fresnel systems claim that due to the simpler collector design, Fresnel systems are prone to be more cost efficient. On the other hand, as a consequence of its significantly lower optical efficiency, a linear Fresnel collector may cost only about half of a parabolic trough collector per square meter of aperture area in order to achieve real cost parity.

Dish/Stirling systems can achieve high efficiencies. They are modular and therefore also suitable for small scale installations in the kilowatt range, but can also be used for large power plants and should then profit from economies of mass production. Apart from cost reduction, a quite universal task, the special challenge here is to achieve the low operation & maintenance cost and thus high reliability required.

The trough design developed by Schlaich Bergermann has been selected for the majority of the Spanish power plants. They also successfully developed their own dish/Stirling systems as well as the tracker and concentrator for Infinia Corp. Moreover, they developed and built innovative heliostats with excellent optical quality for central receiver systems. Therefore Schlaich Bergermann is familiar with the whole range of solar thermal electricity generation technologies.

According to their calculations, the Solar Updraft Tower is the most cost effective way to generate solar electricity. This is substantiated also by the numbers calculated and published by others: The California Energy Commission e.g. found levelized electricity costs of 21.53 US-Cent for parabolic trough power plants under Californian conditions[4], substantially more than the cost we calculated for a 200 MW solar updraft tower under solar radiation conditions comparable to California (see Table 2).

4.5.4 Expected Market Development

We expect that the Solar Updraft Tower market will develop as follows

- First Southern European countries with subsidies, namely Spain. Then
- California and the Southwestern States of the US. Thereafter
- North Africa and the
- Rest of the world’s sun belt.

Spain. The next step from the successful operation of the solar updraft tower prototype in Manzanares to a proven commercial technology will, most likely, also be taken in Spain due to the very favorable conditions there. Most important are the high solar insolation and the feed-in tariff. In the past, over 29 €-Cent per kWh have been guaranteed for 25 years. The revised and reduced feed-in tariff is likely to be introduced in 2011. Thus, for the solar updraft tower, revenues in the range of 24 to 26 €-Cent can be expected.

Other European Countries. Countries like Greece, Italy, Portugal and France are following the Spanish feed-in tariff example.

California and the other Southwestern States of the US. There are several factors that make a positive market development for the Solar Updraft Tower very likely there:

- Electricity demand is rapidly growing.

[3] See www.solarpaces.org => projects
[4] See http://www.energy.ca.gov/electricity/levelized_cost.html

- State policies target at reducing dependence from fossil fuels and at reducing CO_2-emissions. This is reflected by tax credits and Renewable Energy Portfolio Standards.
- There is already a track record of solar thermal electricity: The SEGS parabolic trough plants in the Mojave desert.
- Daily and seasonal electricity demand and electricity production of solar updraft towers nicely match due to the fact that demand (from air-conditioning) peaks in the afternoon when the solar updraft towers without additional storage also produce most electricity.

North Africa. North African countries like Algeria, Egypt, Libya and Morocco are already active in the field of large-scale solar power generation. Morocco and Egypt applied for a GEF grant to support their solar activities. The power plant Kuraymat in Eqypt started operation in 2010. The projects in Algeria (Hassi R'Mel) and Morocco (Ain Beni Mathar) will follow.

At present, because only parabolic troughs are considered a proven technology by the Word Bank's GEF, there is no alternative to this technology for countries working with the GEF. As soon as solar updraft towers are accepted as proven technology, this technology that allows for a much higher local scope of supply will be very attractive to North African countries. Algeria had issued a request for proposal independently of the GEF, nevertheless, only proposals based on a proven technology shall be accepted for the time being.

North Africa is a promising region for solar updraft towers also because, apart from producing electricity for local demand, electricity can be exported from Africa to Europe, too. The required grid connection partially exist (links from Morocco to Spain) or will be built soon (begin of construction of a connection from Tunisia to Sicily is scheduled for 2011). Additionally, the DESERTEC project, if realized, will implement a high capacity high voltage direct current grid around the Mediterranean, including east-west and south-north links.

Rest of the world's sun belt. The rest of the world's sunbelt will follow thereafter as soon as solar thermal electricity in general and solar updraft towers in particular have been established as standards. Countries who are already active in the field of solar thermal electricity like the members of the IEA-SolarPACES[5] organization are likely to be the forerunners in this group. Australia, Brazil, Mexico and Iran are candidates.

4.6 Summary and Conclusions

Fossil fuel prices will continue to rise, as resources are limited and demand is rising rapidly. Solar Updraft Towers today are already directly competitive with oil-fired power plants. Due to rising costs for all fossil fuels including natural gas, they will soon be also competitive with natural gas fired combined cycle plants. The need for carbon-free environmentally benign power generation technologies will further boost the demand for solar power plants.

[5] See http://www.solarpaces.org