Solar Updraft Towers:
Their Role in Remote On-Site Generation

(Schlaich et al. 2005)

10.391 Final Project
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April 29, 2008

Introduction

Solar insolation is the most abundant source of constantly replenishing energy. Many renewable energy generation methods directly harness solar radiation. The broad category of solar-thermal technologies uses solar radiation as a source of heat to drive a heat engine.

Solar updraft towers use solar radiation to create a convection-driven updraft current that powers a turbine. Air is heated in a greenhouse-like structure and directed up a chimney or tower, where the buoyancy-based pressure difference drives the air across a turbine or array of turbines. A basic schematic is shown in Figure 1. The simplicity of solar updraft towers, their lack of moving parts and expensive materials, and their ability to utilize diffuse or indirect solar radiation present a contrast to other solar-thermal technologies.

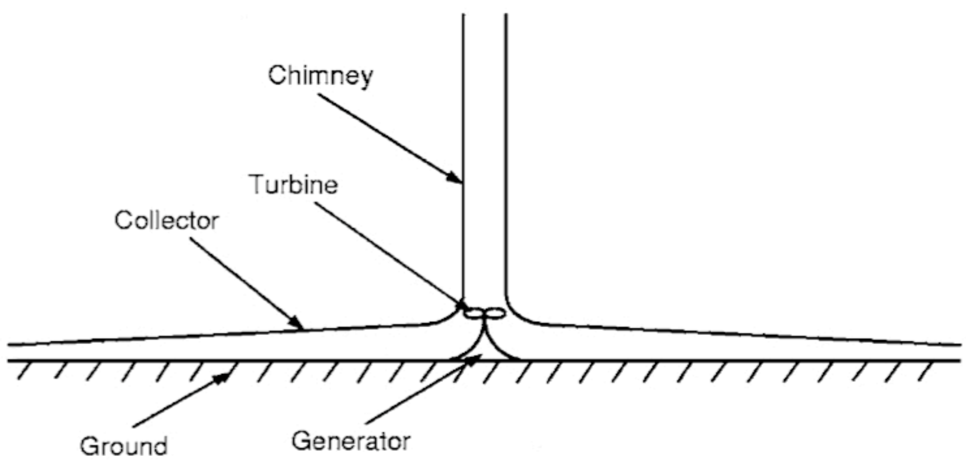

Figure 1: General diagram of solar updraft tower (Pretorius 2006).

Solar updraft towers have been well studied, but have not yet been widely built. Studies have explored the conversion efficiencies of the individual components (Gannon 2003, von Backstrom 2003) and the overall plant efficiencies (Gannon 2000, Pretorius 2007), as well as various plant configurations (Kreetz 1997). The only large-scale solar updraft tower built was erected in Manzanares, Spain, in 1982. The plant operated for approximately 8 years, and provided a body of technical knowledge (Schlaich 1995, Haaf 1983, Haaf 1984) that has been used to verify and further theoretical models of solar updraft tower performance.

Problem Statement

Solar updraft towers provide another renewable power option for areas that are good candidates for solar concentrating or solar photovoltaic power generation facilities. Proposed projects have typically focused on large towers in countries with well-developed energy infrastructures. This paper focuses on the potential for the use of small-scale solar updraft towers in remote, less developed regions. This paper describes the power generation principles of solar updraft towers, their construction and operation, the technological challenges facing solar updraft towers, and cost factors in the construction and operation of solar updraft towers with a focus on their application to small-scale plants in developing countries. Previous studies focusing on this issue are discussed, and the advantages and disadvantages of solar updraft towers are compared with competing solar technologies.

Functional Principles

Two basic principles are behind power generation in solar updraft towers, the greenhouse effect and buoyancy-driven flow. Solar irradiation passes through the glass of the collector, is absorbed by the ground below, and re-emitted to the air under the greenhouse. Convective effects from the ground also account for some of the air heating. The high-temperature, lower density air is funneled toward the tower. The buoyancy of the air creates a pressure difference in the column of the tower, driving the air from the base of the tower to its upper outlet. The kinetic energy of the air is captured by the turbine system, which is typically located at the base of the tower.

Components

The three primary components of a solar updraft tower are the solar collector, the tower or chimney, and the turbine. The following sections describe the important components, their role in the tower, and their materials and construction.

Collector

The solar tower uses a greenhouse-like collector to heat the air that drives the power plant. The collector surface gradually rises closer to the tower, to direct the heated air towards the tower, then curves up sharply at the base of the tower in order to transition the air flow up the tower. The tower material can be any glass-like material, with high transparency to the solar spectrum but with low transparency to the infrared radiation emitted from the warmed ground.

The collector of the prototype plant built at Manzanares is shown in Figure 2. The Manzanares plant’s collector was constructed from a combination of glass and plastic materials, designed to explore the durability and effectiveness of a variety of materials. The glass panes were spaced on a 1m by 1m lattice, and the plastic sections were arranged in 6m by 6m sections. The shape of the collector is typical of solar updraft tower design. The outer edge of the collector is roughly 2 meters off the ground.

Figure 2: The collector at the Manzanares plant in Spain (Schlaich 2005).

The Manzanares plant provided a useful evaluation of the performance of the greenhouse. The roof proved to be insensitive to dust accumulation, with the infrequent rains in the area providing sufficient for self-cleaning (Schlaich 1995). The durability of the glass roof proved to be exceptional, with none of the panes from the collector of the test plant broken during the seven years of operation, while some portions of the plastic roof ripped as early as the first year of operation.

An additional benefit of the collector is that the ground area under the collector can be used as a greenhouse for growing plants or as a drying area for plant material.

Chimney

The chimney (or tower) of a solar updraft tower is the thermal engine of the plant. The heated air from the collector is funneled into the chimney, where the buoyancy difference between the heated air and the surrounding atmosphere creates a pressure difference that drives the air up the chimney.

Several factors contribute to the physical design of the chimney. The chimney should be designed to minimize the frictional losses and to maximize the pressure difference in the tower. The pressure difference in the tower is proportional to its height, so maximizing the height of the tower is critical to improving the efficiency of the tower. Schlaich suggests that reinforced concrete would be a cost effective way to create a stable tower with a lifespan of up to 100 years (Schlaich 1995). Other possible construction options include reinforcing frames covered in various membranes, including cable-net or corrugated sheet, and supporting guy wires. The prototype plant at Manzanares was constructed as a framed, guyed tower, approximately 195 m tall and 10 m in diameter, covered with corrugated sheeting approximately 1.25 mm thick. The tower was erected without any large equipment; the tower was hydraulically lifted from below as each 4 m tall segment was placed under the tower and attached to the existing structure.

Turbine

The solar thermal updraft tower uses a turbine or array of turbines to generate power. The turbine or turbines operate as cased pressure-staged generators, similar to a hydroelectric plant. Turbines are placed near the bottom of the tower, for ease of access for maintenance and easy connection to the generating equipment. A single turbine can be mounted on vertical axes inside the chimney, while multiple turbines can be placed either in the chimney or in the transition area between the chimney and collector, as shown in Figure 3.

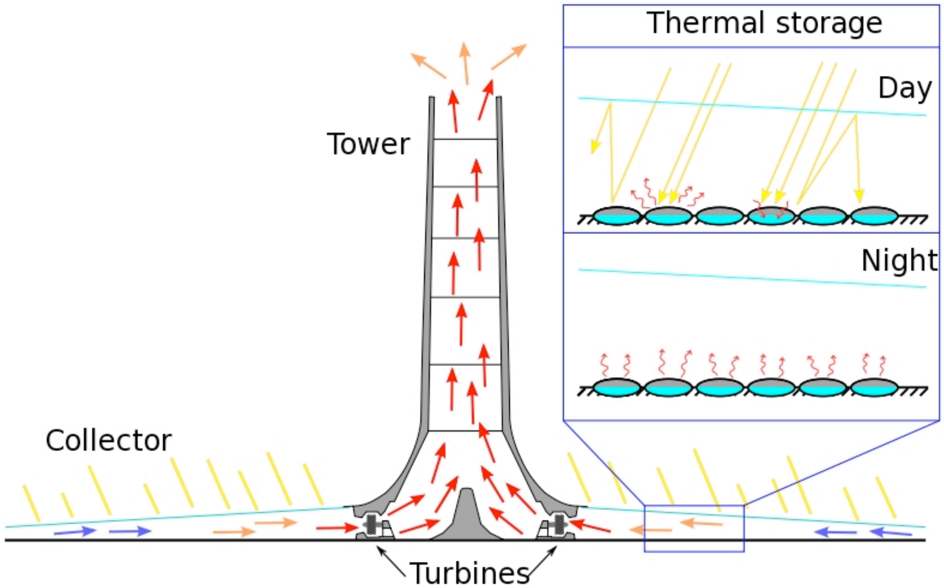

Figure 3: Schematic of a tower with horizontally mounted turbines (http://commons.wikimedia.org/wiki/Image:Solar_updraft_tower.svg).

The turbines are subjected to relatively steady airflow compared to those of wind generator plants, and thus subject to less physical stress. The blades of the turbine feather to adjust to different levels of airflow and pressure drop. As the only component of the system with moving parts, the turbine's reliability is critical. The manufacturer examined the turbine from the Manzanares power plant; it showed little wear after seven years of almost continuous operation (Schlaich 1995).

Governing Equations

The power output of the tower is directly related to the input power and the efficiencies of each component. That is,

$$P = \dot{Q}_{solar}\eta_{coll}\eta_{turbine}\eta_{chi}\eta_{tower}$$

where $\dot{Q}_{solar}$ is the power input from solar radiation, and each η represents the efficiency of each component, with the last efficiency being for the tower as a whole. The product of the efficiencies determines the overall efficiency of the plant.

The power output of the plant is dependent on two physical properties of the plant, the area of the collector and the height of the tower. The solar input to the plant is proportional to the area of the collector, while the efficiency of the tower is dependent on its height. The other efficiencies of the tower are not dependent on the conceptual design of the tower.

The solar energy input into the system is dependent on the area of the collector and the solar insolation onto the collector, where G is the normalized solar insolation:

$$\dot{Q}_{solar} = G \cdot A_{coll}$$

The efficiency of the tower is dependent on its height. The tower efficiency can be described by

$$\eta_{tower} = \frac{P}{\dot{Q}}$$

The power from the flow is dependent on the pressure drop in the tower. The power contained in the flow is

$$P = \Delta p \cdot v_{max} \cdot A_{coll}$$

The pressure change in the tower is related to the buoyancy change in the heated air. The air column in the tower creates the pressure difference driving the flow.

$$\Delta p = (\rho_{atm} - \rho_{tower})gH$$

Without a turbine in the tower, all the pressure difference in the tower is converted to velocity. The power contained in the flow is then

$$P = \frac{1}{2}\dot{m}v_{max}^2$$

We can equate the two expressions for the power in the flow to find the velocity in the flow.

$$v_{max} = \sqrt{2gH\frac{(\rho_{atm} - \rho_{tower})}{\rho}}$$

Using the Boussinesq approximation and the ideal gas law, the expression for the maximum velocity simplifies to

$$v_{max} = \sqrt{2gH\frac{\Delta T}{T_0}}$$

Combining this with our second expression for the power contained in the flow, we can find that the efficiency of the tower is

$$\eta_{tower} = \frac{gH}{c_p T_0}$$

Theoretical Power Output

Based on the equations developed in the previous sections, the total power generated by the tower is

$$P = GA_{coll}\frac{gH}{c_p T_0}\eta_{coll}\eta_{turbine}\eta_{chi}$$

Thus, the power generated by the tower is proportional to the area of the collector and the height of the tower. An easy way to think about this is that the power is proportional to the volume of the cylinder with a base the size of the collector and a height equal to that of the chimney, as shown in Figure 4.

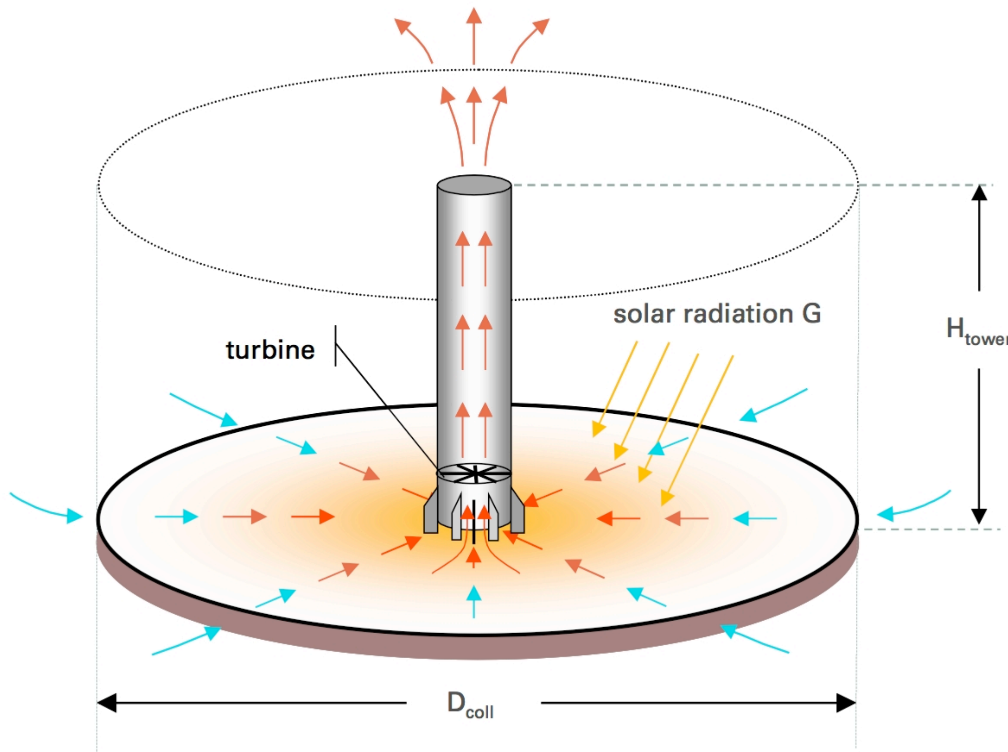

Figure 4: Power output is proportional to the cylinder shown (Schlaich 2005).

The ability of the tower to convert the input solar insolation is the product of the efficiencies of each of the components and the efficiency of the tower overall. Assuming that the efficiencies of the individual components are high, the efficiency of the solar updraft tower is directly tied to the tower efficiency. As stated in the previous section,

$$\eta_{tower} = \frac{gH}{c_p T_0}$$

Evaluating for typical conditions, where c_p=1012 J/kg-K, T_0=300 K, and g=9.8 m/s^2, we find that the tower efficiency is roughly 0.000032 H. With the other efficiencies near one, this gives

$$\eta_{overall} = 0.000032H$$

A very tall tower is required to achieve even a modest tower efficiency. For example, a 1000 meter tall tower is required to achieve an efficiency of about 3%.

Limitations and Losses

In addition to the major effects of the dimensions of the solar updraft tower, minor losses also play a role in overall tower efficiency. Each component will have associated losses.

The collector has many associated minor losses. One important source of loss is the ability of the collector to effectively capture and retain solar energy. The roofing material is the significant factor for this issue. Due to the greenhouse-like strategy, it's desirable to have the material be highly transparent to solar radiation, highly reflective to the heat re-radiated by the ground under the collector, and highly insulating. Materials that come close to fulfilling all three requirements are typically not a good choice economically. For example, insulated glazing units would be a good material choice for the collector, but they are significantly more expensive per unit area than single-paned glass. Another source of loss in the collector is friction losses. Typically, the supports for the collector are thin and widely spaced, and the losses associated with them and drag from the collector and ground relatively low compared to the heat loss issues. The chimney can also have associated friction losses, but again, the losses associated with the drag in the chimney are minor.

The turbine presents two types of loss, the loss from the turbine itself, and the loss due to the turbine’s impediment to the flow. The maximum power is achieved when the pressure drop at the turbine is two thirds of the total pressure difference available (Schlaich 1995). Thus, the efficiency of the turbine is at best 67%. The loss associated with the turbine itself can be similar to that from a cased hydroelectric turbine, possibly better than 90%. Including the pressure loss at the turbine, the power output of the solar updraft tower can be expressed as

$$P = GA_{coll}\frac{2}{3}\frac{gH}{c_pT_0}\eta_{coll}\eta_{turbine}\eta_{chi}$$

where each η represents the minor losses associated with each component that are variable based on the construction of the tower, rather than the physical design and scale of the tower.

Technological Challenges

Solar thermal updraft towers combine three mature technologies that are affordable and realizable today. The solar thermal updraft tower does not require any consumable resources and very little external support and maintenance. The technological challenges associated with solar thermal updraft towers are mostly related to performance. The production curve of a solar thermal tower is relatively smooth on a short-term basis due to the effects of the thermal mass contained in the ground under the collector and the bulk of the flow, but a solar updraft tower does not produce power steadily during the diurnal cycle. The tower's production depends on input solar energy, so most power is produced during the day at periods of peak irradiation. The greatest challenge for solar updraft towers is producing power that corresponds with the demand curve.

Energy Storage

Energy storage in the collector has been explored as a method for re-shaping the power output profile of a solar updraft tower. The most commonly suggested method for creating energy storage is to place extra thermal mass under the collector in the form of black containers of water (Kreetz 1997). Figure 3 shows the storage located under the collector. As shown in Figure 5, the extra thermal mass evens out the power output profile. The level of storage used can be adjusted to create a power profile with similar characteristics to the demand profile.

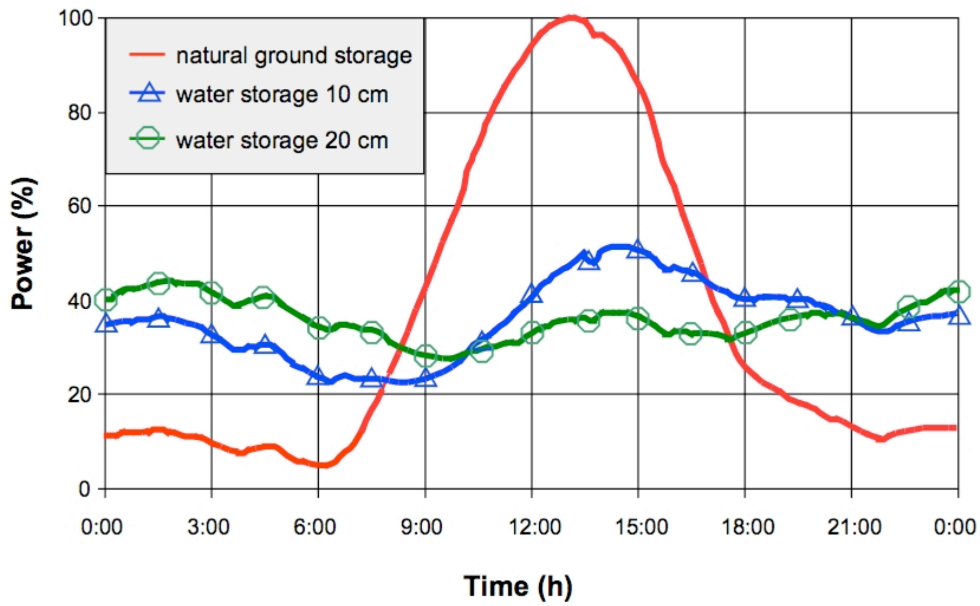

Figure 5: Effect of energy storage mechanisms on power output (Kreetz 1997).

Lessons from Manzanares

The test facility at Manzanares provided most of the existing practical data on the construction and operation of a solar updraft tower. In addition to providing data on the construction and material choices for solar updraft towers as described in previous sections, the facility also provided extensive operational data that has been used to construct computer performance models. The model allows the results from the Manzanares text plant to be generalized to other geographic areas with differing levels of solar insolation and thermal storage mass. The operational lessons taught by the tower have also proven that the towers are reliable and require very few personnel for regular operation.

Cost Evaluation

The main cost of a solar updraft tower is in its construction. Operation and maintenance are minimal, with experiences at Manzanares suggesting that the cost of maintenance per installed capacity much lower than that of most other renewables, including wind, geothermal, and conventional solar thermal plants. The cost evaluations presented in this section primarily consider the construction costs for solar updraft towers.

Cost of Existing Installation

The power plant at Manzanares cannot be used as a basis for cost estimates. The structure was designed and built to have a lifespan of three years for its role as a test facility (Schlaich 1995). Construction materials, particularly for those of the chimney, were designed with cost-effectiveness for the short term in mind, and would be unsuitable. For example, the guy wires supporting the chimney were made of simple steel rod, as opposed to the galvanized cables usually used for permanent applications. The costs of construction were also influenced by the fact that the tower was the first of its kind, and built alone, taking advantage of neither economies of scope or scale. Additionally, the Manzanares facility was funded largely by the German Ministry of Research, and so does not represent the realities of the cost to the investor. Thus, the cost of a general unit plant cannot be based on the Manzanares plant.

Theoretical Cost Estimates

Several cost estimates have been generated by Jorg Schlaich and his firm, Schlaich Bergermann und Partner. All cost analyses have pointed towards the fact that solar updraft towers will benefit from economies of scale, in part due to the increase in efficiency for larger tower heights, as discussed in the Governing Equations section. Thus, large towers have the best cost per kilowatt of installed capacity.

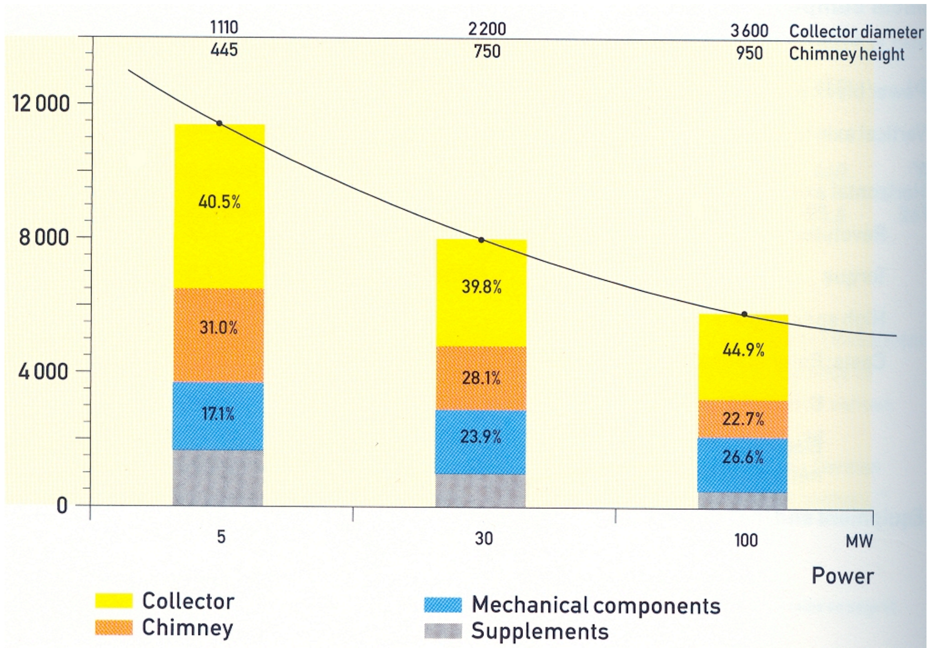

Figure 6: Solar updraft tower component costs in 1995 DM/kWh (Schlaich 1995).

The Solar Chimney by Jorg Schlaich provides both estimates of capital costs and cost of energy per kilowatt-hour (Schlaich 1995). Estimates are provided for the construction costs of a plant located in a high solar irradiation area in southern Europe, that is, locations roughly similar to Manzanares. Figure 6 shows the cost breakdown in terms of Deutsche Marks per kilowatt of installed capacity as a function of plant size, showing the clear cost improvement for larger plants. (The conversion rate from DM to 1995 dollars is 0.70.) Construction costs vary from location to location; by comparison, a 30 MW solar updraft tower built in India is expected to cost about 56% as much as the equivalent European plant, due to reduced construction costs for the chimney and collector. Schlaich consulted with construction experts in India to create his cost comparison.

Schlaich also provides cost of electricity estimates based on the construction costs and operating costs using the nominal annuity method. Figure 7 shows the resulting costs based on plant size, depreciation time, and interest rate. Again, the advantage of larger plant size is clearly shown. With additional plant life, the cost of electricity for the plant drops quickly. For example, with an 8% nominal interest rate and a depreciation period of 20 years, the cost of electricity for a 100

MW facility is calculated to be roughly 0.209 DM/kWh. If the plant functions for an additional 20 years past the depreciation period, the cost of electricity drops to about 0.110 DM/kWh. In terms of 2008 dollars, that's roughly 11 cents per kilowatt-hour.

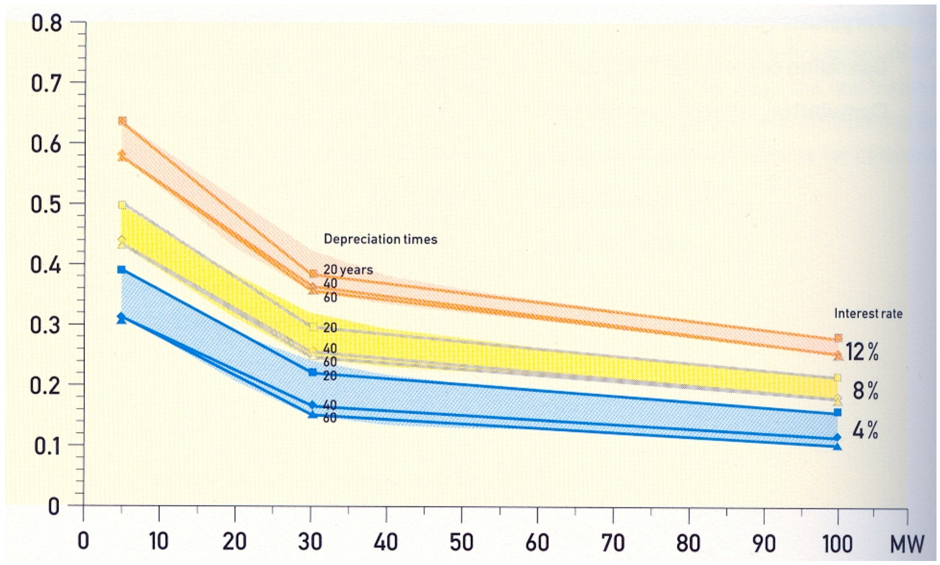

Figure 7: Cost of electricity in 1995 DM/kWh (Schlaich 1995).

An update for 200 MW towers was provided by Schlaich Bergermann und Partner in 2002 with more exact component cost estimates provided by the glass and turbine industries. For a 200 MW solar updraft tower with a nominal interest rate of 11% and a construction period of 4 years, the cost of electricity would be about 0.14 DM/kWh, which is roughly 0.15 2008 dollars per kilowatt-hour. Energie Baden-Wurttemberg compared the costs to equivalent capacity coal and combined cycle plants, and found that the cost of electricity would be 0.116 and 0.104 DM per kilowatt-hour, respectively.

Cost Saving Factors

The cost of electricity for a solar updraft tower is dominated by construction costs, so reductions in component costs, labor costs, or financing costs can all have significant impact on the cost of electricity.

Reducing the component and labor costs can significantly improve the cost of electricity. Component and labor costs can vary with location. While the turbine and generator cannot be contracted locally, the tower and collector construction materials can come from local sources. Labor costs can also be reduced significantly by the use of local labor. The collector is especially amenable to local manufacture and assembly.

Financing costs can have a significant effect on the cost of electricity. Because of the high capital costs of a solar updraft tower, the cost of electricity is sensitive to interest and inflation rates. Solar updraft towers can benefit greatly from clean energy-favorable policy. Low interest rate loans encouraging sustainable energy can provide a significant advantage to the towers. Financially, another advantage that solar updraft towers have is that they do not require any fuel, and are thus insensitive to the unpredictability of fuel prices. They also are insensitive to fuel and carbon taxes.

Cost Optimization

Recalling Figure 4, the power produced by a solar updraft tower is proportional to a cylinder with a base the size of the collector and the height of the tower. Thus, there is no fixed combination of tower height and collector area to attain a specific power output. The optimal building sizes for a specific power output can be based on cost principles. For example, in areas where labor is cheap, building a larger collector may be cheaper than building a taller tower.

Role in Remote Communities

Because of their low maintenance requirements, relatively predictable output, high durability, and non-existent fuel requirements, solar updraft towers could play an important role in remote communities. Solar updraft towers could be used to provide base power for private use around the clock and additional electricity during the day for small-scale local industry. Low maintenance, non-existent fuel requirements, and high durability allow the tower to function with little outside help. Local personnel without specialized training can perform minor repairs to the collector. The use of local labor and parts can also help keep costs down, especially when compared with other renewable power plants, such as photovoltaic panels and wind turbines, which are typically constructed by specialized manufacturers.

Existing Studies

Several existing studies have considered the use of solar updraft towers in developing regions, with a variety of climates. While solar updraft towers are most effective in regions with high solar irradiation, some studies have investigated their use in moderately sunny areas.

China

One study focuses on the possibility of placing solar updraft towers in the Ningxia region of China (Dai 2003). There are a wide variety of reasons that rural villages in the area may be good candidates for solar updraft towers. The Ningxia region is to the southeast of the Gobi Desert (as shown in Figure 8), and has higher solar insolation than many other regions of China. In much of rural northwestern China, grid-connected electricity and the means for many sources of renewable power are unavailable or unreliable. The low operational cost and freedom from external systems are very attractive. In particular, water shortages are a problem in rural China, so the freedom from cooling water systems necessary for traditional solar thermal power systems is a significant advantage. The ability to take advantage low construction and labor costs is another advantage of construction in the area. In general, solar updraft towers can be sized to suit villages, and the dual use of the collector as a greenhouse can be very appealing in a rural setting. In this region of China in particular, the government has encouraged the use of greenhouses to extend the vegetable production season.

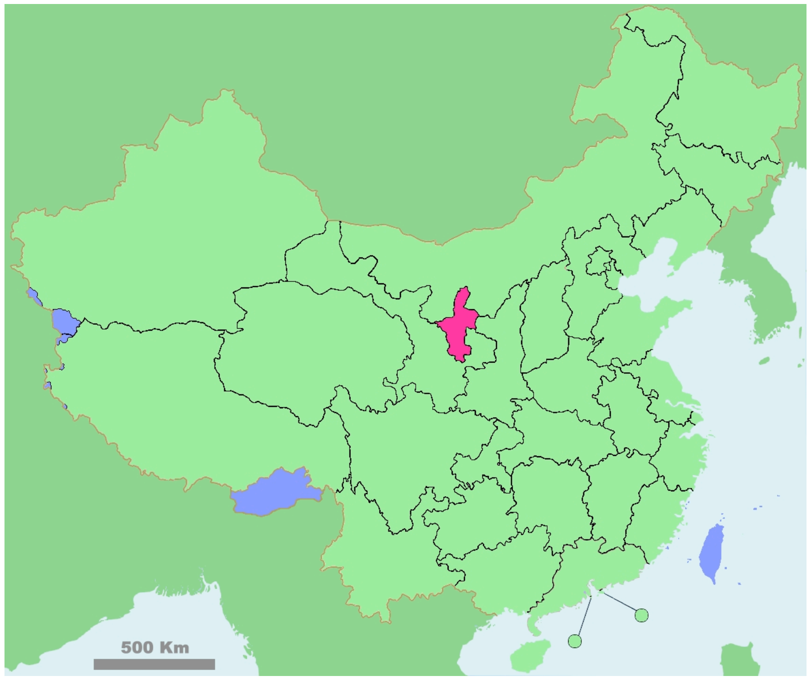

Figure 8: Ningxia region of China in pink.
(http://en.wikipedia.org/wiki/Image:Ningxia_CN.png)

In general, the application of solar updraft towers to the Ningxia region reflects the application of solar updraft towers in generic rural settings. The advantages of freedom from external support, water, and fuel, dual use of the collector, and the robustness of the plant apply in many rural locations.

Africa

Studies have also investigated the use of solar updraft towers in Africa (Onyango 2006, Pretorius 2006). Large portions of Africa have high levels of annual solar radiation, as shown in Figure 9, and are thus good candidates for solar energy. Many of the same issues surrounding the use of solar updraft towers in rural China discussed in the previous section apply in the case of rural Africa as well. Many areas do not have reliable sources of electricity, fuel, or water, so the independent, resource-free operation of the plant is critical to the success of any power plant in the area. The dual use of the collector area for agriculture is an added benefit. Financially, the use of local labor can both reduce construction costs and contribute to the local job pool. The cost of electricity is also improved because higher solar insolation leads to higher energy production, so equivalent yields can be attained with a smaller plant.

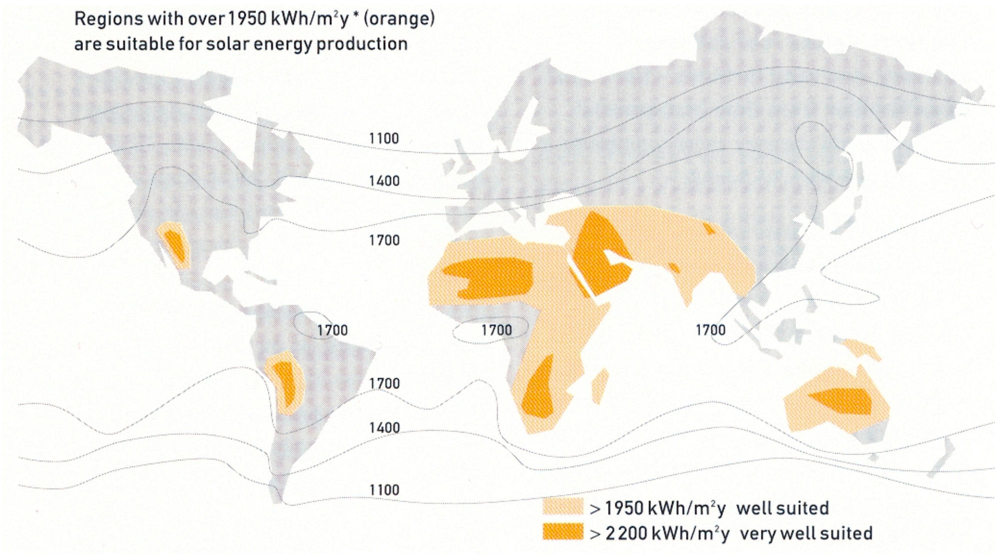

Figure 9: World solar irradiation levels (Schlaich 1995).

Competing Technologies

Several other solar energy technologies fill the same niche as solar updraft towers. Similarly to solar updraft towers, these technologies may be self-contained, have little maintenance requirements, no fuel requirements, and are capital intensive. Concentrating solar power and solar photovoltaic panels are considered as alternatives to solar updraft towers.

Concentrating Solar Power

Concentrating solar power uses reflectors to concentrate solar radiation to heat a working fluid that is used to drive a thermal cycle. In concentrating solar plants, solar-tracking curved reflectors are used to concentrate direct solar radiation to a central receiver carrying a working fluid. As with solar updraft towers, areas with high solar insolation are best for the operation of concentrating solar plants. Cloud cover should also be minimal, as concentrating solar plants cannot utilize diffuse radiation.

The efficiency of concentrating solar plants for utilizing direct solar irradiance typically falls in the range of 10-30% (Johansson 1993). Trough-style plants, which use parabolic mirrors to focus light on a center-run absorber, typically achieve efficiencies of about 12% (Tester 2005). The plant construction costs typically run about 3000 dollars per kilowatt electric installed capacity (NREL 2003). Plants are built up from series of individual trough units. Trough-style units have a longer operating history than other types of concentrating solar plants, and thus issues with their use are well known. Water use for evaporative cooling, high maintenance costs for the necessary cleaning of the mirrors, repair of the working fluid system, and maintenance of the tracking elements, and lack of energy storage ability are all significant issues for trough plants, some of which are also shared with other concentrating solar plants.

Two emerging concentrating solar power technologies, power towers and dish engines, may also have a role to play in isolated rural communities. Power towers use spherical heliostats to direct power toward a central tower receiver that uses a working fluid, such as molten salts. Power tower construction costs are suggested to be in the rage of 3000-4000 dollars per kilowatt electric installed capacity (Tester 2005). Power towers share many of the same issues as trough plants; water use for evaporative cooling, maintenance costs for cleaning and operating the mirrors, and the inability to operate in cloudy conditions. Additionally, power towers have the disadvantage that they typically have to be built as large units, as opposed to many other solar technologies. On the other hand, power towers have the advantage that the working fluid can be used to store energy for continuous operation, and thus can be built to provide electricity around the clock.

Solar dish engines use a tracking dish reflector to focus solar radiation on a central collector that typically employs a Stirling engine to produce electricity. Solar dish engines are projected to have costs of about 3500 dollars per kilowatt electric installed capacity with efficiencies of up to 30% (Tester 2005). Solar dish engines have very similar disadvantages to trough concentrating solar plants; the most important difference is the self-contained Stirling engine does not require water cooling or other external cycle mechanisms.

Solar PV

Photovoltaic cells use solar radiation to directly produce electricity through the photoelectric effect. The efficiency of contemporary solar photovoltaic panels is roughly 18%, but that performance degrades slowly through the years of use. The cost of these panels is in the range of 7000 dollars per installed kilowatt electric of capacity, however there is very little associated maintenance and operation costs, particularly with non-tracking panels (Tester 2005). Panels can be installed in facilities of any size, but have absolutely no capacity for energy storage, putting them at a distinct disadvantage to solar thermal technologies.

Photovoltaic plants are the current leading solar technology for use in remote locations. Solar photovoltaic panels have been installed in remote communities, such as India and Senegal (Ramana 1997). Relatively speaking, the low maintenance level of the facilities, passive energy collection, easy on site construction, and long development period have all contributed to their popularity as a source of energy for remote communities.

Comparisons

Several different factors contribute to the final value of a power system. In the context of providing power for rural or remote communities, there are several important factors to consider, which may be different than in the case of grid-connected power. In the case of supplying electricity to a central distributed grid, perhaps the single most important factor is cost. In the case of supplying electricity to disconnected communities, cost is also an important factor, but power reliability and plant maintenance and operation level are also very important factors.

Cost Comparisons

In the case of costs, traditional solar thermal plants, that is, concentrating solar facilities, have a large advantage over solar updraft towers and photovoltaic panels. Construction and installation cost for the different types of concentrating solar plants can be as little as half the cost for solar updraft towers and photovoltaic panels. On the other hand, concentrating solar plants have ongoing maintenance and operating costs that need to be accounted for. Operating and maintenance costs may add up to 2 cents per kilowatt-hour to the cost of electricity for these plants (NREL 2003).

Solar updraft towers have an advantage over the other technologies we are considering here because the unit construction and installation cost can be greatly reduced by using local labor and materials. Schlaich calculated that the cost of building a solar updraft tower in India would be roughly 56% of the cost of building the equivalent tower in Europe, because of the use of local materials and labor. At that price, the construction of a solar updraft tower would be cost competitive with the concentrating solar technologies. The costs of the concentrating solar technologies and photovoltaic panels are driven mainly by expensive specialty components. The use of local parts and labor cannot significantly improve the costs of those facilities.

Power Reliability

In a remote community, with only one electric plant to rely on, the reliability of the plant can be a critical factor in its utility. All solar technologies have the issue that winter outputs are lower than summer outputs, however, some plants have more day-to-day, hour-to-hour, and minute-to-minute fluctuations in power output. On a related note, some of these plants have more overall predictability.

Solar updraft towers may be at the top of the list for reliability and predictability. The large thermal mass associated with the ground area under the collector provides both a buffer against second-to-second solar irradiation variation and a storage mechanism that allows the plant to keep operating at night. The plant is able to take advantage of the diffuse sunshine of light to moderately cloudy days, giving it a distinct advantage over the other solar technologies discussed, which are completely dependent on direct radiation.

Power towers are the next most reliable source of electricity. Power towers have a large thermal mass and thus are relatively insensitive to momentary fluctuations in solar radiation. The large thermal mass also allows a power tower to provide electricity overnight.

Trough concentrating solar plants have some inherent thermal mass in the system of the working fluid. Additional thermal storage can be created using reserve fluid, but at an additional cost. The thermal storage associated with trough concentrating solar plants is typically on the order of minutes, but can be extended to hours with the current storage technologies.

Photovoltaic panels have no mode of energy storage. Second-to-second irradiation variation has an impact on the performance of the panels.

Maintenance and Operation

The level of maintenance and operation required to run a plant daily can be a make or break issue for electric plants operating in remote communities. Fuel and other consumables may be in short supply, replacement parts may be unaffordable or difficult to obtain, and the skilled labor required to maintain and operate the plant may be difficult to provide. In many ways, the best plant in a remote area would be one with no regular input requirements and low maintenance requirements.

In terms of operation and maintenance, solar updraft towers and solar panels are the easiest plants to run. Neither requires any consumable input. Both are very resistant to environmental exposure. Solar panels have no moving parts, and a broken unit can simply be wired out of a system. The one delicate part of a solar updraft tower, the turbine, is protected from the worst environmental effects at the base of the chimney. The rest of the plant also has very low failure rates. Glass panels from the collector are relatively easily replaceable by local materials, and the plant can function acceptably with a low number of missing panels. Because of these infrequent failure and minimal input requirements, neither type of plant requires the attentions of a group of service personnel. While it is desirable to have a full time maintenance staff, these plants could be tended very infrequently.

Solar dish engines require more maintenance than either solar updraft towers or photovoltaic panels. Solar dish engines use large tracking motors that may require maintenance, and the mirrors require regular cleaning for optimal functionality.

Power towers and trough concentrating solar plants both require the same basic maintenance as solar dish engines; motor maintenance and mirror cleaning, however, the number of motors per unit power may be significantly larger in these cases. Power towers and trough concentrating solar plants both use heat engines to provide electric power, the most common method of cooling for the heat rejection stage of the cycle is to use evaporative cooling. This requires a regular input of make-up water. The maintenance of the equipment for the power cycle provides an additional maintenance factor for both of these systems. For trough plants in particular, the maintenance of the absorber tubes can require a lot of work. Full time employees are typically required to maintain and manage both of these types of plants.

Other Factors

Land use can be an important factor. Due to their low conversion efficiency, solar updraft towers use a significantly larger land area than other solar technologies (roughly one order of magnitude more). They are not suitable for use in areas where land is at a premium.

Structural integrity issues may also have an effect on making solar updraft towers more or less cost effective. Areas of high magnitude earthquakes are unsuitable for solar updraft towers because the costs of building a high tolerance tower drives up the cost of electricity significantly.

The collector of a solar updraft tower may also be used as a greenhouse area. This can significantly extend the growing season in many areas that are being considered for tower placement.

Plant size can also be an important factor. Solar updraft towers are best built at larger sizes, and thus may be more suitable for medium size remote communities. Power towers have similar issues. Trough concentrating solar plants are built from smaller units but have shared cycle equipment, which also makes them more suitable for medium scale use. Dish engines and photovoltaic panels are discrete units that can be assembled into plants of many sizes.

Comparison Conclusions

No clear preferable system is found among the systems under consideration by these direct comparisons. Concentrating solar plants may be the cheapest, although solar updraft towers may be able to approach their low capital costs. Power towers and solar updraft towers have the steadiest power generation. Photovoltaic panels have the easiest construction, and, along with solar updraft towers, the lowest maintenance and operational requirements. The choice of a solar power system depends on the weight that you place on each of these functional requirements based on the needs of the local community.

Conclusions

Solar updraft towers have many aspects that recommend them for use in remote, isolated communities. Their predictable and steady power output makes them especially suitable for use in smaller communities that require steady power output for use in small-scale industry. In developing areas, such as western China, Africa, and parts of India, connections to the power grid either do not exist of may be unreliable. The development of small-scale industries requires an uninterrupted power output, which can be provided by solar updraft towers. Solar updraft towers are most efficient at larger sizes; this supports the use of towers for power outputs beyond just the basic provision of electricity for homes. The power output curve of a solar updraft tower can be tuned to provide the appropriate balance of production at different times to satisfy both residential and industrial use.

Solar updraft towers can deliver the required power at as low a price as concentrating solar plants, provided that the towers are built with local parts and labor. This is an additional advantage of solar updraft towers; they can utilize local construction materials, which other types of solar plants cannot. Costs are kept low after construction due to the very low maintenance requirements of the plants.

The low maintenance requirements may also be an important factor in the decision to construct solar updraft towers in remote communities. Specialty replacement parts are not required for these plants; basic maintenance of the collector can be performed by those skilled in construction labor. The feathering turbine of a solar updraft tower is the only complex, actively controlled part in the system, but the turbine can function with the blades set at a fixed angle with a reduction in efficiency. In general, solar updraft towers are very robust.

The fringe benefit of using the collector area for agriculture may also be appealing in some communities.

Overall, solar updraft towers are very suitable for use in remote communities as a power source for both residential and industrial use, based on reliability, cost, and operational factors. They can provide a suitable energy source in many remote areas, including areas that are not currently supplied by conventional means.

References

von Backstrom, TW (2003). “Calculation of Pressure and Density in Solar Power Plant Chimneys.” *Journal of Solar Energy Engineering* 125: 127-129

Dai YJ, Huang HB, Wang RZ (2003). “Case study of solar chimney power plants in Northwestern regions of China.” *Renewable Energy* 28: 1295-1304

Gannon AJ, von Backstrom TW (2003). “Solar Chimney Turbine Performance.” *Journal of Solar Energy Engineering* 125 (1): 101-106

Gannon AJ, von Backstrom TW (2000). “Solar Chimney Cycle Analysis with System Loss and Solar Collector Performance.” *Journal of Solar Energy Engineering* 122 (3): 133-137

Haaf W (1984). “Solar towers, Part II: Preliminary Test Results from the Manzanares Pilot Plant.” *Solar Energy* 2: 141-161

Haaf W, Friedrich K, Mayr G, and Schlaich J (1983). “Solar Chimneys, Part I: Principle and Construction of the Pilot Plant in Manzanares.” *Solar Energy* 2: 3-20

Johansson TB, Kelly H, Reddy AKN, and Williams RH (1993). *Renewable Energy: Sources for Fuels and Electricity*. Island Press, Washington D.C.

Kreetz H (1997). “Theoretische Untersuchungen und Auslegung eines temporaren Wasserspeichers fur das Aufwindkraftwerk.” Diploma Thesis, Technical University Berlin, Berlin, Germany.

National Renewable Energy Laboratory (2003). *Assesment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts*. NREL/SR-550-34440.

Onyago FN, Ochieng RM (2006). “The potential of solar chimney for application in rural areas of developing countries.” *Fuel* 85: 2561-2566

Pretorius JP, Kroger DG (2007). “Sensitivity Analysis of the Operating and Technical Specifications of a Solar Chimney Power Plant.” *Journal of Solar Energy Engineering* 129: 171-178

Pretorius JP, Kroger DG (2006). “Solar Chimney Power Plant Performance.” *Journal of Solar Energy Engineering* 128 (3): 302-311

Ramana VP (1997). *Rural and renewable energy: perspectives from developing countries*. Tata Energy Research Institute, New Delhi, India.

Schlaich J, Bergermann R, Schiel W, and Weinrebe G (2005). “Design of Commercial Solar Updraft Tower Systems – Utilization of Solar Induced Convective Flows for Power Systems.” *Journal of Solar Energy Engineering* 127 (1): 117-124

Schlaich J (1995). *The Solar Chimney: Electricity from the Sun.* Edition Axel Menges, Stuttgart Germany.

Schlaich Bergermann und Partner (2002). “The Solar Chimney.” Technical brief.

Tester JW, Drake EM, Driscoll MJ, Golay MW, and Peters WA (2005). *Sustainable Energy: Choosing Among Options*. The MIT Press, Cambridge, MA.