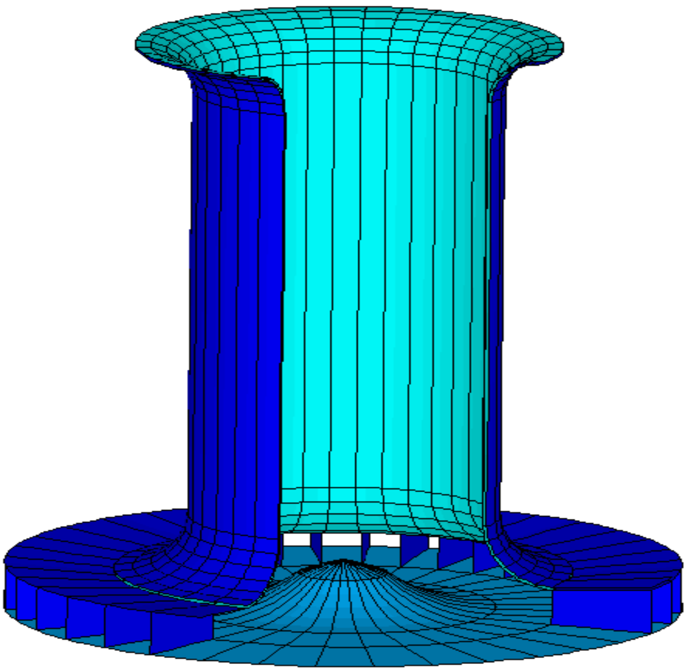
ENERGY TOWERS

for Producing Electricity and Desalinated Water without a Solar Collector



This technology is the most important breakthrough in finding a replacement to fossil fuel and breaking the cost barrier of sea water desalinization

By Prof. Dan Zaslavsky

The contributors of this report are the members of the development team of "Sharav Sluices Ltd." that did most of their work within the frame of the Technion R & D Foundation.

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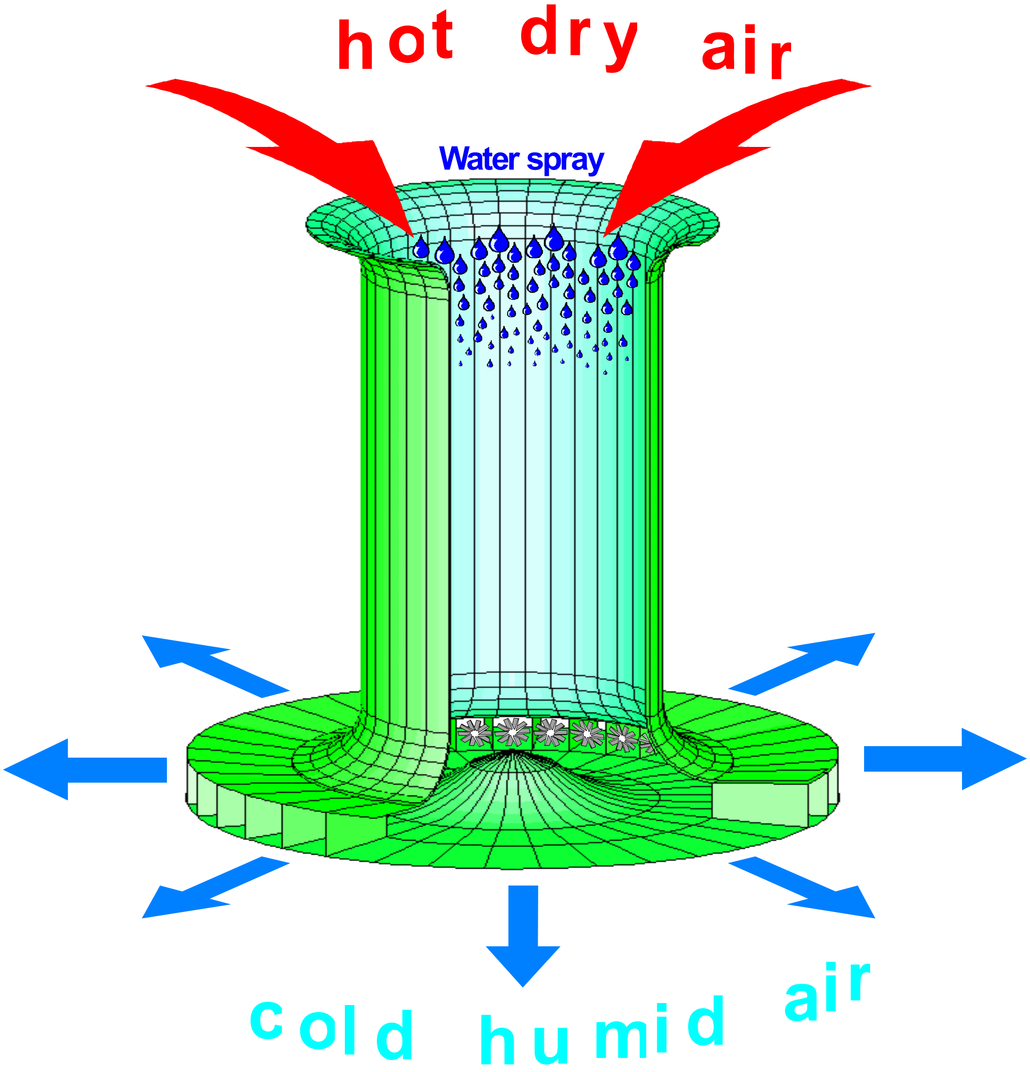

Figure 1 - The Energy Tower principle

"...And the angel of the LORD appeared unto him in a flame of fire out of the midst of a bush: and he looked, and behold, the bush was not consumed.

Exodus 3,2

Executive summary

The "Energy Tower" is a technology which was independently developed at the Haifa Technion--Israel Institute of Technology. This technology enables electricity production in arid and warm environments, utilizing the abundance of hot dry air of such climatic zones as a source of potential energy.

According to the analysis of the "Energy Tower" concept, this technology should be the most economically promising to date of all technologies which are being developed to produce large masses of environmentally clean electricity from renewable sources. An Energy Tower outperforms hydro, solar, wave and wind turbine sources of electricity, in terms of cost per unit, and also in terms of the ability to provide an uninterrupted power supply and a global potential about 15-20 times the present global consumption of electricity.

Unlike previously designed "solar chimneys", which required solar collectors to heat air to generate an updraft part of the day, Energy Towers cool warm atmospheric air, and generate a downdraft, which is present 24/7/365. It has also been shown that in addition to the electricity supply, there are close to ten major benefits as material-tangible byproducts, just as important economically. In addition to supplying electricity, Energy Towers offer further major benefits such as producing desalinated water at half the cost, built in pumped storage at a very low cost and no energy losses etc. Another list of non-tangible products has to do with environmental benefits, economical benefits and political revolutions.

The principle

For this technology to be cost effective the construction of the chimney must be scaled up. Optimal dimensions are from 1000 - 1200 m in height, and 400 - 500 m diameter, although it can be highly competitive even at 600 - 700 m height. Water is pumped up the tower and sprayed into the shaft. As the water falls, it partially evaporates, and thus cools the air. This cooler air is denser and falls also down. In effect, the chimney is a controlled vertical wind making machine using the fruit of the sun instead of the direct solar radiation. It is very much like the well known phenomenon called "wind shear" only contained within the vertical shaft.

The air in such an Energy Tower can reach high velocities. The kinetic energy as well as built up pressure will be converted to mechanical energy, driving turbines at the tower's base, which will then convert this energy into electrical energy. If the tower is tall enough then even at night there is sufficient heat in the atmosphere to allow airflow through the tower. ***An Energy Tower can be conceptualized as a machine for producing wind on-demand, 24 hours a day, 365 days a year.***

Proof of the physical principle and the underlying technology

The basic principles utilized by the "Energy Tower" have been repeatedly reviewed by independent consultants in different countries. These reviews have indicated that the physical principles determined by "Sharav Sluices" company, are feasible, as are the projected economic benefits. An Energy Tower can be built using proven technologies. While a tower of 1200 m in height may seem to some improbable, or at least, untested, all structural engineers we have consulted with indicated that the concept lies well within current engineering capabilities and in fact can be considered text book material. The confidence is such that a letter of intent has been formulated with the engineering firm "Alstom", with the aim of constructing a prototype facility, probably at first in Israel. However, there are many sites in the world which are better than the one in Israel in the South Arava, North of Eilat.

Economy

The Israeli Ministry of Energy nominated an expert review committee to investigate the project. This committee found that an Energy Tower is an economically attractive method of electricity generation, and that a considerable economic margin is present when

electricity from an Energy Tower is compared with electricity generated from conventional fuel sources (coal, oil, nuclear or natural gas). Furthermore, this early cost-benefit analysis did not include ecological accounting (or what is commonly called "externalities"), which would further increase the margin of utility for an Energy Tower, as opposed to a conventional generation scheme. Moreover, this estimate omitted also consideration of the by-products, such as half cost sea water desalination, built-in pumped storage, sea fish farming, growing of crops for supplying the so called bio-fuel to replace fossil fuel for transportation, etc. And above all, ***the committee evaluation took place long before the unexpected price hike of fuel.***

The committee investigated the potential cost benefit of setting up an Energy Tower in the Southern Arava Valley, which runs on a North-South axis between Israel and Jordan. In this region, the projected cost of electricity was found to be 2.47 ¢/kWh at 5% discount rate, and 3.88 ¢/kWh with 10% discount rate, over 30 years, including operations and maintenance of 0.556 ¢/kWh and four years construction. Thus, the electricity costs from an Energy Tower were found then less than the average electricity costs of coal, oil, or natural gas combined cycle power stations. When considering the economics of power generation alone, the range of possible costs from conventional power sources widely overlapped those obtained from an Energy Tower. However, let us emphasize again that electricity generation is not the only direct economic benefit that accrues from running an Energy Tower, and these added benefits of an Energy Tower outweigh, by far, the economics of conventional power sources. These fringe benefits would vary from site to site, and are estimated to range from 4 to 14 ¢/kWh, depending on the situation. It is worth also mentioning, again, that since the analysis was made the cost of fuel hiked significantly.

<u>A comparison with competing solar technologies</u>

An Energy Tower's projected cost of electricity production is the lowest of all current renewable sources, with the exception of some very large hydro-power stations under very favorable conditions. However hydro-electric sources of all sorts do not exceed about 6% of the present global electricity consumption and it is totally missing in Israel. This is while the potential of electricity production by Energy Towers is not less than 15-20 times the complete electricity consumption by humanity today.

For example, electricity generated from photovoltaic cells costs in the order of 30-40 ¢/kWh. The investment in average kW from photovoltaics is in the order of $50,000. (It strongly depends on the load factor, or what must be the availability of the electricity supply). For an Energy Tower, the investment is $2,300/kW, over an order of magnitude less. The projected cost of electricity from the best solar thermal technology under development is 15.5 ¢/kWh - and this power is only available for 6-8 hours a day. The investment in a wind turbine is usually over $ 3000/kW average (and about one third for an installed MW), and here again, intermittency is a problem that limits the use of wind-turbine generated power as an overall renewable solution. In countries with good wind conditions it may replace only about 20% of the electricity supply with no known tangible by-products. Thus, an Energy Tower is an additional source of energy that is obtained indirectly from solar radiation, similar to wind, hydro and bio-mass, and not directly from the solar radiation but it is much cheaper and enjoys also about ten different very valuable by-products and a similar number of other advantages.

Another very important advantage of the Energy Towers over parabolic troughs using solar thermal, photovoltaic and solar chimney, is that the area needed for the Energy Towers is the smallest. Solar thermal requires 8-24 times larger area to produce the same amount of electricity. Photovoltaic requires about the same and a solar chimney requires 100-300 times a larger area.

The potential of Energy Towers

At the above cited cost, the potential for power generation using Energy Towers in Israel has been analyzed, and found to be more than twice Israel's projected future electricity consumption.

The theoretical global potential of Energy Towers was calculated, as an academic exercise. A possible global potential power generation using Energy Towers has been conservatively estimated to be 230,000 billion kWh/year. This figure has been calculated by assuming an electricity production cost for the Tower as high as 3.93 ¢/kWh, or 6.42 ¢/kWh at 5% and 10% interest rates, respectively. This is at the poorest site. We have disregarded sites where the net output was less than 200 MW average. This mapped global potential came out about 16 times the present electricity global consumption. Adding some marginal areas like the

South of Europe or the shores of the Gulf of Mexico along Texas, could possibly double the global output, though at somewhat higher cost.

Fringe benefits or by-products

There are nearly twenty fringe benefits that devolve from the installation of an Energy Tower. Half of these are material-tangible byproducts; other benefits are of an intangible macro-economic nature environmental and of strategic political impact. These fringe benefits could possibly also be translated into economical values. Following are some of them.

Let us start with the material-tangible byproducts:

- ***Adaptation of supply to demand by utilization of a built in pumped storage capacity.***

A built-in capacity with no additional energy loss and minimal additional investment may improve the economics of an Energy Tower by more than 30% (in the order of 2 ¢/kWh over and above the average tariff that can be obtained in many sites). In the process the up pumping of spraying water is stopped at hours of peak demand. The net electricity supply capacity is then increased temporarily by 70-80%. There are three more methods to obtain this adaptation.

- ***Desalination***

  Desalination of sea water, brackish water, sewerage, waste water can be incorporated. This potential is attractive, in that capacity can be added in a modular fashion. The projected investment saving for desalination using this technology is over 50% and the saving in the energy outlay is about 33% when compared to conventional Reverse Osmosis. The cost savings for sea water desalination reached about 45%, when contrasted with current methodologies. Utilizing approximately about 20% of the Tower's energy, calculated according to base line dimensions of 1200X400 m North of Eilat, it is possible to desalinate 200 million m^3 water per year. This amount of water is equivalent to the addition of about 400 m^3 per capita per year, while the water supply in Israel today is less than 300 m^3. This water would cost 30 ¢/m^3. It can be reduced even to 25 ¢/kWh by some optimization. This is a major benefit - indeed, it is conceivable that an Energy Tower might one day be built for the sole purpose of desalination - allowing human habitation of previously unviable desert regions. At this cost per cubic meter, water is cheap enough for industrial applications, and for a broad range of agricultural applications. Getting a royalty or mark up of just 5 ¢/m^3 leads to a net additional income of about 0.3 ¢/kWh**.** This figure may be doubled.

- ***The cheap desalinated water can be used to produce bio-fuels***

Among the crops to be grown in the arid area where the Energy Towers will be built, one can include sugar plants to produce ethyl alcohol and oil plant, thus providing substitutive to gasoline and diesel fuel for transportation. It can be done without taking over land and water that have been used for conventional agriculture and already cause price elevation of conventional agricultural products. It will also prevent further deforestation.

- ***Aquaculture***

By using the water en-route to the Tower and retain it in ponds for a day or more. Each Tower of standard design has the potential to provide facilities for the production of 160,000 tons of sea fish. This would provide income that is well above the cost of water supply to the Tower, and would eliminate the environmental pollution problems associated with sea-based aquaculture. Taking a pay of a quarter per kilogram fish will amount to about 1.3 ¢/kWh**.** All it takes is to retain the sea water supplied to the Tower for one to two days in the ponds around the Tower. Today, the fish production there does not reach 3000 tons. The global production in sea fishing in fish ponds is 95 million tons, and the global potential to use the Energy Towers is way over 130 million tons per year. This is not only a cheap supply of protein. It would prevent destruction of the sea fish population because of over fishing.

- ***The first three benefits of running an Energy Tower are expected to come very close to 3 ¢/kWh in all or most sites. The Israeli government decided to provide a benefit of 2 ¢/kWh for clean energy from renewable sources. Selling pollution rights through existing international mechanisms may provide another 2 ¢/kWh. In summary, it is anticipated to have not less than 7 ¢/kWh additional net gain.***
- ***<u>Prevention of salinization in large irrigation projects</u> - Salinization is presently destroying some of the largest irrigation projects, and is affecting irrigated agricultural land in many locations world-wide.*** **The drainage water left after irrigation accumulates salts which eventually turn ground water and rivers more and more salty. Using the diverted drainage water to produce electricity in an Energy Tower, produces yet more concentrated brine. This is much cheaper to dispose of. The overall result is that the expensive disposal of the salty drainage**

water is reduced to about 5% of its cost that would be without the Energy Towers. An additional benefit of some 10 kWh electricity is produced for each cubic meter of evaporated water in the Energy Tower. In getting the brackish water away from the main water path, one can save about half a cubic meter fresh water for every brackish cubic meter removed.

- ***Additional tangible benefits***

- Cooling water for thermal stations using steam to run turbines, including solar thermal.
- Air cooling for gas turbines improved efficiency (1% for every centigrade).
- The use of concentrated sea water against fresh sea water to recover a considerable amount of energy.

- ***Non tangible benefits:***

- Zero-emission electricity generation (no pollution or greenhouse gases).
- Avoidance of reliance on imported fuel.
- Immunity from future fuel price instability and the inevitable cost rises.
- Immunity from cost fluctuations.
- No need for a strategic fuel reserve.
- Avoidance of heavy pay for security.
- Improved balance of payments both by saving and by industrialization.
- Operation of the "Energy Towers" is not only a way to reduce greenhouse gasses emission, but it has a cooling effect on the globe.
- The Towers have a positive feed-back as it increases the energy output as the climate warms up.
- There is no doubt that the very success of the first Energy Tower might have a tremendous strategic effect on the battle against the oil merchants, anti Western culture and terrorism.

Marketing

The application of this new technology has been estimated, by actual detailed mapping, to be highly productive in over 40 countries. Installation of an Energy Tower, in engineering terms, is a relatively simple procedure. The electricity supply can be extended by long supply lines of high voltage D.C. If full development of the concept were to take place, benefits accruing from this technology could directly reach some 2/3 of humanity within 25 years, and have an indirect benefit for everyone. Energy Towers could easily replace global fossil fuel demand for electricity generation and even for transportation by clean fuel.

The market is estimated at about 25% per year increased demand and about 2% per year old power station replacement,

During intermediate times natural gas, a cleaner fuel than petroleum, could conceivably be diverted to use for transportation. Should battery technology improve, then electrically powered transport may replace fossil fuels entirely. Secondly, should fuel cell technology advance, then electricity from an Energy Tower could perhaps be used to produce hydrogen to power fuel cell driven transportation. However, this seems to be the least likely, the farthest away and the most expensive. Best of all the desalinated water nearly half the cost of today's prices, could serve for growing special crops from which fuel replacements could be produced for transportation.

The most dramatic possible outcome

Thus Energy Towers could turn out to be the democratic world's most effective weapon with which to maintain political freedom and to prevent irreversible environmental degradation at the planet. Notably, South of Europe is good enough to supply electricity from Energy Towers far more than half a billon people (see tables 15 & 17). This fact, as well as the very wide diversity of sources to Europe from at least 6-7 countries, provides protection against future dependence of Europe on fuel supply from Muslim countries.

Energy Tower technology addresses the following global problems:

- **Solves not only the problem of supplying very cheap electricity from clean renewable sources. It will solve also the problem of clean fuel for transportation.**
- **Reduces pollution and greenhouse gas emissions due to fuel burning.**
- **Overcomes the shortage of cheap good water, over pumping and salination and desertification of agricultural land.**
- **Preserves marine ecosystems by encouraging sustainable aquaculture.**

- ***It may be proven that the "Energy Towers" technology is one of the only possible ways to help reversing the warming up effect and in addition provide a positive feed back because the tower's output would increase if the globe gets warmer. This is the most exciting new discovery to be studied in the future.***

END OF SUMMARY

1. Background

1.1 A brief history

The project has its origins in late **1982**, when **Prof. Zaslavsky,** a Professor at **Haifa's Technion--Israel Institute of Technology,** was working on the solar ponds project with "Ormat Ltd." on the Dead Sea. Despite a success in reducing the initial investment to one third, he felt that the project has no hope to become economically justified, as is. Over the course of this project, he became convinced that renewable energy for electricity generation in large masses would be more efficient and, in all possibility, more economically attractive, if it did not require a solar collector. The infrastructure cost of the solar collector and the need for additional energy conversion would eliminate, in all probability, any advantage. Some basic thermodynamic laws make it inefficient unless we can raze considerably the temperatures involved. The oldest forms of energy used by man are all renewable - wind for windmills, biomass for burning, and hydropower for water mills and later on for hydro-electric power. **None of these requires the use of an artificial solar collector. They have used the fruits of the sun not its direct radiation.**

Zaslavsky reasoned that a solar chimney per se was a sound concept - but how could it be utilized without heating up masses of air to rise it up in the chimney? One afternoon, the thought hit him - why not reverse the process? The earth itself has an atmosphere that absorbs enormous amounts of energy from the sun. There would be no need to heat any air up - vast amounts of energy are shifted across the planet daily by convective systems - the atmosphere itself is a huge reservoir of heat energy. Just as a hydro-electric dam uses gravitational energy to generate electricity, so too, could an Energy Tower. Cool the air in a tower by sprinkling it lightly with water from a gentle atomizer, and the cool air would become heavier, and would begin to flow **down** the chimney. The vast reservoir of potential energy contained in the heat of the atmosphere could then be tapped, without any need to artificially heat it up. He has began to realize this abstract idea in actual engineering terms, and in 1983 he prepared a two volumes report to the Israeli Ministry of Energy. About this time he has discovered that the American physicist **Dr. Philip Carlson** had used some of the main principles in a theoretical study of this idea, and had been granted a U.S. patent in 1975. Subsequently, the Technion team, headed by **Zaslavsky,** added a number of patentable features to the core concept, which have had the effect of decreasing the cost effectiveness ratio by a factor of about 7:1. Patents have to date been filed in 15 key countries.

The Project Team at the Haifa Technion was supported in the main by the **Israeli Ministry of National Infrastructures (formerly the Ministry of Energy),** by financial contributions from the **American Technion Society - Baltimore Chapter**, various research foundations and primarily, by the Haifa Technion itself. **The Israeli Electric Corporation** followed the project's progress, reviewed it and assisted financially and professionally. The project team was comprised of scientists and engineers from 5 departments, including 15 professors and 20 professionals with a Ph.D. degree. About 20 theses for higher degrees were written by personnel involved in the project team. In all, over 150 man-years have been spent on the project development to date and the equivalent of about 10 million dollars.

The work done has been summarized in 30 volumes, all in Hebrew.

1.2 Underlying principles of "Energy Towers" technology

The basic principle of an Energy Tower's operation is very simple. A tall and large diameter tube is constructed (see figure 1). The tube is built in a hot and dry area and optimally should not be too far from and too high above a large source of water. The source is anticipated to either marine or brackish estuarine water. The water is pumped up and sprayed from the top of the chimney, using pre-existing spray technology. The descending water partially evaporates taking up energy from the air for the latent heat of evaporation, and thus cooling the air. The colder air is denser than the warm air around, and flows downward. This airflow through the chimney is therefore the opposite of regular chimneys, where warmer air rises. The air emerges at the bottom to drive the turbines. The spray of non-evaporated water is collected at the base of the shaft, and piped back to the sea. If the sprayed water is sea water the amounts of salt that comes out with the air can reach 20 million tons per year. However, only in a solution the water droplets should not be adsorbed on the vertical part of the tube to permit best cooling process and full recovery of the gravitational energy of the water droplets. However, none of the droplets should fly out of the horizontal outlets. **This problem was probably the only one that required from the development team to walk over an untreated path.**

1.3 Climate change and other reasons to replace the use of fossil fuel

There is currently much debate regarding the justification of changing to renewable and clean energy sources. There is also an ongoing discussion about the ways in which a corporation or state could be fined for not following carbon emission regulations. The arguments about global warming and about the reasoning behind justifying replacement of the fuel use by very expensive alternatives is unsettled.

The simplest way of analyzing the impact and effectiveness of this technology as a means of guarding against possible climate change or other predicted damages, is to adopt an actuarial approach to the data analysis. If one examines the following ratio R

$$R = \frac{P*D}{(1-P)EC} \tag{1.1}$$

where,

P **probability of anticipated damage D**

EC **the extra cost that has to be invested in order to prevent the damage D**

If R > 1, it is statistically worthwhile to replace the present use of fossil fuels by an alternative renewable source. It is even more so if EC is negative.

We do not have to settle the debate if the world is warming up and if the warming is man made. We also do not have to estimate the damage. It is enough if we have a technology the cost of which is not much higher than the cost of conventional power using fossil fuel. It is even better if the cost of the alternative energy source is smaller than in conventional power station and the suggested parameter R is negative.

There are two very interesting things that should be stated at this juncture.

a. There are many types of damage caused by dependence on oil, gas and coal, apart from the costs associated with global warming, such as health costs, security expenses, etc. Thus D is not a negligible figure in any case.

b. Any source of energy which is cheaper than the use of oil, gas and coal causes R to go to infinity and then turns negative and one should replace the use of fossil fuel. The technology of Energy Towers is calculated to be cheaper than the use of gas, oil, coal or nuclear power. Moreover, Energy Tower technology resolves a number of environmental problems, which turn PD, the numerator in equation 1.1, into a significant figure.

The common method used till now to check the economic reasoning of turning to alternative energy is to sum up the damages, the cost of energy and the cost of corrective changes, all these as a function of the extent of the changes. Unfortunately, to calculate exactly where the total cost is minimized, very accurate data are required. **However, if we are lucky, equation 1.1 is solved very easily. In our case, it has been proven that $R \to \infty$ and in effect it turns out to be even negative. This is all one needs to approve of the technology.**

Issues associated with the use of fossil fuels that would be factored in would include:

1. **Air pollution.**
2. **Damage to human health and the associated health costs/ loss of productivity.**
3. **Reduced solar radiation and changes in crops.**
4. **Ecological damage of various kinds, including acid rain.**

All the above externalities could come close to the nominal cost of the fuel.

5. **165 countries committed themselves to Kyoto Protocol - thus, it may be said with confidence that there is a consensus that global warming is a reality.**

   The problem confronting developed and developing countries with increasing energy needs, is what to do about it. Certainly, the continued and increasing use of fossil fuel is acknowledged to be problematic. Countries such as China, with burgeoning energy needs will inevitably turn to burning coal in alarming quantities, should no alternative be offered.
6. **Penalty for not meeting the Kyoto Protocol demand is unavoidable.**
7. **In the opposite, one can sell today credits for permitted pollution.**

Fossil fuels - particularly oil based products, leave economies vulnerable to the following issues:

1. **Sensitivity to price rise and worse, price fluctuation. It has been demonstrated that variability and instability of fuel prices can cause a reduction in the gross product of a country of several percentage points.**
2. **Large investments in security and defense become inevitable and may reach even twice the nominal cost of the fuel.**
3. **Political dependence on foreign regimes for fuel supply.**

4. **It may be observed that the unequal distribution of fuel sources is not a negligible factor in present day cultural wars and terrorism.**
5. **Alternative energy sources unevenly distributed around the world can do damage to developing nations.**

"Energy Towers" can uniquely lead to several important politico-social contributions that are not directly related to the production of electricity per se. As you may observe, as the numerator in equation (1.1) increases in value, (*and it does so even without factoring in any anticipated climatic changes*), and EC in the denominator vanishes or even becomes negative, then the advantages of the Energy Tower concept become immediately salient. As someone once remarked - "The Stone Age did not end because humanity ran out of stones, because stones became expensive or even environmentally damaging". The same may be said one day that the Early Industrial era has been depended on fossil fuels. It is the time now to move to a new age. It is recommended to read an article by Prof. Dan Zaslavsky called "New Horizons for Renewable Energy" published by Neaman Institute in Technion, in mid 2007. This article shows that nearly 60% of the use of fuel can be replaced almost right away using the criterion of equation 1.1 above, mainly by three groups: improved efficiency in energy use; the use of the classical fruits of the sun, and by solar radiation to supply heat. The "Energy Towers" technology brought here makes the achievement of coming out of the "Fuel Age" definitely possible with several added values to nearly 100%.

1.4 Project considerations and review

When reviewing a project of this nature, a number of important factors need to be thoroughly investigated. These can be analyzed as a series of interrogations into the project rationale and methodology.

<u>Issue no.1</u> - Computation of the net power production and desalination output

This is a long list of highly diversified questions related, among others, to the following:

- The source of the energy utilized by the technology stems from the famous Hadley Cell atmospheric circulation. This produces the world's arid land and carries in the order of 2-4x10^{16} kWh heat/year which is a fraction of the incoming solar energy over the equatorial and arid belts on the northern and Southern part of the globe (about one part in 20). There are some estimates of the heat involved which are much higher;

- Thermodynamic principles of energy transformation such as transformation of heat to mechanical energy;
- Climatic conditions of temperature, humidity and wind speed in the Tower's profile up to some 1.5 km above ground every hour of the day and all days of the year;
- The effect of prevailing wind in enhancing or reducing the net power output;
- Measurements and computation of energy loss coefficients;
- Experimental coefficients of the rate of evaporation of water spray;
- Geometry of the air flow in the shaft;
- The type of turbines and method of their optimization and control;
- Variations in geography;
- Water supply;
- Design of pumping energy system;
- Water spraying method, water filtration and collection of salt spray, spray excess and distribution over the top entrance, etc.

The detailed resolution of these issues has been derived using computational methods, wind tunnel tests and actual tests in a demonstration Energy Tower. Experiments about droplets behavior were run also at a 1:1 scale. These results indicated a requirement for several optimization decisions to decrease the cost-benefit ratio of running an Energy Tower, which were subsequently implemented.

Eight different computational methods used by different people besides the analytical formulation led to results which did not differ by more than a couple of percent. 1:50 scale chimney tests came within $\pm 20\%$ of the calculated outputs. This is with a safety factor knowing that much lower Reynolds numbers must lead to lower rates so that the results are conservative.

Unfortunately, many attempts to compute the net deliverable power made by casual reviewers were not particularly thorough, and were deficient in physical and engineering reasoning. A common error was, for example, to make incorrect assumptions about the rate of air flow, independent of a coherent view of the overall performance. Their result was a determination that the Tower simply could not work. Our determination of the rate of airflow was obtained through an engineering decision to always aim for the maximum net output, and this potential problem is therefore circumvented. Most important - several independent computation methods were compared and all of them were compared with experimental results.

***Issue no. 2* - Available technologies**

The policy of the development team was to avoid, if at all possible, the need to develop new basic technologies or new materials. With the exception of one case, this rule was thoroughly maintained.

A superficial review led some to think that the dimensions of the structure would pose a serious problem. This is not the case. The one problem where the team came closest to walking on untreated ground was that of the method for eliminating non-evaporated saline spray from the air at the base of the Tower. This problem initially appeared intractable. Fortunately, an elegant solution was found which has been theoretically and experimentally checked.

All engineering decisions for the project have been conservative. Rules of dimensional analysis were used when necessary, using different scales for different processes. Finally, commonly used safety factors were used.

The tendency of some reviewers to factor in additional safety parameters, over and above those required resulted in artificial computational errors, and an invalid conclusion that the project was non-viable or unnecessarily expensive. Probably the most outstanding remarks were made by a senior in the Ministry of Finance. One such pearl was: "If it were a good idea someone would have already built it" his second statement was: "according to our experience every thing eventually costs twice and takes twice the time to finish". The development team's representative could not hold himself already at this point and told him: "Having the same experience we have already multiplied every figure by two." This character happens to come from the famous school that: "do not approve of any budget for design unless they have approved first of the project execution". (This is not a joke).

All the project's technical elements have been thoroughly reviewed more than once by outside experts. As an example, one of the leading firms in the world which has installed about 20% of all power stations, reviewed the turbines, the pumps and the generators that constitute about 2/3 of the whole investment in the project. They said they are ready to produce all of them, and their

estimation was that the cost would be about 30% lower than what has been estimated by the development team.
One of the most important reviews of the structure was at the request of the Minister of Energy. The conclusions were summarized in seven volumes, where the following were checked: the forces involved, the best choice of materials, the best choice of geometry and the best choice of construction procedure. This amounts to about a quarter of the investment. He has also estimated that it could be done with about 30% investment.

***Issue no. 3* - What environmental problems and communal external costs are eliminated, and what others are created?**

There are several major environmental problems which will be reduced by the Towers:

- **Environmental damage due to the use of fossil fuel in conventional power stations and by transportation;**
- **Water shortage and desertification processes, which are prevented by providing cheap desalinated sea water;**
- **Salinity damage due to over-pumping of aquifers, evaporative salinization of agricultural land, and the accumulation of brackish drainage water which spoils ground water and arable land in many sites in the world.**
- **The limitations of conventional aquaculture are due to lack of land for ponds near the sea shore, and the expense of pumping water inland. Another problem with traditional aquaculture is pollution of the marine environment. These problems can be alleviated by combining aquaculture with Energy Tower technology. First, filtration before spraying the sea water into the Tower will eliminate suspended solids. Then, the heavier brine will tend to flow slowly on the sea bottom and spread over large areas with very small mixing. It will gradually diffuse and be diluted to the point that the change can hardly be measured.**

Additional related environmental benefits are due to supplying protein from fish which requires only about 1 kg dry food per kg fish. This compares to 2 kg dry food per kg chicken, 3 kg for 1 kg pork, and 5 kg dry food per one kg of beef. Thus, we save land and fresh water by turning to protein supply by fish.

Over fishing in the sea can be eliminated. Notably, since 1950 till present, the fishing has been increased from about 20 million tons to 95 million tons. Sea over fishing threats the very existence of fish population. The potential around the Energy Towers will easily exceed 130 million tons of sea fish growing in ponds and large addition to irrigated lands.

About a dozen relatively minor environmental problems are created by the Energy Towers. The overall conclusion is extremely positive by any measure. However, this did not prevent the development team from working to overcome the most important of the specific environmental problems posed by the Tower.

- **Among the environmental problems caused by the Tower are: possible salinization of the surrounding area by water spray ejected from the base of the tower; sea water leakage from the feeder canals and reservoirs; the environmental impact of returning concentrated brine to the marine environment; cold and humid wind; visual "pollution"; vocal noise; electromagnetic noise; disturbance of air traffic; disturbance to free movement of animals; sucking migrating birds into the tower and shadow projection around the Tower.**

The most serious problems are the first three: salinization by sea water. After a very extensive research we have demonstrated that they can be eliminated by a proper design.

- **Probably the most exiting aspect raised recently is that the towers may provide a real mechanism to reverse the global warming effect. This is beyond the reduction of greenhouse gas emission. It is really by improving the global cooling mechanism. Moreover, the towers have a positive feedback in the sense that in a warmer world the production of electricity and water will be increased.**

Issue no. 4 ***- What is the economy of this technology, measured by common economic yard sticks, compared to the economy of conventional energy sources?***

The difficulty confronting zero emission electricity production is that existing technologies are either too expensive or too uncommon, or both. For example, the potential for expanding hydro-electric power is negligible, and existing projects may be adversely affected by climate change.

The economic justification of the Energy Towers is based, in the first analysis, on the cost of electricity only. Electricity from the Towers was found to be competitive with conventional electricity from coal, oil, nuclear sources and natural gas. However, added benefits may

increase the income over and above the opportunity prices for the electricity, and even double it (see table 2). Under the conditions in South Arava near Eilat and the grants by the State of Israel the additional income over the replacement price will exceed 6 or even 7 ¢/kWh. The internalization of the communal external costs from environmental damage and strategic problems add another dimension to the economic evaluation, leading possibly to the largest additional advantages. The environmental cost advantage caused by burning oil or coal has been estimated to be of 6-7 ¢/kWh electricity and it is not less than 2 cents for burning natural gas. Some items add to the commercial value of the Towers and some have a national importance of a macro economic nature.

We have estimated the risk that the cost of electricity production will be larger than projected.

The risk is small (a standard deviation of about 20%). This risk will become even smaller with the standard error reducing to about 10% after the first stage in the suggested work program. We have assumed that the cost with 10% interest rate is rounded up to 4 ¢/kWh, and then we have assumed 40% upward error. A larger error has a probability to happen less than one part in thousand. Once we reduce the standard error to 10%, this probability reduces to much less than one part in then thousand. Then with the anticipated added benefits, the income can certainly be above 10 ¢/kWh. The t**ypical return period is then 4-5 years and the Internal Rate of Return may even exceed 25% and will not be lower than 20%. This is still not without the additional benefits.**

<u>Issue no. 5</u> - The potential of the technology and possible marketing

How much hot and dry air is there, and what part of it can be readily exploited; how far can electricity be transferred from the locations where it can be economically produced; to what extent do the Energy Towers need backup by conventional fuel, etc?

Global electricity demand increases about 2.5% per annum. In addition, a further 2% capacity must be added annually to replace old stations. Global consumption is presently estimated to approach 14 thousand billions kWh/year. The theoretical global potential for power generation from Energy Towers is about 15-20 times this figure. The annual demand increase adds up to 630 billion kWh per year, every year.

It would be quite realistic to assume that the Energy Towers' share can grow into at least half of this figure or at least some 300 billion kWh /year, every year (nearly 50% of the

market). Notably, a single full scale Energy Tower of a standard design in the South of the Arava Valley, which lies between Israel and Jordan, would provide a little above 3 billion kWh per year for delivery. This means that the market will be for at least 100 new Towers per year, or an investment of about 100 billion dollars a year. However, this figure might be tripled. Be it because a larger part of the market or investment in the byproducts that will add to the size of the market considerably.

There are about 40 countries where "Energy Towers" could be used with relatively high efficiency. Modern electricity transmission lines of high voltage D.C. can be used to carry the electricity 3000 km away, for not more than 1¢ /kWh. This is enough to cover some additional 30 grades North and South. Thus, in the Northern area of the globe - Greenland and North of Alaska and the Northern part of Siberia and Scandinavia are excluded. The Southern area of the globe has little land.

The farthest mass of land and population from sites of "Energy Towers" seem to be China and Korea, the farthest point close to 5000 km away from Pakistan and India where electricity can be produced using effectively the Energy Towers. This marketing capacity will not be reduced if the transmission cost will be higher.

<u>Issue no. 6</u> - What is the state of the project and what steps are necessary to complete it?

Development has been essentially completed. The development team is confident enough to advocate at this stage that preparations should be made as soon as possible to start erecting the first full scale commercial unit.

In order to answer some of the questions in this category, a work program was prepared with nearly 15 major work groups and incorporating some 70 different tasks (table 24). The original plan was to design a full scale Tower and to undertake to comply with the statutory requirement to locate sites for the first commercial units. The plan also included proposals for further improvement of the technology and marketing efforts.

Some interested parties considered the erection of a pilot plant on the scale of 1:7 or above 50 MW average output as redundant. This is despite the fact that the electricity production costs of such a Tower (about 700 x 200 m) are still attractive. The Israel-India Steering Committee, which has been investigating building an Energy Tower in the State of Gujarat, decided on a 1:3 dimensional scale for a demonstration plant before proceeding to a full scale commercial unit. The demo-plant is defined by its residual value, as determined by its future electricity production and sales. The size of this demo-plant was estimated to be 400 m height and 150 m diameter, or 600 x 100 m, with a net energy production above 6.5 - 10 MW. There are several conclusions to be drawn:

- (1) One can build an economical viable Tower with dimensions which do not raise doubts due to the unusual size construction; However, it should be clarified beyond any doubt that the size will deter only those ignorant in the field of structural engineering and it has no other rational justification.
- (2) The problem is really that the cost is still high enough and the necessary time is rather long for just an intermediate experimental development stage. The chances are better to find another way to gain confidence and start earning profits as soon as possible.
- (3) There are basic differences in climatic behavior between the lower 300-400 m and the rest of the tower's height. Thus, a small size pilot is not really fit for learning.
- (4) The most important issue in making sure that the future design is operational the way it has been anticipated is strict quality and reliability assurance. And this demand cannot be replaced by a pilot and will not be alleviated even after several full scale stations have been built.

Basically, there are, in principle, three possibilities:

- A full scale plant for maximum profit and the strongest push for further advance;
- A middle scale plant with reasonable profit and possibly some additional benefits;
- A small scale plant with only spending - a long unnecessary delay and very little gain in know-how, if at all.

The common qualities are that each one of the three will require 4 years to erect, and the erection cost of even the smallest alternative is financially heavy, for the duration of tests. The experience till now can be summarized that no investors were ready to join an experiment with no profit. Most of the interested parties were not aware of other ways to get the necessary assurances by the right way of design and performance procedures for maximum reliability and quality assurance which is the essence of modern industry. However, there are such ways that can be easily applied and they will be discussed in the following.

The first stage of the work program included design, specifications and quotations by qualified contractors. **By then, the standard deviation of the electricity production cost estimate would**

have been reduced from about 20% to less than 10%. The actual meaning in practical terms is that an error assumed before of 40% in the electricity cost a larger error has a probability in the order of 1/10,000 or less. (This is to have an error larger than two times of the standard deviation). Getting a better estimate of the cost with only 10% deviation this means that the probability for an error larger than 40% is larger than four standard deviations, which means an unbelievably rare chance of failures not at all common in standard engineering.

This early work should include also the statutory process to build a power station in a specific site. It should include a promised pay for the electricity and for the byproducts.

Adding a very careful assurance of quality and reliability by competent contractors and other careful procedures, will be enough even without a pilot, and no pilot should be a substitute for the right design and erection performance.

One is not free not to have the most strict quality assurance even after building a pilot - we should therefore go directly to the full scale with very strict reliability and quality assurance. If we are lucky, the economical margins would be so large that the probability to have an error larger than this margin would become absolutely negligible. This happens to be the case.

1.5 Reviews of the concept in the scientific and technologic literature

In the following discussion, some of the main scientific and technological reviews of our concept will be discussed, in the way of providing a general overview.

In 1999, 13 volumes of a work summary were completed by the request of the Israeli Ministry of National Infrastructures; some 2500 pages in total. **The net deliverable output at this time was estimated by independent teams using 8 different computation methods. The differences were no more than 2-3% over a range of parameters. The computed results were tested in a wind tunnel and in a 21 m height demonstration shaft.**

Since 1999, at least 17 research brochures were presented to the Israeli Ministry of National Infrastructures. Among the subjects handled were 1:1 tests of spray production of different drop size distribution and rate of flow, with or without electrostatical load; methods of collecting the sprayed brine droplets to meet the strictest standards against saline pollution; there were actual tests of the turbine model; there were studies on the Tower's production and optimization, etc.

Significant improvements were obtained in the output, however, the data provided in the following are those that we received before these improvements.

The first reviewing committee

The first expert reviewing committee nominated in mid 1983 included 12 members, each in a different discipline. This committee was nominated by Prof. Haim Eilata and Eitan Gur-Arieh, the Chief Scientist and the Head of R&D Division of the Ministry of Energy, respectively, in 1983. They worked on the project for several months, and all their conclusions were positive. This committee warmly recommended that the project be promoted and given a high priority.

The second reviewing committee

In 1994, the Israeli Minister of Energy, then Mr. Moshe Shachal, nominated a 7 member expert committee, headed then by Prof. M. Sokolov of the Tel-Aviv University, to review the project. Among the committee members were two experts in thermodynamics and hydrodynamics; an expert in weather physics (climate in general and rain formation in particular); a structural engineer; the Chief Scientist of the Ministry of Energy; an electrical engineer with a wide experience in erecting different types of power stations; and the head of R & D at the Israeli Electric Corporation. Each one of them employed his own professional team. The Committee also hired professionals for special tasks such as redesign of the main shaft construction by Prof. Yair Tene. It also consulted representatives of the Water Commission for the State of Israel, the Ministry of Commerce and Industry and the Ministry of Environment. The work continued for more than a year, and 18 special brochures were prepared for the reviewers at their request. The committee's conclusions were:

- **All physical principles were proven and re-proven beyond doubt.**
- **The project can be built completely by proven technologies.**
- **There is a broad economic advantage compared to conventional sources of energy.**
- **There are several knowledge gaps that could be bridged, and these would have a high probability of further improving the overall economy of the project.**

There was one notable reservation by Prof. Zehev Levin, the meteorologist. He argued in a special letter of reservation that, according to his results, the output is only 1/3 of what was estimated by the development team. A later publication by him argued that he managed to get a ten fold output (!). The reviewing team had very serious reservations regarding Prof. Levin's statements that have changed from one meeting to another and demonstrated, beyond all kinds of fundamental errors, also a bad spirit. Recently, a French physicist (Denis Bonnelle) with no ties to the project, has written an extreme critique of Levins et al:

"The reason why I didn't speak much about your project is that I knew it mainly through a scientific paper ("Numerical Simulation of Axi-Symetric Turbulent flow in Super Power Energy Towers", by Shalva Tzivion, Zehev Levin and Tamir Reisen, from Tel Aviv University), which you'll find attached, and whose results are peculiar (viz. fig. 5 and 6)." Bonnelle notes that Levin's analysis includes several fundamental mathematical and physical errors, and his observations mirror some of his original comments.

Much work has been done since. Different aspects of the idea have been confirmed and reconfirmed and significant improvements have been made, as predicted.

The third reviewing committee

More recently, ***the project was confirmed by a review of over 70 scientists and technologists from India's Technology, Information, Forecasting and Assessment Council (TIFAC).*** **On May 10th, 2000, TIFAC approached the State of Israel to cooperate on future work to build a large demonstration plant and commercialize the project.** A positive answer was given by Israel in a letter from the Minister of National Infrastructures.

A mutual Steering Committee convened in Jerusalem a year later, in May 21-24, and this committee issued the following action points:

a) ***Both governments of Israel and India should take action to promote the project for the benefit of the two countries.***

b) ***A demonstration plant should be built with an average output power of 6.5-10 MW. The dimensions should be such that once constructed, the demo-plant could recover at least its operating expenses from future electricity production.***

c) ***The development team estimated that in order to meet the Indian requirements the dimensions of the demo-plant should be about 400 m height and 150 m diameter, or other equivalent dimensions. The investment needed for all the preparatory activity to the point where a full scale commercial construction could be initiated is about***

100 million dollars. This includes the cost of the demo-plant which would be about half of this sum.

d) ***A site should be chosen for the full scale commercial unit. As many extra benefits of the Energy Towers should be incorporated as possible, without loosing sight of the main purpose of producing cheap, reliable electricity.***

e) ***The Indian delegation declared their intent to raise about half of the needed investment. In the immediate stage, over a maximum of 18-24 months, cooperation between teams in Israel and India will be initiated as much as possible with an intermediate budget (up to 3 million dollars). They will be bound by mutual secrecy agreements.***

f) ***A more comprehensive agreement on rights should be prepared at a later stage when the large sum financing becomes a reality.***

Changing the Indian Ministry administration possibly due to some kind of political shuffle, has caused large delays. A work program and report were prepared by a subsidiary of "TATA", and were very positive, however, these have never been officially presented. Some clerks wrote to the Energy Towers' development team that "… the Tower site is too close to Pakistan and too far from the sea". This is a completely unjustified nonsensical response, in fact shear nonsense. The development team and the Israeli Ministry could never clarify what happened. Moreover, the man in charge in "TATA" unofficially told us that the results of their work were extremely positive and attractive. However, he was not allowed to send us a copy.

- ***The most recent review was undertaken by Environmental & Resource Technologies Pty Ltd., of Australia. In parallel with the critical check of the output and cost, they were actively looking for sites and negotiating different forms of cooperation. This Australian group requires the initial prototype Tower to be a relatively large one, at 1:2 scale, or about 1:7 of the output, an average of some 50 MW.***

- ***The Israeli Ministry of National Infrastructures has summarized the work program with Alstom - HydroPower to design a full scale unit of about 350 MW and 1200X400 m Tower. The Israeli official representative nominated by them was Uri Wirzburger.***

An obstacle in the path of developing this technology is that experimenting with a large model is expensive, and investment requires a serious commitment to the technology. Other renewable technologies may produce more expensive electricity, in fact much more expensive such as 3-5 fold, but they can be installed in a modular fashion. However, those alternative solar installations work only one third of the day; **notably, to produce the same product, these installations require an area of about 24 times larger** (when compared with the structure of the Tower alone, and 8 times more when the fish pond area is included). Thus, an initial investment which is easier to obtain (despite the diminished potential returns) is preferred by industrialists without imagination and by clerks without any understanding. On the other hand, the confidence of Alstom, as indicated by their letter of intent, should give investors in this project confidence. Alstom has built about 20% of the power stations in the world. They have specialist expertise in hydro power pumps and turbines and generators. So far, they have checked the output, the hydro design, and seen no difficulty with these. They have also estimated the cost to be some 30% less than the development was estimated. They have been looking for a partner in the construction field, so that they will be in a position to do a similar check of the remainder of the investment, and then, they can jointly work to build a full scale power station. Alstom have had economical problems and everything was messed up.

- **In Israel a series of meetings took place between the experts from the ministry of infrastructure with the right members from the Prime Minister Office and the Ministry for the Negev and Galilee Development.** They have decided that the Energy Towers should be declared by the government as a national infrastructure project and be promoted. It was very clear that the "Energy Towers" project would be the most significant contribution, not only to the Israeli Neghev, but to Israel as a whole and to the Western global culture. There was already a date set for the meeting to confirm it. Mr. Peres literally threw it below the table because he thought that it will hurt his declaration of the "Peace Valley Canal". Every expert in the country considered the Peace Valley Canal" as a prattle which would be a real danger to both Israel and Jordan. It has been proven not only an economical nonsense, but it would lead to three literally disastrous environmental problems.

1.6 Some technical details

The thermodynamic principles and the power source of energy

The phenomenon of a downdraft by a water spray has been well known for centuries. In the last few decades it has been studied extensively due to its dangerous effect on aviation. It is often referred to as "**wind shear**". **The "wind shear" effect is caused by an occasional cloud shedding rain in an arid air. A downdraft is caused typically at 20 m per second speed and a diameter of one km. The "Energy Tower" technology is in effect the containment of the process of wind shear inside a tall and large diameter hollow shaft with an open top and openings around the bottom** (see figure 1 at the beginning of the article). Rain is replaced by a continuous spray of water at the top. The water partially evaporates and cools the air from dry bulb temperature to close to its "wet bulb" temperature (see fig. 3). The cooled air is denser. As an example, air cooled by 12 degrees centigrade is approximately 4% heavier than the ambient air (a pressure difference of some 480 Pascal in a 1200 m high cooling tower). The heavier air then falls down and comes out at the bottom. More dry and warm air is sucked in from the top and the process continues endlessly. It is exactly the opposite of an updraft of hot air in a regular chimney. The flowing air drives turbines and generators that produce electricity. A part of this power is used by pumps that push water from a water source to the bottom of the tower and then onward to the top of the tower to be sprayed across the diameter of the shaft. A rough partition of the energy components under conditions in the Southern part of the Arava Valley in Israel (1200x400 m tower, 40 km away from the sea and 80 m above the sea level) is given in figure 2 below.

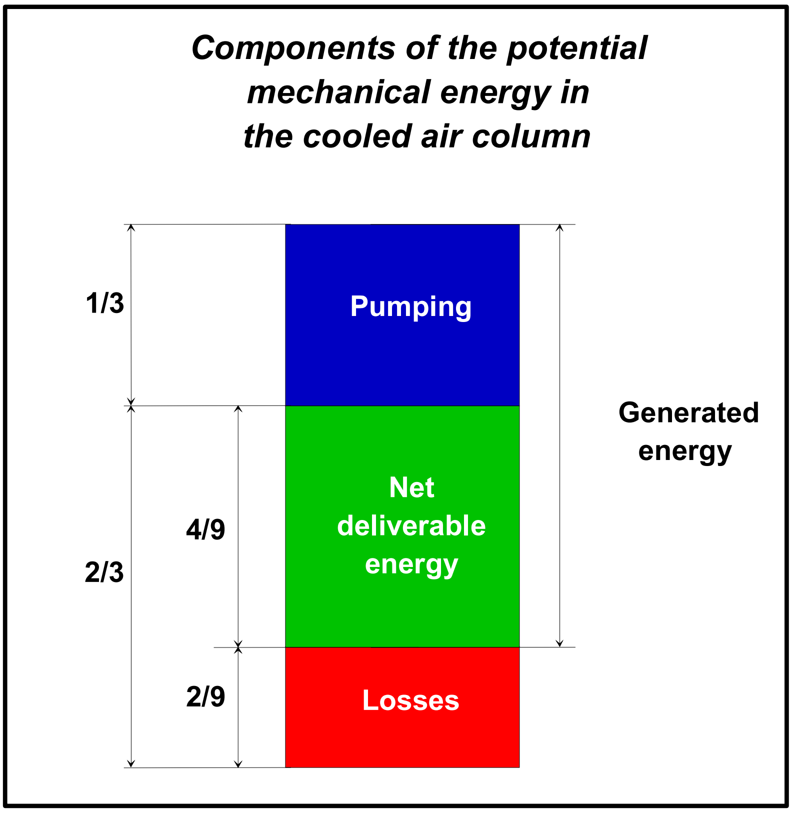

Figure 2 - Components of the mechanical energy North of Eilat

Using several independent methods of analysis, a medium size model (21 m high, about 1:60), experiments and wind tunnel models (about 1:2000); we have proven the following statements:

Under a wide range of conditions one can produce more electricity than is needed for pumping.

a) For example, in the Southern Arava, north of the City of Eilat, the mechanical energy is apportioned approximately as follows: 4/9 for electricity delivery, 3/9 for pumping and 2/9 as energy losses as the air flows through the shaft (see figure 2, above).

b) The mechanical energy is a certain fraction of the heat taken out of the air and is about 0.7 to 0.8 times the highly familiar term $(T_{maximum} - T_{minimum})/T_{maximum}$ which is in our case dependent almost exclusively on the height of the tower H_c . T_{max} is the outside air temperature at the base of the shaft and T_{min} is the outside air temperature at the apex. The overall efficiency of turning heat to mechanical energy is then roughly equivalent to

$0.7\frac{H_c}{30000}$ where $H_{c,}$ (the shaft's effective height) is in meters. (As an example - assume dry adiabate curve and $T_{max}\,300\,\text{Kelvin}$, $\left(T_{max}-T_{min}\right)\cong\frac{H_C}{100}$).

Interestingly, the overall efficiency for turning heat into mechanical energy for 1200 m cooling height is only 2.8% and the efficiency to net deliverable electricity is in the specific case about 1.2%.

This simple description may be somewhat optimistic in that the outside air temperature may change less than in "dry adiabate".

The concept of the Energy Tower as developed by this team, may be compared favorably with the older technology, the "Solar Chimney", which utilizes an updraft of air, warmed by an expensive solar collector at the base of the tower. Despite the similarity between the updraft chimney and the present downdraft shaft, the updraft technology has severe limitations. The following analysis details the inefficiencies inherent in an updraft chimney utilizing a solar collector. This "Solar Chimney", promoted by Prof. Schlaich of Stuttgart, Germany, operates under different conditions to the concept developed by our team, although it obviously occupies the same branch of the genetic tree, when viewed from an evolutionary perspective.
Assuming 50% efficiency of a solar collector, which is roughly needed to heat the air by the solar collector in the case of an updraft driven Solar Chimney, the overall efficiency would be at best 0.6% for a 1.2 km chimney. The value was actually measured by Prof. Schalich's team in South of Spain (Almeria). It was less than 0.1% efficiency for a smaller chimney. Multiplying the height by 6 to reach 1.2 km chimney, one gets an overall efficiency no higher than 0.6%. We shall avoid here to further elaborate on this issue. Moreover, the efficiency of the solar collector, and energy losses from flowing air under the collector, lead to high mechanical losses and reduced considerably the electricity production. From about 2200 kWh/year solar incidence on a horizontal square meter in Israel, one then gets at most 11.5 kWh/m^2/year electricity. The actual figure would actually be less. If the solar collector cost is only 50 \$/m^2, or 5 \$/year/m^2/year, including investment return and interest and operations and maintenance, then the contribution of the collector alone to the electricity cost is 42 ¢/kWh. This would impact on the economic viability of the project, and render it uncompetitive. Interestingly the area needed to produce 1

million kWh/year is well over 75,000 m^2 of a solar collector. The area of the Energy Towers structure is about 250 square meters per million kWh per year. This means that the solar chimney's area is 300 times larger. If we assume an overall efficiency of 10% of some solar technology it would lead to 4500 m^2 to produce 1 million kWh/year. This would be the theoretically net area. In practice it will turn to be not less than 6,000 m^2. As we shall show later, the necessary structural area needed to produce 1 million kWh/year with the Energy Towers would not exceed 250 m^2. So, the three areas relate to each other as 300 to 24 to one, respectively. The promoters of the Updraft Chimney and especially the Australian group "Enviromission" do not clarify these points. The anticipated costs of production ratio is roughly 16 to 4 to 1, respectively.

It was in an attempt to avoid this problem, among others, that lead Professor Zaslavsky to the concept that has been investigated by "Energy Towers" - the avoidance of the need for a solar collector. Energy Towers do not require a solar collector. The Energy Tower utilizes atmospheric hot air, which can be made to flow at very high rates through the energy shaft. ***The Energy Tower is a wind producing machine that can operate 24 hours a day. The older Solar Chimney technology could only operate efficiently for 6 - 8 hours a day, and would need expensive adaptations to allow it to operate at night. For this reason, Professor Zaslavsky's team rejected the Solar Chimney concept, and instead opted to design a "wind shear" generator, that would tap into the readily available heat potential energy of the Hadley Cell circulation - the "Energy Tower".***

c) The net deliverable power N [Watts] of an Energy Tower can be expressed succinctly by the following:

$$(1.2) \quad N = A_c \eta_t \left(\frac{2}{3} E_{net}\right)^{3/2} \frac{1}{\sqrt{F\rho}}$$

Where:

- A_c is the cross-sectional area of the main shaft [m^2];

- η_t is the efficiency of the turbine - transmission - generator aggregate [-] (say 0.85);
- E_{net} is the net mechanical specific energy (per unit volume of air) [Pascals] which can be computed as the sum of the excess static pressure of a cooled air column (E_C) minus the pumping energy required for spraying a certain amount of water per cubic meter of air (E_p) divided by η_t plus the recovered energy of the non-evaporated sprayed water (E_{Ri});

$$E_{net} = (E_C - \frac{E_P}{\eta_t} + E_R)$$

- ρ is the average air density [kg/m^3];
- F is the energy loss coefficient [-].

The total energy losses per unit volume $E_{Losses} = \left(\frac{Q}{A_C}\right)^2 \rho F$ and $F = \left(\frac{A_C}{A_D}\right)^2 + f$;

- f being the loss coefficient due to frictions;
- $\left(\frac{A_C}{A_D}\right)^2$ being the loss coefficient due to throwing of Kinetic energy out of the Tower base.

This formula is a result of an analysis showing that the term $\frac{2}{3}E_{net}$ in parenthesis gives the theoretical maximum possible net deliverable power and that exactly $\frac{1}{3}E_{net}$ is devoted to energy losses. The rate of air flow Q [m^3/sec] can then be expressed by:

$$(1.3) \quad Q = A_c\left(\frac{2}{3}E_{net}\right)^{1/2} \frac{1}{\sqrt{F\rho}}$$

Interestingly, the ratio N/Q is

$$(1.4) \quad \frac{N}{Q} = \eta_t\left(\frac{2}{3}E_{net}\right)$$

independent of the loss coefficient F.

E_{net} increases more or less in proportion to the Tower height and the extent of average air cooling. Thus the taller the Tower, the more electricity is produced /cubic meter of air or /unit weight of sprayed water.

While equations 1.2 and 1.3 can be proven analytically, the loss coefficient F has been the subject of extensive experiments in wind tunnels and subject to several independent analyses using Computational Fluid Dynamics (C.F.D.).

In a 1000 m Tower, the net power N for delivery makes about 1% of the heat involved in the water evaporation which is provided by the hot air. The amount of electricity produced is about 5-6 kWh/m^3 **sprayed water. It is closer to 9 kWh/m^3 evaporated water.**

Great efforts have been made to estimate each one of the parameters in equation 1.2. Most of the calculations were made for the average values of the climatic conditions. This renders some degree of conservatism (over 3% power) because the average power is higher than the power at the average conditions. The energy loss coefficient - F, was measured in wind tunnel models. Here too, it is certain that the real loss coefficient will be smaller and the net power higher. A characteristic value of F in the wind tunnel model was 0.85. Using a Computational Fluid Dynamics Model, it is estimated that F may be decreased in the full scale to 0.7 mainly due to Reynolds numbers in the order of 10^8 compared with 10^5 in the wind tunnel. The net power increase may be 10%.

The loss coefficient F is made up of two parts. One part is due to friction losses which, in the full scale, can be reduced to about 0.5. A second part depends on the amount of kinetic energy lost in the out-flowing air. To be exact, this part is almost exactly equal to the inverse of the ratio of outlet areas (A_D) to the cross sectional area of the Tower (A_C) squared which was called the "air flow slowing ratio". Notably, here we find another good advantage to the Energy Towers compared with the solar chimney with updraft heated air. The reason is that it is possible to slow down the outgoing air in the Energy Towers by a factor of 2 or 3. This is practically impossible in the solar chimney.

(d) Regardless of how large the loss coefficient F is, it is impossible to obtain a negative figure for N, the deliverable power from equation 1.2. As long as $E_{net}>0$, large F can reduce the net deliverable output to the point where it is not commercially attractive. However, it cannot turn the net deliverable electricity

negative. High losses do not lead to a negative net outcome, as some reviewers mistakenly suggested. This is because F multiplies the term of the Kinetic energy $\frac{\rho Q_a^{\ 2}}{2A_c^{\ 2}}$.

(e) The fundamental question is whether the produced electricity exceeds the electricity consumed for pumping. The answer to this question depends on the sitting of the Tower, the climatic conditions, and other variables that will be unique to each installation. As an example, in the base line design, 40 km from the Bay of Eilat, 80 m above sea level, we get positive net deliverable energy, but, every additional 100 m elevation of the tower base above sea level will reduce the net deliverable electricity by about 5%. A tower based one kilometer above the level of the water source will have even under the same climatic conditions only half the net deliverable power.

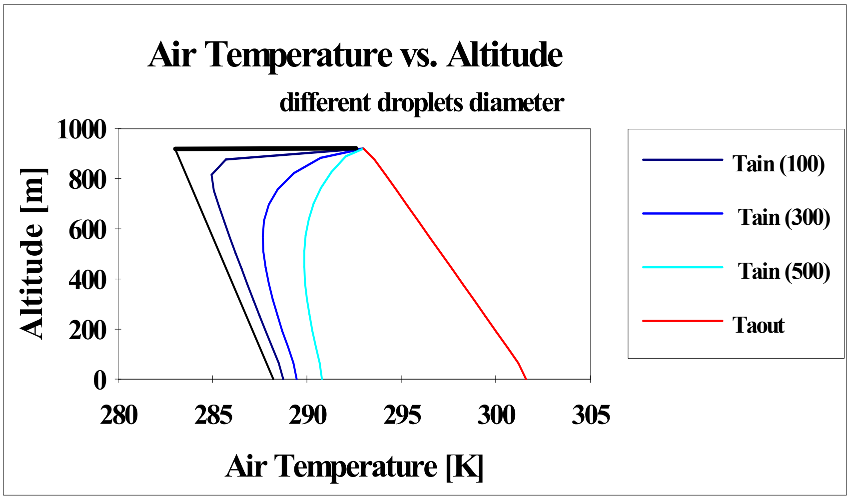

Figure 3 - Temperature change with elevation (Left line - inside air, half centigrade per 100 m, assumed to follow wet adiabate assumed to warm downward; Right line - outside air, one centigrade per 100 m, assumed to follow a dry adiabate assumed to warm downward In reality, on the average downward warming is less than a full degree centigrade per 100 m. The other three lines are for droplets average sizes of 100 Microns, 300 & 500)

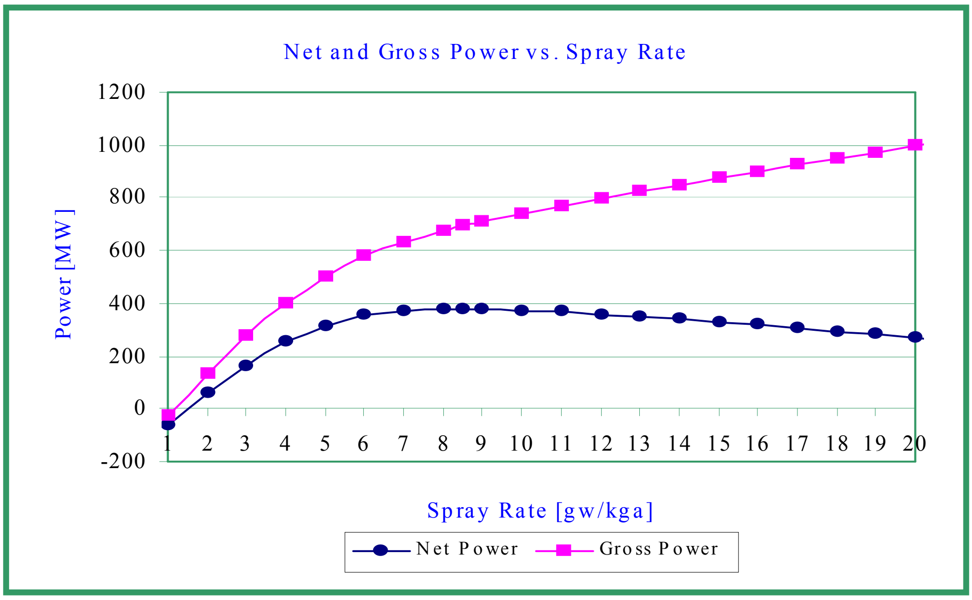

Figure 4 - Gross and net power vs. spray rate in grams of water /kg air

The cooling of the air is gradual as in figure 3. The right hand line shows the temperature of the outside air, assuming here that it follows a dry adiabate of about 1 centigrade per 100 m. The other lines, on the left, are the cooler inside air. These lines approach asymptotically a wet adiabatic line with a temperature gradient of slightly less than 0.5 centigrade per 100 m.

In figure 3, the cooling rates with spray droplets of 100 microns in diameter, 300 microns and 500 microns are observed. The more water sprayed and the finer the droplets, the more efficient the cooling. However, more energy is then used for pumping. The extent of the usable potential of the mechanical work depends on the area between the left side lines and the right side line, which expresses how much the inside air column, is cooler and heavier than the outside air. **The optimal droplet size must be chosen, by factoring the economics of smaller droplets for better cooling and larger droplets for lower energy spending for pumping and spraying, and also to prevent spray drift.**

Figure 4 shows another optimization of spray rate for net deliverable power of a given Tower, at given climate conditions and a given droplet size. In figure 4, one can see the gross power as a function of the spray intensity (in grams of water per kg air). **The gross power is extremely important because it can be used when pumped storage is utilized.** For an explanation, see also section 1.8. It is possible to fill an elevated reservoir with water during hours of relatively low electricity demand. During hours of high electricity demand, there will be no need for all or part of the power for pumping. Thus, the electricity delivery rate can rise from the line of net output in figure 4, and comes close to the upper line in figure 4 of gross power. This is a dramatic advantage over other forms of renewable energy sources which have no way of conforming the supply to the demand - although some hydro schemes use pumped storage, and return water to the dam during off-peak periods. It is a built-in capacity of the so called "pumped storage", however, with practically zero energy losses as compared to over 30% losses in common forms of pumped storage. The economic value of this quality is nearly 2 ¢/kWh under the conditions of the Southern Arava Valley and the electricity tariffs in Israel. In the above examples, it means a possible increase in the output from 400 MW to 700 MW.

In summary, it is necessary to choose the optimum droplet size and the optimum excess water spray in order to optimize the Energy Tower at a specific site. This is in addition to optimization of the turbine settings that determine, among other things, that the energy loss will be very nearly the optimal value of $\frac{1}{3}E_{net}$ (eq. 1). There are still some other optimization items.

Power calculations

As we have mentioned, the power and the flow were computed using 8 different methods: an analytic method which was indispensable in order to understand the physics of the whole process; 2 calculations of a one-dimensional model that simulates in reality a three dimensional flow by using the energy loss coefficient from wind tunnel model simulations; 4 different two-dimensional formulations of the flow with cylindrical symmetry and a three dimensional flow simulation using two modern techniques of computerized fluid dynamics. The cylindrical symmetric computations and the three dimensional computations employed a turbulence model called $(k-\varepsilon)$. **We practically obtained the same results using all eight methods, with the exception that the energy loss factor found in the wind tunnel model was larger than the one found in the C.F.D. model with Reynolds number 3 orders of magnitude larger.**

Recently, a new, more advanced grid has been composed to compute more complicated cases of tower operation. This may be especially useful for cases with strong outside wind and for regulating both the water spray distribution at the top and the turbines around the bottom for maximum net deliverable electricity output. We hope to further refine and improve our geometrical design and power control methods.

The computation is done with a model of 5 parallel computer units. For the full size, the three dimensional computation takes 5 days to obtain one result. One of the interesting outcomes is that the figure used in most of our economic computations the estimated output was over 15% conservative. When the grid density was gradually increased, the resulting output increased also asymptotically. The errors also decreased logarithmically.

Several other optimization cycles were a part of the design effort. These include among others:

a) A choice of the right type of turbines, decisions about the speed control and control of the guide vanes and runner blades. Variable speed turbines with AC-DC-AC electricity systems seem most attractive.

b) Choice of optimal aperture area of the turbines (0.6-0.7 of the cylinder cross section).

c) Choice of optimal slowing ratio (AR) due to diffuser sizes and opening angles between radial vertical walls and between the floor and the ceiling downstream from the turbines (totaling 2-3 times the crossection area of the cylinder).

d) The shape of the top air inlet to minimize the high energy losses which are possible in the presence of outside wind. (Radius at least half the radius of the cylinder and turning multi direction wind flow to a vertical one).

e) Choice of optimal height and diameter of the Tower. (The overall optimum seems to be between 3:1 to 5:1 height to diameter).

The computation must be made for a specific Tower at a specific site. It can be done for the specific temperature and humidity air profile, every hour of the day. In many computations, we oversimplify the computation for different reasons, according to various assumptions:

a) Assuming the outside air profile follows a dry adiabate temperature obtained by the air at the top pf the Tower which is to be directed down the tower;

b) Annual average climatic conditions;

c) Different wind profiles;

d) One dimensional flow computation, choosing large coefficients and optimal air speed to best represent the real flow. This is to shorten the computation time from several days to a fraction of a second in order to be able to map the performance over the whole year across a continent, such as Australia.

Figures 5 and 6 show the average net power outputs and the annual energy outputs as a function of the tower net cooling height H_C and the diameter D_C for a slowing ratio AR=2 (A_D/A_C). Where, a first approximation of H_C is the height from the ground to the top end of the straight cylindrical shaft; A_D is the total area of the outside outlets at the bottom; A_C is the crossection area of the cylinder.

The site under discussion here is 40 km North of Eilat, Israel, and 80m above sea level (near Yotvata).

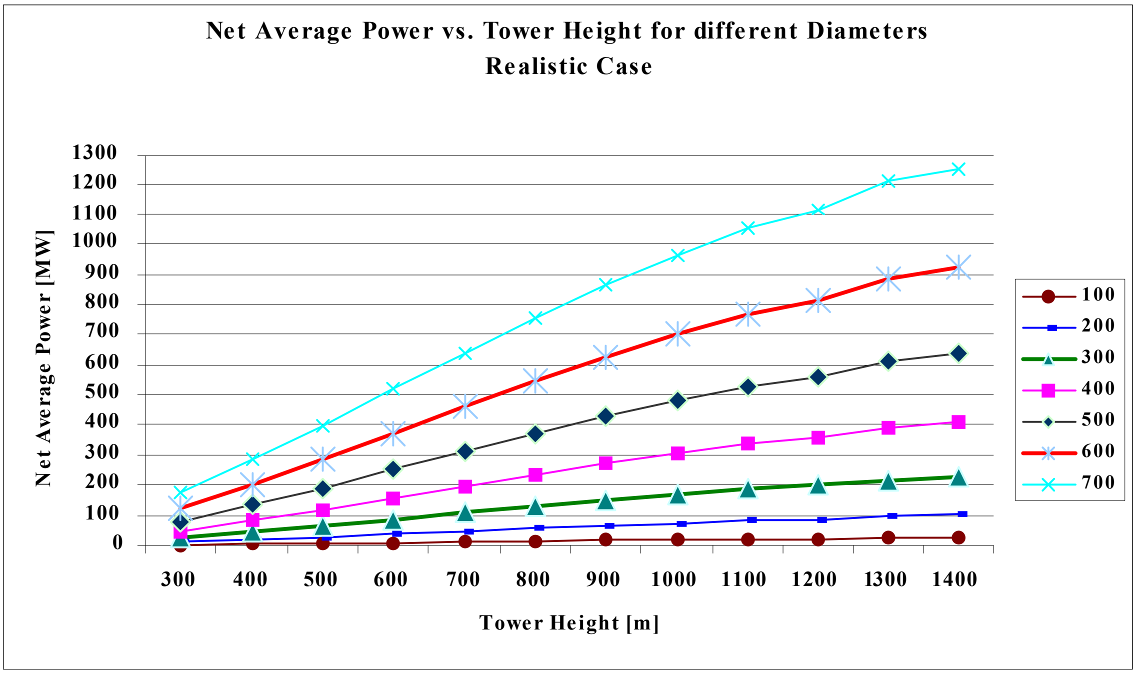

Figure 5 - Net average power vs. tower height for different diameters (AR=2)

[near Eilat, Israel] [AR=A_D/A_C] (see fig. 1)

Notably, the net deliverable power increases roughly with the linear dimensions of the Tower. If the same proportion is maintained between the height and the diameter the power increases very close to the third power of the linear dimension.

As the rate of airflow and the rate of water spray increased as the square root of the height (eq. 2), the net deliverable output increases linearly with the Tower's height. This is at least one reason to construct tall Towers.

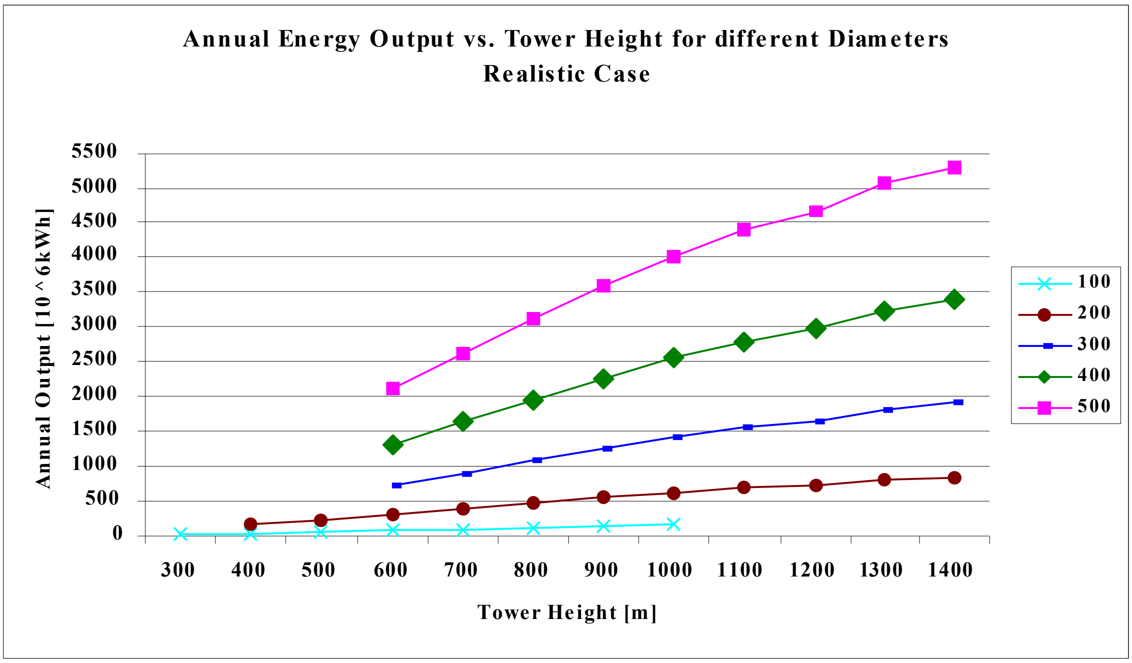

Figure 6 - Annual energy output vs. tower height for different diameters (AR=2)

[near Eilat, Israel] [AR=A_D/A_C](see fig. 1)

The structure

The structure is the most obvious reason for many people to worry and ask questions about the feasibility of the technology. However, this has been the least problematic of the design considerations. At least three designs were made using reinforced concrete; however, it became very obvious that a steel frame is the preferred construction type. There is one exception when one intends to load a water reservoir for pumped storage on the Tower itself. There exists a specific problem of shear stresses

Four independent design efforts were made. The main forces to consider, as with all tall vertical structures, are wind forces and it is important to measure these concretely in wind tunnels and using modern computational methods. Earthquake forces, even in the most active areas with horizontal accelerations of over 0.3 g, do not present a serious design problem, as these forces are only a fraction of the anticipated wind forces. There exist a specific problem of shear stress due to relatively movement of continental blocks. This calls for some methods to release the stresses that are produced between foundation and the upper structure.

We have used structural geometries that have fixed angles between bars of only 2 lengths. A consideration is that the geometry utilized has redundancy built into its geometrical stability. Even if a large airplane were to puncture a hole in the structure, the lines of force within the structure would bypass the damaged area and the structure would remain stable.

The geometry is repetitive and the diverted load effectively fills the space. The inventor of this family of geometries, Prof. Michael Burt, calls it "I.P.L." (Infinite Polyhedral Lattices). See for example figure 7.

The structural effort has been summarized in a whole volume of over 250 pages. Nomograms of the structural dimensions and weights were composed using some generalized parametric description. The single points of the different designs fitted very well. Thus, costs could be computed and optimal choices made. Extrapolation and interpolation helped us with estimating the structural costs as a function of different dimensions.

Prof. Yair Tene has written a 7 volumes review of the structural design ordered by the Reviewing Committee. He studied alternative materials, alternative geometries and alternative methods of erection. His conclusions were, among others, that the cost of the steel structure could be reduced by 30% compared to the design made by the development team.

As mentioned above, a reinforced concrete structure could become a preferred alternative only if a top reservoir of water should be installed on the structural top.

It should be noted that a 800 m office building is in the process of construction and it is far more demanding than an empty cylindrical shaft.

Possible shear of the foundation is more important to meet than just earthquake acceleration.

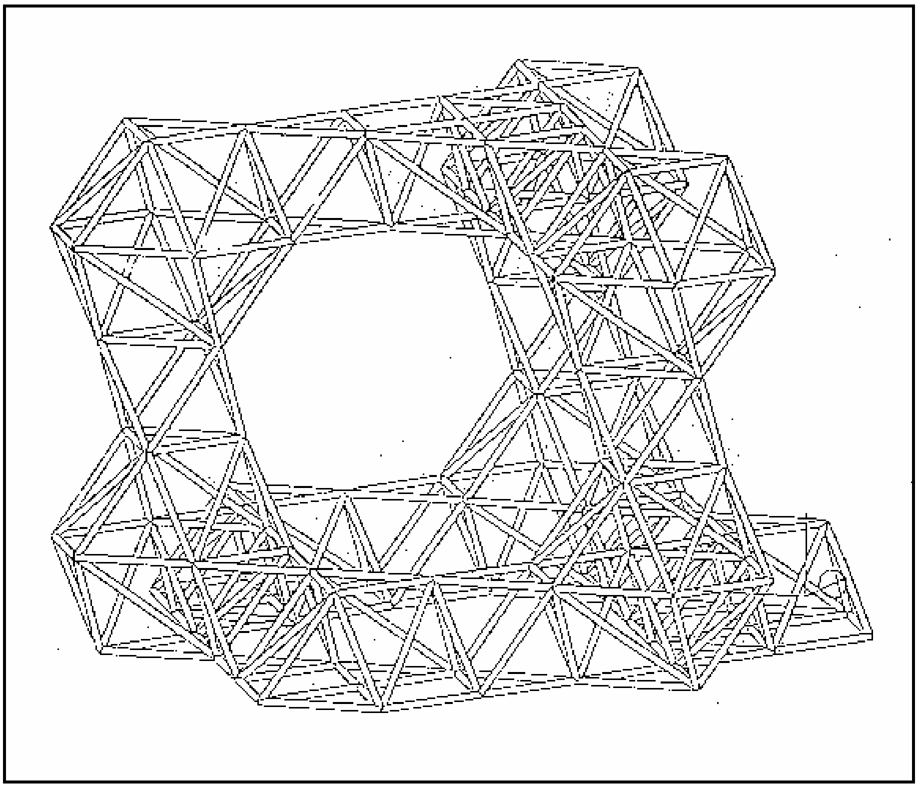

Figure 7 - I.P.L. geometry structure

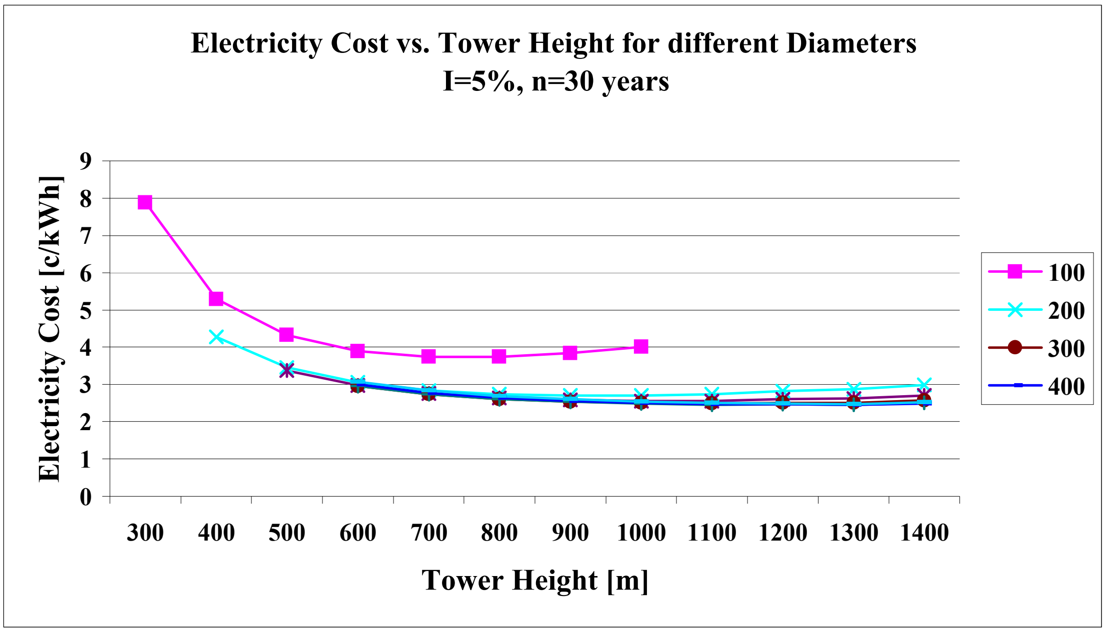

Figure 8a - Electricity production cost from Energy Towers with 5% discount rate

[near Eilat, Israel]

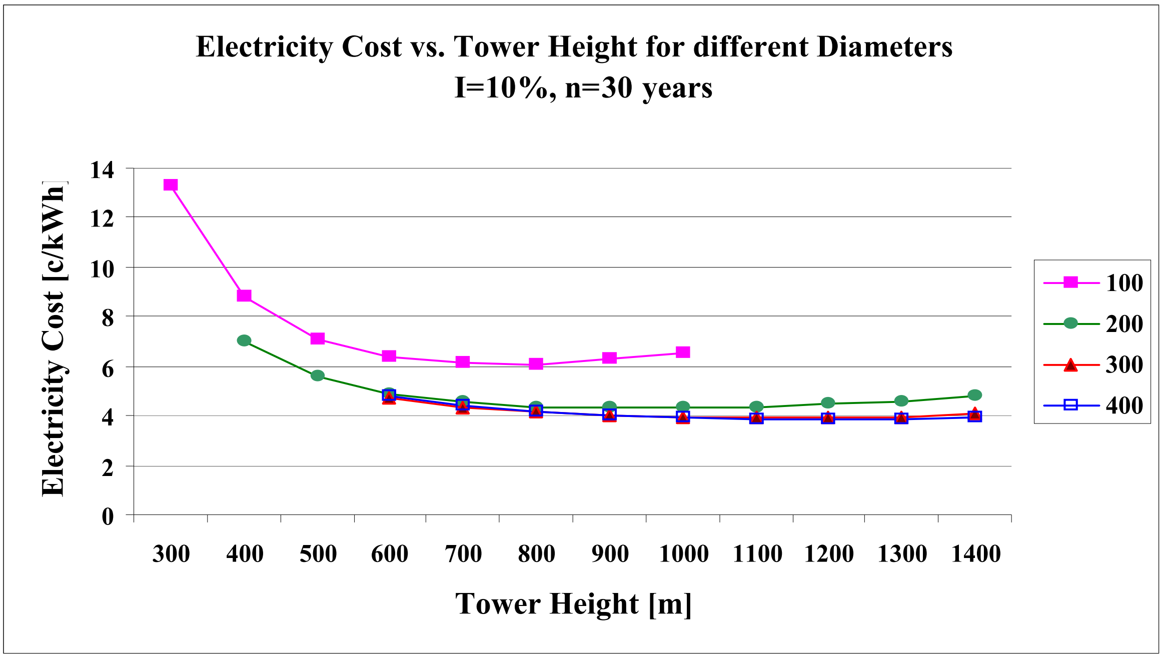

Figure 8b - Electricity production cost from Energy Towers with 10% discount rate

[near Eilat, Israel]

Tables 1 and 2 show the computed net deliverable power and the annual net electricity delivered for different Towers dimensions, near Eilat - Israel. The investment in the tower construction is given in table 3. The electricity production cost is given for 5% discount rate and 10% discount rate in tables 4 and 5.

Table 1 - Net average output (MW) for different tower dimensions for AR=2

[near Eilat, Israel]

		Height (m)											
		300	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**
Diameter (m)	**100**	2.4	4.6	7.0	9.5	12.1	14.6	17.0	19.3	21.3	22.7	24.7	26.4
	150	5.7	10.7	16.1	21.7	27.4	33.1	38.6	43.7	48.2	51.2	55.8	59.6
	200		19.5	29.0	39.1	49.3	59.4	69.0	78.0	86.0	91.3	99.7	106.1
	250			46.1	61.8	77.8	93.5	108.6	122.6	135.0	143.3	156.4	166.1
	300				90.2	113.1	135.8	157.4	177.5	195.3	207.2	226.1	239.4
	350					155.6	186.3	215.7	242.9	266.9	283.2	309.0	326.3
	400						245.3	283.6	318.9	350.0	371.4	405.2	426.5
	450							361.3	405.7	444.8	472.1	514.9	540.2
	500								503.5	551.3	585.4	638.1	667.2

Table 2 - The annual energy output (10^6 kWh) for different dimensions and for AR=2 availability is 0.95 [near Eilat, Israel]

		Height (m)											
		300	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**
Diameter (m)	**100**	20	39	58	79	100	121	142	161	177	189	206	220
	150	48	89	134	180	228	276	321	363	401	426	465	496
	200		162	242	325	410	494	575	649	716	760	829	883
	250			384	515	647	778	904	1020	1124	1193	1301	1382
	300				750	942	1130	1310	1477	1625	1724	1882	1993
	350					1295	1551	1795	2021	2221	2357	2572	2715
	400						2042	2360	2654	2913	3091	3372	3550
	450							3007	3376	3702	3929	4285	4495
	500								4190	4588	4872	5310	5552

Table 3 - Total investment in towers ($M) of different dimensions, for AR=2

[near Eilat, Israel]

		Height (m)											
		300	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**
Diameter (m)	**100**	21	26	32	38	46	56	67	80				
	150	42	51	60	71	83	97	113	131	149	168	192	220
	200		87	101	117	135	156	178	201	225	247	277	310
	250			156	179	205	234	264	295	325	352	388	428
	300				260	296	335	375	415	452	485	530	579
	350				359	407	458	511	562	609	648	705	763
	400				483	546	613	680	745	803	851	921	992
	450				636	717	801	886	966	1038	1097	1183	1268
	500				822	923	1028	1133	1231	1319	1392	1497	1598

Table 4 - Cost of electricity production in Towers of different dimensions; discount rate 5%; operations and maintenance taken as 0.556 ¢/kWh; construction time 4 years, with investment spread over 4 years: 20%, 20%, 30%, 30% ; project life 30 years [near Eilat, Israel]

		Height (m)											
		300	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**
Diameter (m)	**100**	7.88	5.29	4.32	3.90	3.74	3.74	3.84	4.01				
	150	6.67	4.53	3.68	3.27	3.08	3.00	3.00	3.05	3.14	3.30	3.43	3.63
	200		4.27	3.46	3.05	2.84	2.74	2.71	2.71	2.74	2.81	2.87	2.99
	250			3.38	2.97	2.76	2.64	2.58	2.56	2.56	2.60	2.63	2.71
	300				2.96	2.74	2.61	2.54	2.50	2.49	2.51	2.51	2.57
	350					2.74	2.61	2.53	2.48	2.46	2.47	2.46	2.51
	400						2.64	2.56	2.50	2.47	2.47	2.45	2.50
	450							2.60	2.54	2.50	2.49	2.47	2.51
	500								2.60	2.55	2.54	2.51	2.55

Table 5 - Cost of electricity production in Towers of different dimensions; discount rate 10%; operation and maintenance taken as 0.556 ¢/kWh; construction time 4 years, with investment spread over 4 years: 20%, 20%, 30%, 30% ; project life 30 years [near Eilat, Israel]

	Height (m)											
Diameter (m)	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
100	13.29	8.79	7.10	6.37	6.10	6.10	6.26	6.57				
150	11.19	7.48	5.99	5.27	4.94	4.81	4.81	4.90	5.05	5.33	5.56	5.91
200		7.02	5.60	4.90	4.54	4.36	4.29	4.30	4.35	4.48	4.59	4.80
250			5.47	4.76	4.39	4.19	4.08	4.04	4.04	4.12	4.16	4.30
300				4.74	4.35	4.13	4.01	3.94	3.92	3.95	3.96	4.06
350					4.35	4.12	3.99	3.91	3.87	3.88	3.86	3.95
400						4.18	4.04	3.94	3.89	3.88	3.85	3.93
450							4.11	4.01	3.94	3.93	3.89	3.96
500								4.10	4.03	4.01	3.96	4.03

1.7 The electricity costs

In figure 8a, one can see the estimated production cost of the deliverable electricity with 30 years projected life, 5% interest, 9.1% interest during construction and 0.556 ¢/kWh operation and maintenance expense (the assumption was 12 \$/installed KW). As we have shown, the increase of the thermodynamic efficiency corresponds roughly to the height of the tower. However, the net deliverable power grows at a power higher than 3 of a characteristic linear dimension of the tower. The actual costs presented in figure 8a reflect relatively low interest rates. In the business plan, it has been assumed there is a 20% owner's investment with a 16.5% return and an 80% loan at 8.5% interest for an average investment cost of 10.1%. **The cost at 10% discount rates is shown in figure 8b.**

An interesting relation between the rate of water spray and energy production can be inferred from equation 1.4. For a 1200 m Tower, 1 m^3 of sprayed water enables the production of 4-6 kWh deliverable electricity (the lower figure is for a higher rate of excess water spray). However, at half the Tower's height, the production of electricity/m^3 of water spray is also about one half. **Therefore, the cost of water supply and pumping is relatively less for a taller tower.**

All the above lead to the choice of very large tower dimensions.

Interestingly, as far as the electricity cost is concerned, there is a very wide and flat minimal range between the heights of roughly 700 m and 1400 m and for diameters of 200 to 500 m.

At the optimal dimensions, the cost of electricity in the South of Arava, North of Eilat, is 2.47 ¢/kWh with a discount rate of 5%, and 3.88 ¢/kWh at a 10% discount rate. This competes with every known technology, with the possible exception of very large hydro-power projects, especially cheap combined cycle projects with closely available natural gas sources (see the following table 6a). More recent updating of the costs must take into consideration a very significant rise in fuel costs. This is in part the nominal costs. However, defense costs almost triple the real cost of fuel. Thus, the following table is minimizing the actual advantage of the Energy Towers.

Table 6a - Characteristic electricity production costs (¢/kWh) by major electricity suppliers, for years 2005-2010 (1996 US dollars) (75% load factor, 30 years)

Replaced technology	**Cost extreme range**		**Representative average costs**	
	5% discount rate	10% discount rate	5% discount rate	10% discount rate
Nuclear	2.47-5.75	3.90-7.96	3.31	5.05
Coal	2.48-5.64	3.74-7.61	4.07	4.99
Gas	2.33-7.91	2.36-8.44	3.98	4.47
Energy Towers	1.68-3.93	2.51-6.42	2.47	3.88

Table taken from: "Projected Costs of Generating Electricity - Update" 1998, Published by Organization for Economic Co-operation and Development and International Energy Agency (OECD/IEA).

The last line with cost of electricity production in the Energy Towers takes its figure from table 7. Representative average rates are in the South part of the Arava Valley, in Israel, with average power about 370 MW. With Tower's deliverable output varying between 200 and 600 MW (table 7) one gets a range of anticipated costs. The cost figures in tables 6a and 6b were obtained long before the rise of fuel costs. At the same time, the cost of electricity from an Energy Tower was not adjusted due to the rise of steel costs from some $ 1400/t to $ 2000/t. The site we are using is an average site between 200 MW and 600 MW, as it can be seen in table 7. Finally, for a real comparison, it is necessary to subtract from the net electricity costs the different benefits and by-products of the Energy Towers which will exceed most of times the whole electricity nominal production costs. (In the example we use it may add up to over 6-7 ¢/kWh). An alternative way to look at it is to add 6-7 ¢/kWh to the replacement price received for the electricity which would be higher even than that in the right column in table 6a. From the sum of the two we can estimate the Internal Rate of Return (IRR) or the payback period (see fig. 16a, 16b, 16c and 16d).

Sensitivity tests show that the increase in fuel costs and reduced interest rates will make the Energy Towers more and more competitive in time. The cost of gas is 53-77% of the electricity cost in table 6a. ***Gas costs are expected to double***. At the moment this request is updated. They have tripled! Even a superficial observation of energy costs shows that there is a wide range of prices due to a wide distribution of economic parameters. The cost of electricity from the Energy Towers will be affected also by climatic and topographic conditions which vary widely, as will be later shown in table 7 and the following tables.

In the following is a somewhat more recent table of electricity costs, however, even this does not yet reflect the full hike of fuel prices and externalities.

Table 6b - Some updated cost information from the OECD of early 2007

Technology based on	Investment costs ($ US/kW) in 2005	Electricity generation costs (¢/kWh)
Large hydro	1,500 - 5,500	3 - 12
Small hydro < 10 MW	1,800 - 6,800	6 - 15
Wind onshore	900 - 1,100	3 - 8
Wind offshore	1,500 - 2,500	7 - 22
Geothermal	1,700 - 5,700	3 - 9
Solar PV	5,000 - 8,000	18 - 54
Solar thermal	2,000 - 2,300	10.5 - 23
Biomass	1,000 - 2,500	3 - 10
Ocean (current, tidal, wave)		5.5 - 16
Coal	1,000 - 1,200	2 - 6
Coal with CCS	1,850 - 2,100	4 - 6
Natural gas	450 - 600	4 - 6
Nuclear	2,000 - 2,500	2.5 - 7.5

Note that the very low costs mentioned concerning the use of photovoltaic cells and nuclear electricity costs are far greater. In a recent publication in "the economist" the minimal cost of electricity from nuclear reactors was 6.7 ¢/kWh. The cost of electricity from photovoltaics received from competing producers was 30-40 ¢/kWh. The same must be said about the solar thermal. The cheapest known technology by "Solel" was accurately estimated to cost 15.5 ¢/kWh. It seems that at least the lower electricity generation cost in the above table is a wishful thinking or some form of miscalculation. Furthermore, the right comparison of the investment should be for an average KW and not the installed kW. If one looks at the load factor of photovoltaic cell which is somewhat between 0.3 to 0.1, then the investment in the average KW would be 3-10 times higher. For the solar thermal, it would be also not less than three times higher for which it would be about 6,000-7,000 $ per average per KW. This is to be compared with $ 2300/KW for the Energy Towers.

A disadvantage of the Energy Towers, at least in their early application, is that they are not as economically attractive when constructed in really small dimensions and they require significant, initial capital investment.

The gross advantage is that other benefits are expected in addition to income from electricity sale.

The dimensions of a demo-plant suggested by India, and later by the Australian consortium, obtained different values at different times. The early requirement was that the net average output should be higher than 6.5 MW and it should not exceed 10 MW (by India). This required roughly the following dimensions and electricity costs at a 10% discount rate.

Power	Dimensions	Costs	Investment
6.5 MW	**316 x 150 m**	**10.44 ¢/kWh**	**$ 43.4 millions**
	445 X 100 m	**8.1 ¢/kWh**	**$ 29 millions**
10 MW	**400 X 145 m**	**7.61 ¢/kWh**	**$48.5 millions**
	550 x 115 m	**6.8 ¢/kWh**	**$ 41 millions**
	620 x 100 m	**6.3 ¢/kWh**	**$ 39.6 millions**

A 6.5 MW station can be built for an investment which does not exceed 30 million dollars, and a 10 MW station for 40 million dollars. Even at these very small dimensions, solar methods are not competitive. The cost of electricity production under the conditions near Eilat does not exceed 8.1 ¢/kWh and 6.3 ¢/kWh for 6.5 MW and 10MW, respectively. However there are several more reasons not to start with a small pilot. We have mentioned some of them in the above.

It has been suggested that a larger demonstration plant of at least 700x150 m or 700x250 m should be preferred, if at all constructed. The main reason is that the electricity is quite cheap for a 700 m high Tower. The second reason is that at this height, it is possible to desalinate sea water for less than 30 ¢/m^3. The investment would be 83 or 205 million dollars and the electricity production cost, at a 10% discount rate, would be 4.94 ¢ /kWh or 4.39 ¢/kWh respectively.

The values for 50 MW, as asked for by the Australians, require 700 X 200 m Tower, 49.3 MW, annual energy in the Arava $410X10^6$ kWh, 135 million dollars investment, and 2.84 and 4.54 ¢/kWh for 5% and 10% interest, respectively. With these projected costs, even wind energy does not compete even without the extra benefits of the Energy Towers.

1.8 The source of energy and estimated potential

The source of heat is a global air cyclic flow named after its discoverer **George Hadley (1735)**. Hot and humid air rises above the equatorial belt. The rising air cools, vapor condenses and rain is shed. The rate of air cooling as it rises with moisture condensation is about half a centigrade for every 100m. The air then turns South and north and descends back to the earth's surface from a height of up to 10 kilometers, at latitudes between 15 degrees and 35 degrees North or South. This belt moves a little from season to season. The descending air warms up, this time a full centigrade every 100 m. The relatively warmer air at high elevation and with little or no vapor left in the air is loosing heat to the outer space in a very efficient way. The closer to the ground the equatorial air becomes saturated the higher will be its temperature at the apex and the more efficient will be the cooling process.

High pressure air belts are formed. Finally, the air turns back towards the equator picking up moisture and heat again. The areas where this air descends become arid. **The hot and dry air forms the earth's deserts; it is not the desert that makes hot and dry air.**

Figure 9 shows the schematics of the Hadley Cell Circulation.

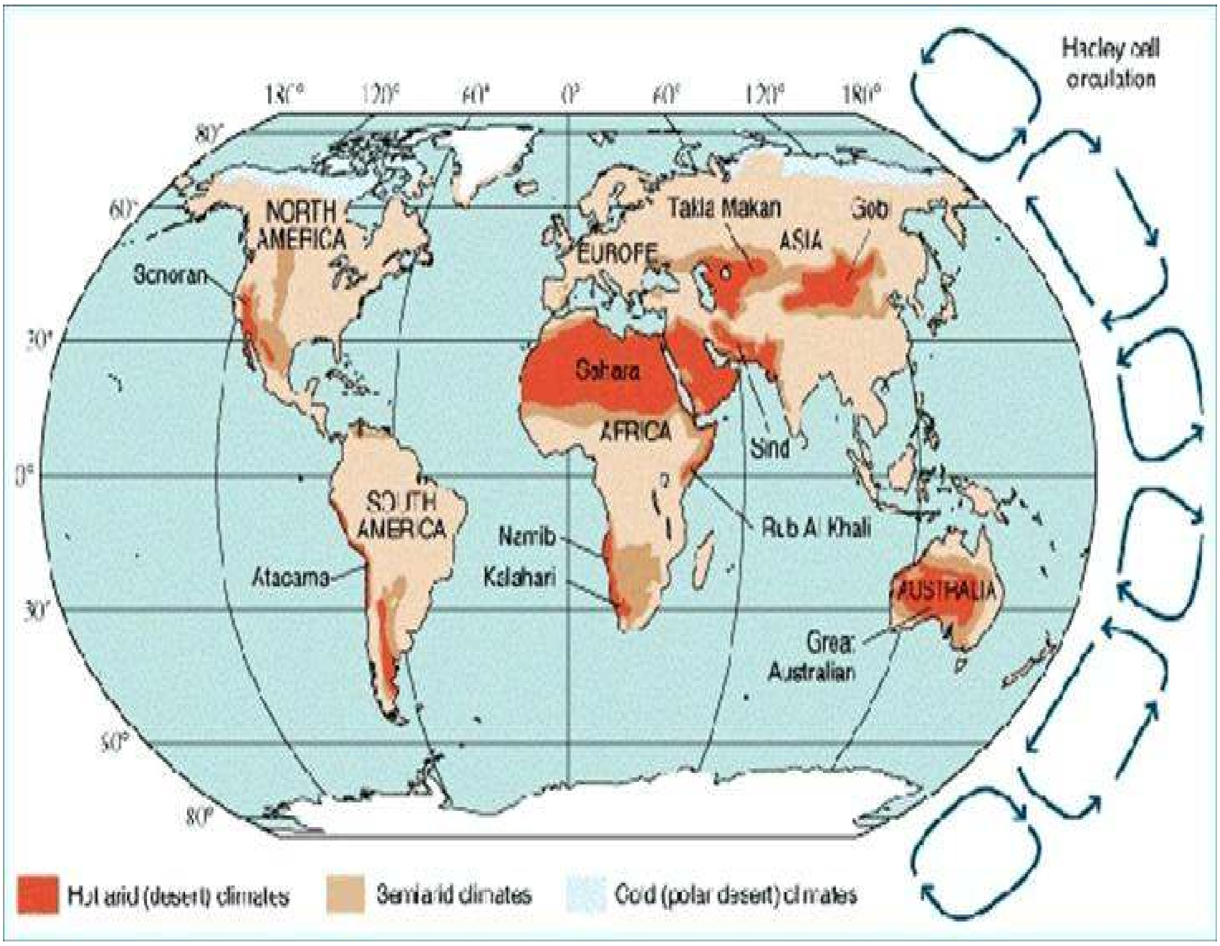

Figure 9 - The Hadley Cell Circulation with two arid belts

Figures 10a and 10b show the desert belts and arid lands painted yellow and bright red and marked by the letter "***a***". Several estimates exist of the global heat transfer which results from the Hadley Cell Circulation.

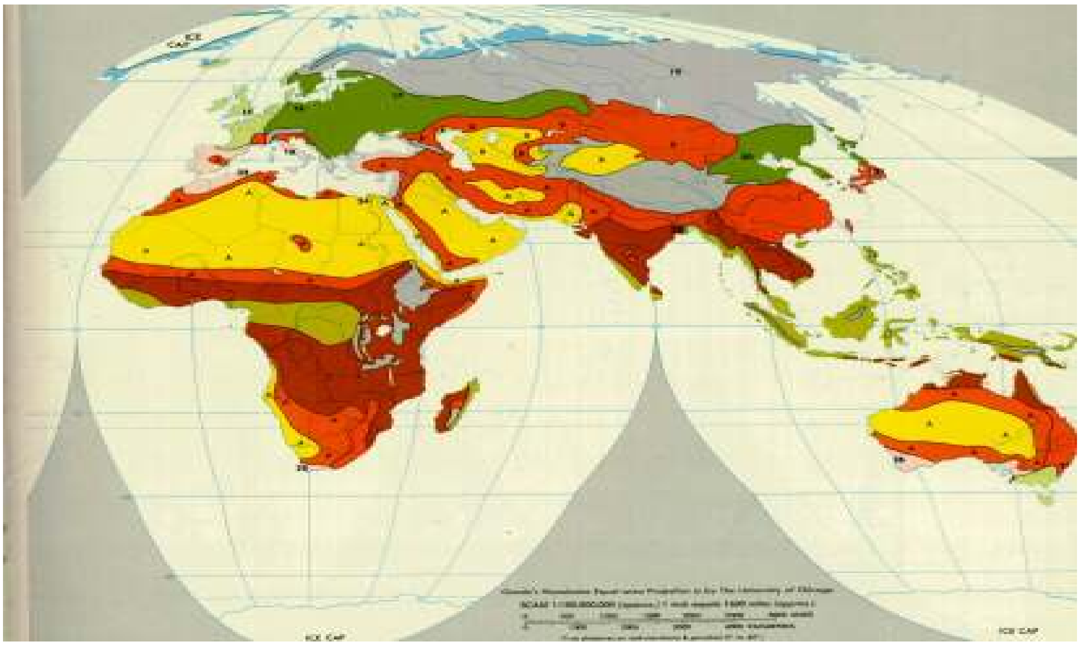

Figure 10a - Climatic zones in Europe, Asia, Africa and Australia. The yellow and bright red areas marked by the letter "A" are desert or arid lands

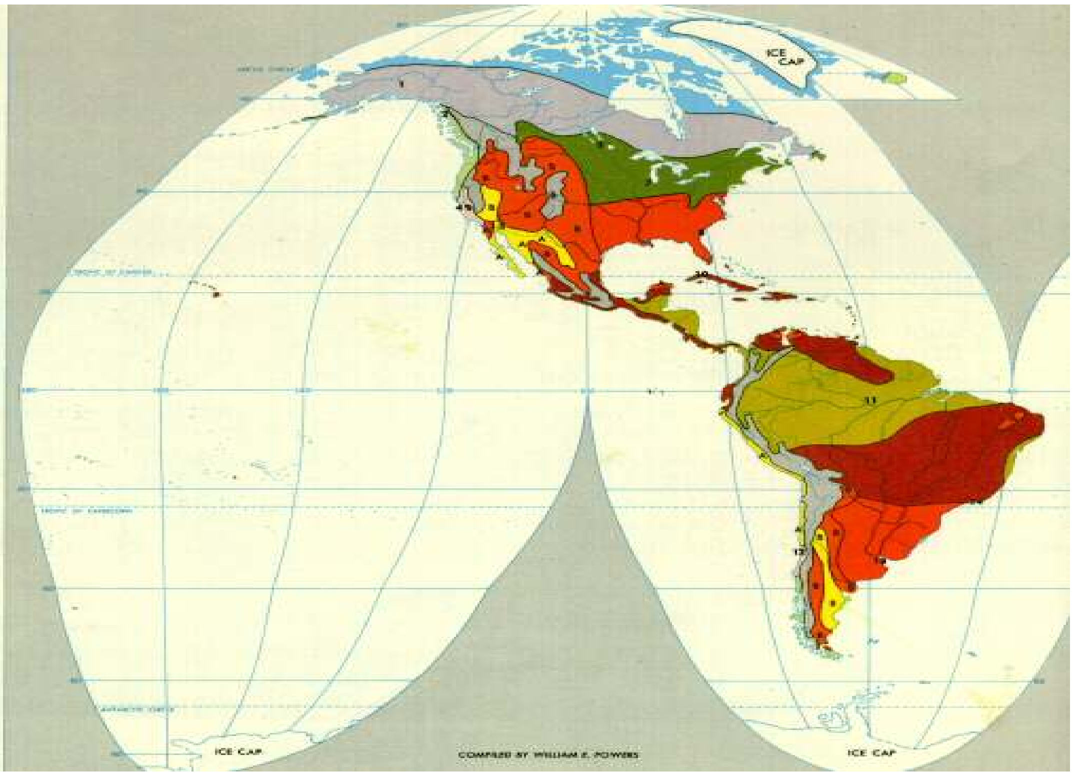

Figure 10b - Climatic zones in America. The yellow and bright red areas marked by the letter "A" are desert or arid lands

One estimate is over 17 million square kilometers of extreme desert and some 25 million square kilometers of arid lands have been formed by the descending air and extra heat.
The heat transfer is estimated between 2 and $4x10^{16}$ kWh/year. This assumes a typical rate of air descent is 1 cm/s and the cooling rate is 10-12 centigrades over arid areas. This heat transfer is about one part in 20 of the incident solar radiation over the relevant global belts.
The overall efficiency of turning this heat into electricity with towers of about 1000 m is in the order of 1%. The theoretical potential of producing electricity is then $2\text{-}4x10^{14}$ kWh/year.
The present global consumption of electricity is estimated as 13000-14000 billion kWh per year. This makes the present consumption one part in 8-30 out of the global potential.
Assuming the future use of all human beings of 5000 kWh/year/capita for 8 billion people, this theoretical quantity is sufficient for 5-10 times more than the population of the globe in the far future.
Recently, the development team has prepared an estimate of the world potential for energy development using a satellite set of measurement data (ECMWF) (by the European climatic mapping body) over 10 years, every hour, and at several elevations. In these somewhat simplified and conservative computations only data of 1200 m above the local ground level were taken into consideration with distances and elevations from and above a water source. The computation was made for a base line design tower of 1200 m height and 400 m diameter, it assumed a very inefficient water conveyance to the Tower of about one percent head losses. The results are summarized in table 7 and are organized in power groups of 50 MW average outputs from 200 MW and up to 600 MW. The number of possible towers was calculated assuming that each tower requires on the average a 400 square km open sky space for importing sufficient hot and dry air. Notably, this is a very conservative assumption. One can crowd Towers in a space less than 20X20 km. For example, into a Valley, such as the Arava Valley, the Towers will create a sink for the hot atmospheric air in a confined geographic space and thus, the installation of Tower at near by highly elevated ground is obvious. Thus, it is possible to utilize ground close to sea level, topographically lower ground, and not utilize as much area as assumed in the computation that led to table 7.
Hot air will flow not only vertically, but will drain from the surroundings. Thus, table 7 assumes a relatively conservative estimate. It may, of course, be offset to some degree due to different existing land uses that does not allow construction of Towers everywhere.

Each value from the satellite data represents 1.125x1.125 degrees on the map or about 125x125 km. In such a large area, it would be possible to find specific points of output much higher than the average across the whole area. As an example, the local results in the South Arava were 370 MW net deliverable outputs, while the representative average value from the satellite for this region in broad terms was only 210 MW. It is only natural to expect this result, because the Arava Valley is narrow. On one side there are 800 m high mountains and on the other side 1500 m high mountains. Remembering that every 100 m height above the sea level reduces some 5% of the net output, obtaining an average elevation of several hundred meters will naturally lower the computed output power by several tens of percents. This is another reason why we should anticipate table 7 to be very conservative.

The total annual power at this table is about 2.3 X 10^{14} kWh/year, about 1% of the heat flow through the Hadley Cell circulation. Thus, we roughly confirm our two former estimates at least by an order of magnitude, and show that they are very conservative.

The summary results at the bottom of table 7 are notable. The world potential, assuming 200 MW as the low economic limit, is 230,000 X 10^9 kWh/year, sufficient for 46 billion inhabitants at power consumption levels equivalent to those of Western Europe. Over time, it is possible that areas of less optimal climatic conditions could be developed, allowing outputs of between 100 and 200 MW. Characteristic areas with such lower performance are to be found in Southern Europe, Texas, Southern and Western parts of India, very large parts of Australia, etc.

Another very interesting possibility is the extremely low projected cost of electricity production in some locations. Theoretically, some 756 towers at costs lower than 1.9 ¢/kWh at 5% discount rate, and below 2.9 ¢/kWh at 10% discount rate can be constructed.

A more accurate computation for a specific system led to somewhat different results for at least two reasons. One is that in reality the outside temperature profile may not follow dry adiabate. The other has to do with the installation cost of the turbines that change from being used for pumping to provide energy and other methods that conform the supply curve to the demand.

Table 7 - The average net power range [MW] from Energy Towers and the total area (thousand of square kilometers) in the world for each range

Average net power (1)	***Area (2)***	**Number of required Energy Towers (3)**	**Annual energy for this area (4)**	**Electricity cost (5% discount rate) (5)**	**Electricity cost (10% discount rate) (6)**
[MW]	*[10^3 km^2]*	*[-]*	*[10^9kWh/year]*	*[c/kWh]*	*[c/kWh]*
550-600	69	173	839	1.68-1.78	2.51-2.69
500-550	233	583	2,679	1.78-1.90	2.69-2.90
450-500	1,017	2,542	10,579	1.90-2.05	2.90- 3.16
400-450	2,248	5,620	20,923	2.05-2.24	3.16 - 3.49
350-400	4,167	10,418	34,221	2.24-2.48	3.49-3.91
300-350	5,989	14,973	42,627	2.48-2.80	3.91- 4.47
250-300	8,597	21,492	51,775	2.80-3.25	4.47- 5.25
200-250	13,137	32,843	64,733	3.25-3.93	5.25-6.42
Total	**35,457**	**88,644**	**228,376**		

There are more ways to improve results from the installation of Energy Towers. As the elevation above sea level decreases by 100 m the net power increases by about 5%. A shorter distance from the sea will decreases the cost of the water conduits. Several or even many towers can be planned around one very large water conduit, reducing the cost of the water supply /tower.

It is possible to transfer the produced electricity a distance of 3,000-5,000 km, including under a large span of sea, for a cost of not more than 2-3 ¢ /kWh, and very possibly much less.

Following is the total potential for different regions in the world. All of them use the estimated head loss along the water conduit of one percent (i.e. 1 m head loss over 100 m conduits length). This assumption leads to a very conservative estimate of the electricity production.

Table 8 - Average net power, the area, the annual energy and the number of required towers for the region of North Africa

Average net power	***Area***	**Annual energy in this region**	**Number of required Energy Towers**	**Number of people served at 6000 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	-	-	-	-
500-550	15	171	37	28.5
450-500	147	1,533	368	255.5
400-450	558	5,165	1,396	860.8
350-400	887	7,382	2,217	1230
300-350	1,016	7,234	2,540	1206
250-300	1,828	11,107	4,570	1851
200-250	2,805	13,820	7,012	2303
TOTAL	**7,256**	**46,412**	**18,140**	**7735**

Table 9 - Average net power, the area, the annual energy and the number of required towers for the region of South and Equatorial Africa

Average net power	Area	Annual energy for this area in this region	Number of required Energy Towers	Number of people served at 6000 kWh /capita
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	-	-	-	-
500-550	-	-	-	-
450-500	55	549	137	91
400-450	281	2,615	706	436
350-400	337	2,768	842	461
300-350	320	2,277	800	380
250-300	401	2,415	1,003	402
200-250	1,346	6,632	3,365	1105
TOTAL	**2,740**	**17,256**	**6,850**	**2786**

Table 10 - Average net power, the area, the annual energy and the number of required towers for the region of India (Asia)

Average net power	***Area***	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Number of people served at 6000 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	-	-	-	-
500-550	-	-	-	-
450-500	-	-	-	-
400-450	212	1,951	706	325
350-400	299	2,456	842	409
300-350	385	2,743	800	457
250-300	518	3,120	1,003	520
200-250	1,180	5,816	3,365	969
TOTAL	**2,595**	**16,086**	**6,487**	**2681**

Table 11 - Average net power, the area, the annual energy and the number of required towers for the region of Saudi Arabia (Asia)

Average net power	**Area**	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Number of people served at 6000 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	41	501	103	83.5
500-550	110	1,270	275	212
450-500	184	1,920	460	320
400-450	155	1,450	388	241
350-400	113	931	283	155
300-350	199	1,420	499	237
250-300	156	942	391	157
200-250	70	346	175	57.7
TOTAL	**1,030**	**8,780**	**2,580**	**1463**

Table 12 - Average net power, the area, the annual energy and the number of required towers for the region of Persian Gulf (Asia)

Average net power	***Area***	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Number of people served at 600 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	69	836	172	139
500-550	177	2,040	443	340
450-500	193	2,013	483	335
400-450	82	764	205	127
350-400	95	787	240	131
300-350	41	294	103	49
250-300	14	83	34	13
200-250	14	67	34	11
TOTAL	**686**	**6,884**	**1,715**	**1147**

Table 13 - Average net power, the area, the annual energy and the number of required towers for the region of California and Mexico (North America)

Average net power	***Area***	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Number of people served with 10000 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	-	-	-	-
500-550	-	-	-	-
450-500	-	-	-	-
400-450	13	118	33	12
350-400	563	4,630	1,409	463
300-350	1,047	7,453	2,618	745
250-300	1,269	7,645	3,173	765
200-250	1,489	7,336	3,722	734
TOTAL	**4,382**	**27,182**	**10,956**	**2718**

Table 14 - Average net power, the area, the annual energy and the number of required towers for the region of Chile and Peru (South America)

Average net power	***Area***	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Number of people served with 6000 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	-	-	-	-
500-550	-	-	-	-
450-500	68	693	171	116
400-450	402	3,739	1,004	1123
350-400	622	5,110	1,555	852
300-350	997	7,097	2,493	1183
250-300	715	4,306	1,788	718
200-250	550	2,708	1,374	451
TOTAL	**3,354**	**23,653**	**8,385**	**3942**

Table 15 - Average net power, the area, the annual energy and the number of required towers for the region of Spain, Italy, Greece (Europe)

Average net power	**Area**	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Number of people served with 6000 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	-	-	-	-
500-550	-	-	-	-
450-500	-	-	-	-
400-450	-	-	-	-
350-400	-	-	-	-
300-350	-	-	-	-
250-300	114	655	284	109
200-250	553	2,665	1,382	444
TOTAL	**667**	**3,320**	**1,666**	**553**

Table 16 - Average net power, the area, the annual energy and the number of required towers for the region of Australia

Average net power	***Area***	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Number of people served with 6000 kWh /capita**
[MW]	*[10^3 km^2]*	*[10^9kWh/year]*	*[-]*	*10^6 people*
550-600	-	-	-	-
500-550	-	-	-	-
450-500	-	-	-	-
400-450	-	-	-	-
350-400	116	907	289	151
300-350	473	3,363	1,183	560
250-300	504	3,033	1,259	505
200-250	909	4,480	2,273	747
TOTAL	**2002**	**11,783**	**5,004**	**1964**

Several interesting conclusions can be drawn from analyzing the above tables 8-16. Even if we limit ourselves to Towers of average power above 300 MW, so that the projected production cost per kWh is less than 4.5 ¢ at 10% interest, we get the following results (table 17). The last two columns show the number of people that can be supplied electricity from the Energy Towers at 6,000 kWh/year/capita, in general, at West European standards, or at 10,000 kWh/year/capita in U.S.A, Mexico and Canada. (The consumption in the U.S.A. alone is nearly 14000 kWh/capita/year).

Table 17 - Regional potential from the Towers producing more than 300 MW average

Region	**Number of people served with Towers better than 300 MW**	**Number of people served with Towers better than 200 MW**	**Electricity per capita per year**
	[billions]	[billions]	[kWh/year]
North Africa	3.58	7.73	6,000
South Africa	1.37	2.79	6,000
India	1.19	2.68	6,000
U.S.A., Canada & Mexico	1.22	2.72	10,000
Chile & Peru	2.77	3.94	6,000
South Europe	0	0.55	6,000
Australia	0.71	1.96	6,000
Saudi Arabia	1.25	1.46	6,000
Persian Gulf	1.12	1.15	6,000
TOTAL	**13.21**	**24.98**	**------**

Adding the Towers with an average output from 200 MW to 300 MW actually doubles the number of people that could be served. Though it is not uniformly correct in all the regions.

The area in North Africa that could be installed with at least 300 MW and up could supply 3.58 billion people electricity at a European consumption level. At the same time, cheap sea water desalination could provide water at volumes 15-25 times that of the River Nile, just by using 20% of the electricity (not less than 400 m^3 per capita per year). Energy Towers at the Southern part of Europe have relatively poorer climatic conditions. Over half billion people can still be provided with electricity at somewhat higher production costs, but with lower transmission costs, and certainly less than the cost of solar thermal and photovoltaic which now is a subject for spending billion of dollars government support. The electricity produced in California and Mexico could serve at least 1.2 billion people at this low rate of 4.5 ¢/kWh or less at the power station gate, extending the use down to 200 MW average power Towers, the supply could be sufficient for 2.7 billion people.

Observing the sea shores of Texas along the Gulf of Mexico, one can identify a huge area with a potential output per standard size towers of between 150 and 250 average megawatt per station. However, the distance from the sea is relatively small and there are still several other ways to reduce the cost per kWh and improve the overall value, as for example, increasing the proportion of energy that goes to the by-products.

The economic success and market penetration of the Energy Towers will depend mainly on the cost of alternative electricity sources and the drive for clean renewable energy. The communal external costs are more and more recognized. For natural gas can be in excess of 1-2 ¢/kWh. For coal or oil it may reach 5-7 ¢/kWh. There were large escalations in liquid and gas fuel costs. The cost of oil came up from less than 30 $/barrel to over 70 $/barrel, and to mid October 2007, it is over 90 $/barrel, and in March 2008 already $ 206 and even $ 211 per barrel. The price of natural gas has been tripled. As an example, Germany passed the "Infeed Law" for payment of over 10 ¢/kWh for clean renewable sources. Spain recently determined a payment of about a quarter EU per kWh for clean renewable energy. Other European countries are following in different ways and different rates.

A government decision in Israel promised already a benefit for clean renewable energy of an approximate figure of 2 ¢kWh which is some arbitrary non rational figure that comes out of arbitrary non professional arguments. As we shall show in chapter 3 on fringe benefits, the advantage of replacing fuel is justified to far higher values.

The cheapest solar technology cannot project electricity cost today for less than 15.5 ¢/kWh for the solar component. While there are hopes for a price reduction, this is still to be proven. The direct use of solar energy cannot supply the huge demand for electricity today, at a feasible cost. Worse, solar energy is operational only 6-8 hours a day, unless a large investment is made for some kind of storage, or fuel is used in the rest of the time.

Energy storage is still expensive and inefficient. Electrical batteries are presently 60-70% efficient. The production of hydrogen and reproducing electricity in fuel cells is 50% efficient. Thus, these two methods of storage nearly double the cost of solar thermal electricity during 2/3 of the day. A very recent development by Prof. Emanuel Peled of Tel Aviv University is of a battery using a fuel cell and two compounds on both sides of this fuel cell and loading it and deloading it by a change in the compounds electrical polarity on the two sides of the fuel cell.

This may become a breakthrough in electricity storage. Still pumped storage is as yet the most efficient and the cheapest. The built in pumped storage of the Energy Towers are still very far ahead by reducing even further the investment and eliminating completely the energy loss.

A common way to misrepresent the cost of solar thermal electricity is to combine 6-8 hours of solar source with 16-18 hours of cheap backup. Averaging 1/4 of the time at 15.5 ¢/kWh with 3/4 of the time at 4 ¢/kWh will produce an average cost of 6.87 ¢/kWh that seems to be reasonable. However, the solar component is still at least 3 times more expensive than the electricity from fuel and we can replace only one 1/4 of the fuel by renewable sources. This is not the case with Energy Towers.

As mentioned above it must be reemphasized that the most efficient way to store electrical energy and conform the supply to the demand is pumped storage. It still requires significant initial investment and about 30% energy loss. This is improved considerably with the Energy Towers by reducing significantly the initial investment and eliminating completely any energy loss.

1.9 Pumped storage and base load

Figure 11 shows the net power output over the year and a characteristic daily cycle for each month, in the Southern Arava Valley in Israel. The annual amplitude of the daily averge is about ± 0.6 of the annual average power. In the figure 11 example, the minimal daily average is about 120 MW and the maximum daily average is 480 MW. The overall average in this example is over 300 MW. The daily cycle has an amplitude of ± 80 to 100 MW. The peak potential production is about twice the average (610 MW compared with slightly over 300 MW). This is under prevailing conditions in the Southern part of the Arava Valley, 40 km North of Eilat, Israel, for a specific tower design.

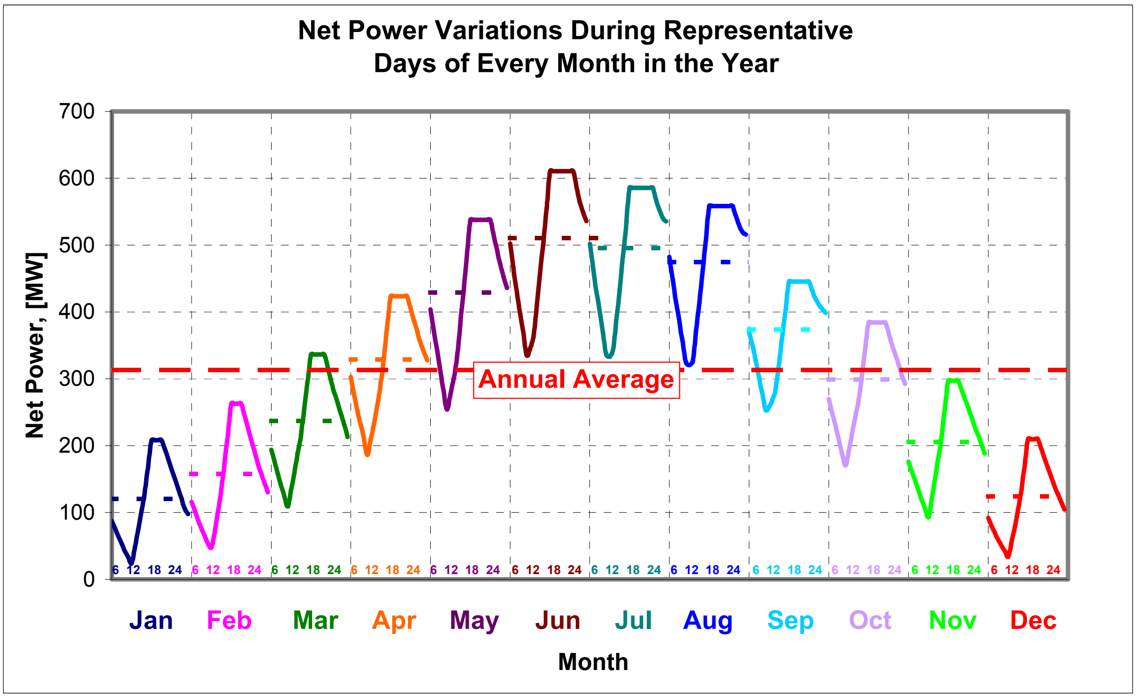

Figure 11 - The power distribution over the year

[near Eilat, Israel]

The individual sinusoid represents a daily change in power at the noted month - the daily average from a gross annual sinusoid with an average at a minimum in January and December and a maximum in June

The change of power rate varies daily, seasonally and randomly at cycle length of typical synoptic changes.

There are 4 ways to conform the supply curve to the demand at a minimum cost without reverting to fuel run backup units.

<u>(1) Pumped storage</u>

As it has been already discussed in the above it is possible to install pumping gear for the maximum daily average with an operational reservoir built at an elevated site. An alternative method would be to install the operational reservoir on the tower itself near the apex**. Thus, more electricity could be delivered at hours of high demand by temporarily interrupting the pumping operation, whilst additional pumping can be carried out during off-peak periods. (See the explanation to figure 4 above).**

The necessary investment in a nearby reservoir is small, and there is nearly no head loss involved as in the common form of pumped storage where the losses usually exceed 30%.

During months where the climatic conditions are less favorable, there would be an anticipated excess of pumping capacity and thus pumping can be carried out almost exclusively at hours of low electricity demand when there is a low return for electricity delivery. This would create substantial economic margins.

Assuming the Israeli electricity tariff for 1996, the net economic gain was found to be 33.7% if full advantage is taken of built in pumped storage. In actual terms, it amounted to some 2 ¢/kWh of the extra income. Pumped storage can easily adapt to the supply curve.

The pumped storage can be used to ascertain also a minimum power during certain times. This leads to a very large savings in investment capital.

<u>(2) Reduced installed capacity</u>

There may be a certain optimal installed capacity which is lower than the peak production capacity. This could lead to a further significant reduction in electricity cost and at the same time, a much reduced difference between the summer peak and the winter hours.

There is also a method for supplying a base load if necessary. This happens if the installed capacity of the pumping gear and the generation gear do not exceed the winter average. The structure and some infrastructure elements have a full cost. However, the power system and pumping gear are cheaper. The result is about 25% increase in the electricity cost**. *It has been found that an installed capacity of about 70% of the peak leads to nearly a 10% reduction in the electricity costs*** in the base line design for the Arava Valley, as they are presented in this brochure. One can obtain a leveled supply with about 25% cost increase. Thus, with between 10% lower costs and 25% higher costs any degree of power rate adaptation can be achieved.

Notably, in 2003, the capacity factor in the Israeli grid was 0.57 on average, which means that much more has been invested to fit the supply to the demand.

<u>(3) Transfer the load from one user to another</u>

It is possible to vary production using the electricity as electricity storage means. An outstanding example is desalinated water. One can produce desalinated water during summer and transition months when the water use is maximal and stop desalination during winter months. The income per kWh can be increased, and the net deliverable electricity for general need comes closer to a base load.

In summary, there are ways to significantly improve the economy of the Energy Towers standing alone at a specific electrical grid.

(4) Possible feed back of the Energy Towers

There is a serendipitous aspect to the Energy Towers operating in arid lands. The usual increased demand for power in warmer seasons, due to air conditioning and irrigation, will be met by the Energy Towers increasing the power output during these warmer and dryer days.

Under most conditions, the demand for electricity in hot countries is larger when the Towers produce more electricity. Thus, the Energy Towers behave as though having positive feedback. This leads to increased income due to higher energy prices at periods of peak demand.

1.10 Different parts of the system

1.10.1 *The spraying system* consists of commercially available water sprayers arranged in spray stations about 8 meters apart. The rate of spray will be controlled to a high level of accuracy by groups of atomizers, adjusting to different distribution patterns at the tower apex.

The whole spray system is supported on a structure close to the top of the shaft. This creates some resistance to the air flow which adds about four percent to the energy loss coefficient. The atomizers are available on the market, and use tried and tested technology. On-off control of the individual atomizers, or groups of them, should produce an exact overall spray rate as well as even distribution over the shaft's top. The spray rate can be adjusted to subtle changes in the prevailing wind. It has been shown that a specific deviation from uniform spray distribution can help obtain higher output rates that counteract the disturbing effects of side winds. Furthermore, gradual changes in the rate of spray stretched over 2-3 minutes would lead to a very smooth change in the turbo-generators system with no overshooting.

1.10.2 *Spray collection* - The excess spray must be taken from the air that comes out at the base of the shaft. If 6 kWh are produced for each cubic meter of sea water which is sprayed, the amount of salt which is carried in the air is 6.7 kg for each net kWh to be delivered. **This is the most serious potential environmental problem involved in the operation of the Energy Towers.**

This problem can be solved by precipitation of the salt brine before the air is released. The precipitation takes place within the Tower, the diffusers (the widening outlets from the turbines at he basis of the vertical shaft) and in a special area around the Tower's floor, where it can be collected and later returned to the sea. ***No solid salt will be released. The spray volume must be large enough to assure all solutes remain in solution and will not precipitate and the cooling efficiency kept to an optimal level all the way to the tower's base.***

The environmental standard imposed by the project developers was that the rate of salt precipitation outside the spray collection area must be less than the background salt precipitation under natural conditions, such as 10^{-9} kg/m^2/sec.

Enhancement of collisions between the spray droplets and their coalescence will produce larger droplets towards the outlet, hasten the precipitation and reduce the size and cost of the salt collection area. The team has managed to eliminate, for example, droplets smaller than 300 microns, or even 400 microns, before the air is out. This allows a droplet precipitation speed of 1.2-1.6 m/s. We have recently demonstrated our ability to control the rate of droplet formation and growth, for a large cloud of droplets in a vertical shaft using standard atomizers.

Figure 12 shows an example of the cumulative droplet size distribution in microns by volume percent. The left side curve is the droplet size distribution after natural collision between droplets over a 19 m fall in an air column at rest. The right hand side curve is obtained as a result of an electrostatic enhancement of this collision as a result of electrostatic attraction.

Figure 13 shows the difference in the cumulative volume percentage with on-off electrical charging regime and continuous charging. It is evident that droplets up to about 300 microns are absorbed into the larger droplets. Several years' experimentation brought the team a complete knowledge and ability to provide an optimal solution to the spray problems.

It is anticipated that eventually the area required for an Energy Tower commercial power station will not exceed 1.5 km in diameter or 520 m^2 /1 million kWh /year. By comparison it takes no more than 1 km in diameter for the Tower's structure and no more than 250 m^2 per million kWh per year. It takes also 200-300 m^2 for a conventional coal station. However, it takes over 6000 m^2 for future thermal solar stations or photovoltaic cells. Notably, the extra area in the ring between 1 and 1.5 km diameter should be used for hundreds of hectares of fish ponds, for water operational reservoirs and for desalination installations.

Our policy would be to concentrate the effort for droplets collision in the part where air flows turn horizontally. We shall use some additional methods besides differential electrostatic charging. Theory and experiments have validated our approach.

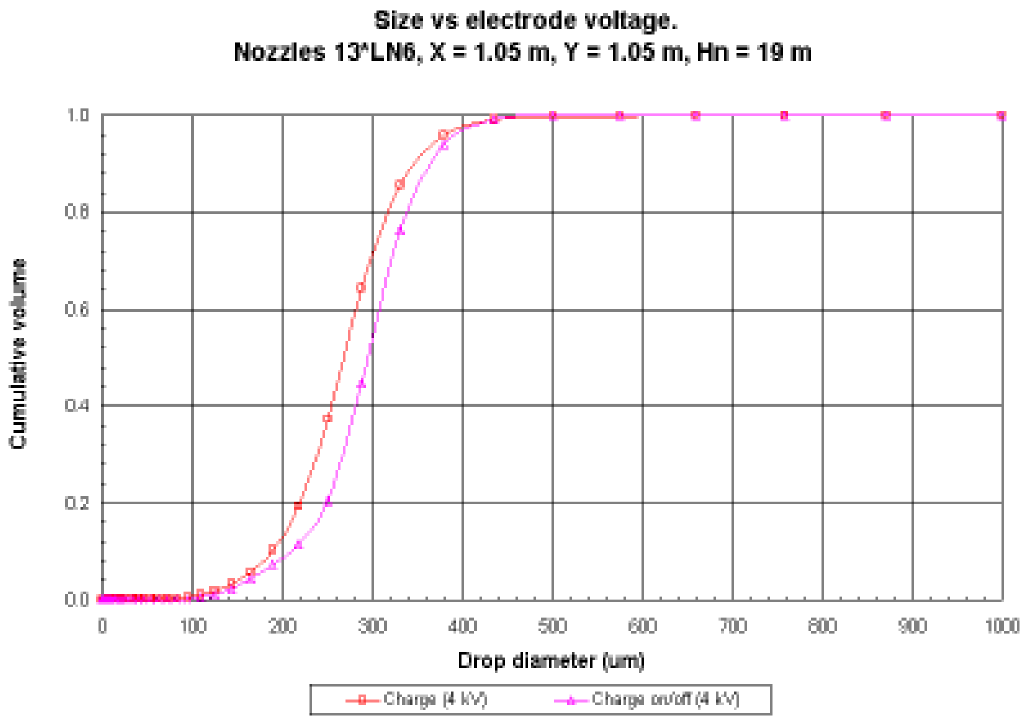

Figure 12 - Cumulative volume of spray droplets

(right curve for on-off charging regime; left curve for continuous charging)

There are several strategies to eliminate fine droplets, and we have achieved acceptable results in this area, however, work continues to optimize this aspect of the process.

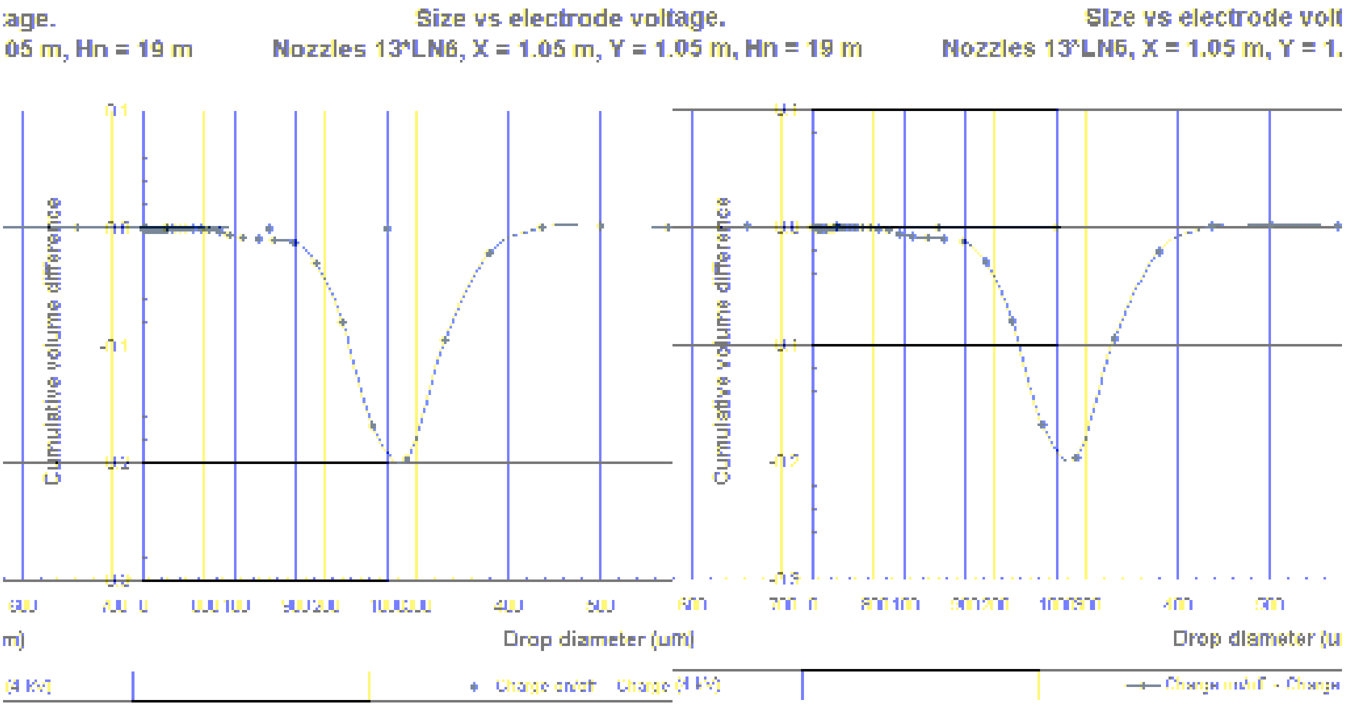

Figure 13 - Differences in cumulative volume between the on-off electrical charging regime and the continuous charging. Note a 20% value reduction taken off the droplets smaller than 280 micros diameter. The original share of these droplets was over 60% and is now a little over 40%

1.10.3 *__Turbines and generators__* - The turbines are of reaction and axial flow type for large volumes and small heads. These were developed early in the 20th century. They are Kaplan type with control of the runner blades angle and the guide vanes angle. The so called "solidity" of the turbine (the ratio of blade area to the overall aperture area) is high, typically with 8 blades and 30 guide vanes. A two speed turbine seemed to be the best choice with a controlled rotation frequency. Today, wind turbines with variable rotational speed and an AC-DC-AC conversion system are preferred. This alternative should be rechecked again with future suppliers.

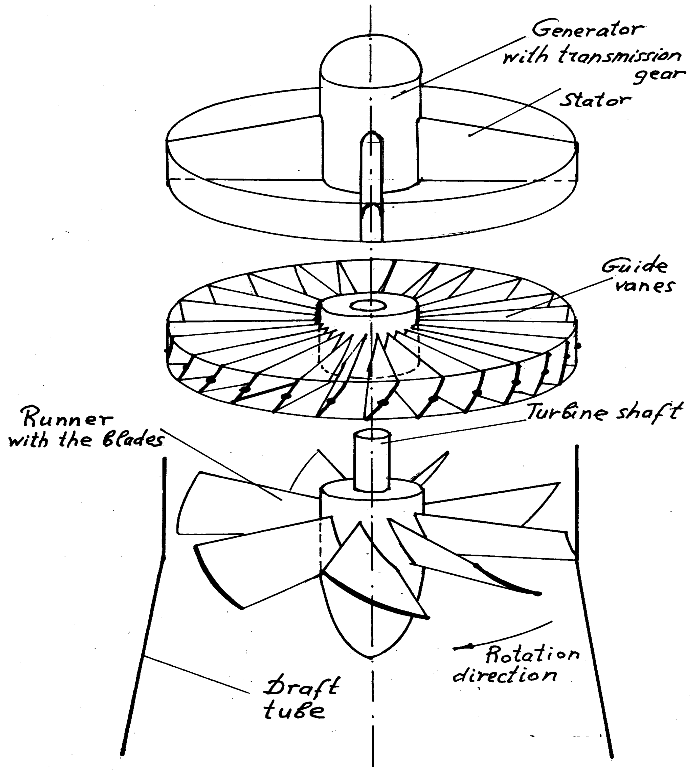

Figure 14 - Schematic view of the turbine

The typical turbine would be 30 m in diameter. 100 turbines would be arranged in two tiers, one above the other, around the bottom of the shaft. The average production of one turbine would be in the order of 7 MW and the installed capacity may be double.

A reduced size model was tested with measuring the output, the efficiency and the droplets adsorption. The turbine action was also simulated numerically and optimized. One of the items still to be worked at is the maintenance regime of in turn individual turbines. We should be able to maintain one turbine while others are at work.

There are several parameters to consider regarding optimization of a Tower: the number of the turbines; the aperture diameter; guide walls directing the air flow into the turbines; the materials used; the rate of flow down in the diffusers coming out of the turbines.

There is absolutely no similarity between the turbines in the Energy Towers and common wind turbines. The energy source in the Energy Towers is head difference E_{net} (see equation

1.1), 2/3 of which can be used optimally. ***The turbines in the Energy Towers are shrouded (the air cannot circumvent the blades aperture).***

In wind turbines, the source of power is a third degree air velocity of which 59% is the maximum theoretically possible exploitation.

Direct mechanical coupling can be designed between about 2/3 of the high head pumps and the turbines, thus saving more than half the investment of the coupled machines (generation, transmission and motor). Several percent of the power are also saved. The big question is to what extent it pays to give up the operation of the electricity generators during peak electricity demand, in order to reduce the overall investment.

The turbines and transmissions may be designed for two speeds using some planetary gears. Alternatively, the turbines may be of variable speed with AC-DC-AC power systems. A certain part of the turbine control may be achieved by using variable pumping capacity, and joining the two by a hydrostatic transmission.

1.10.4 The structure - At least three designs of the tower were made of reinforced concrete. This may be the preferred choice in places where no site is found for a high elevation operational reservoir for the pumped storage. The reservoir may then be installed on the tower itself.

A steel frame structure was found optimal where the pumped storage does not depend on an operational reservoir on the tower itself. Three independent designers used different steel frame geometries and arrived at very similar structural weights and costs. Generalization of these was made by the development team.

Although an Energy Tower may be 3 times taller than the tallest office building in the world (the Sears Towers in Chicago - 450 m), it was the opinion of all experts, without exception, that they would be much simpler to build. (Today, an office building close to 800 m is already in construction).

A significant part of the structural cost is in the outlet past the turbines and diffusers which are needed to reduce the energy losses of the turbines and thus the factor F of energy loss in equation 1.2 in the power formula.

For example, the power N is inversely proportional to the square root of the energy loss coefficient F. The team went to great efforts to choose the largest feasible opening angles for the diffusers so as to minimize their costs. At the same time, F was reduced to less than 0.7. It can be shown that in the updraft "Solar Chimney" described above (in the text above equation 1.2) the loss coefficient would certainly be larger than 1.5.

There is still much potential to reduce the cost of the Energy Towers through structural design and erection methods. Also much can be saved by better measurements of wind speeds and wind drag forces on different structural shapes. Two of the designers estimate that a 30% reduction in structure cost is still possible. This will amount to a 10% reduction of the overall investment.

In recent three dimensional computations of the fluid dynamics made along with wind tunnel experiments, it was proven that the wind forces coefficient C_D which multiplies the wind Kinetic energy term $\rho V^2/2$ (ρ - air density [kg/m^3]; V - wind speed [m/sec]) is reduced considerably when the Reynolds number of the flow increases from 10^5 to 10^9 as is expected under extreme wind storms. **The estimated coefficient was 0.3-0.4. It is considerably less than half the coefficient assumed in building codes, and more nearly one third.**

Due to the large dimensions of the structure, short wind gusts of the strength assumed for low and small structures cannot be realistically assumed. With a wind speed of some 70 m/sec it would take 7-10 sec to circumvent a structure of 400 m diameter. In most structures for which the building code was formulated the meaningful wind gust might take a fracture of one second.

1.10.5 *Different experiments* - The phenomenon of a cooled air downdraft is very well known. There is no need for proof of concept. In fact, it is commonly experienced by people feeling a blast of wind shortly before the rain reaches the ground.

This phenomenon of "wind shear", which causes aviation disasters, results from precipitation over a zone of dry air. The disaster may occur when a downward blast hits the ground or when an ascending or descending plane crosses the down blast. The downward air speed can reach 20m/s and the jet blast diameter can reach one kilometer.

Many experiments were made by the development team in four main fields:

I) Wind tunnel studies and other physical flow simulations.

II) A medium size model study in a 21 m shaft with a cross-section of 2.1x2.1m.

III) Spraying laboratory and droplets study in 1:1 scale.

IV) Turbine models, their control optimization and droplets adsorption.

I) Among the wind tunnel studies were the following:

The top inlet shape was studied in the wind tunnel for over a year. The final result is that the prevailing wind can produce up to 20% net power. The design resulted in an overall 30-60% gain in net deliverable power.

Measurements of the energy loss coefficient F were studied over 2 years in the wind tunnel. Recently, these were confirmed by three dimensional flow computations containing a turbulent flow model. Up to 10% additional power is expected in the full scale power station.

The effect of air circulation was studied in the wind tunnel. It was proven that the circulation will contribute up to 20% of the power. This was unexpected, as the intuitive comparison by most people was that of fluid flow down the drain in a bath tub, which would not yield a contribution to net power output. However, there are even in past literature evidences to the opposite.

Different geometries were studied over the years.

Hot air models of the diffusers were studied and paralleled to a numerical analysis. The stratified flow inside the diffusers has been simulated by heated air instead of cooled air and the simulated Energy Tower's flow was more efficient. (One can imagine an upside down sector of the Energy Tower and hot air rising and coming out through the diffusers and turbines simulated by different resistances to the flow).

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II) Among the 21 m shaft mid size model studies were the following:

a) Production of downdraft by evaporative cooling.

b) Measurements of rates of cooling and derivation of the experimental coefficients in the rate equations when droplets of different sizes are clustered in the space.

c) Prevention of droplet absorption by the shaft walls in order to recover maximum pumping energy and keeping most effective cooling.

d) Qualitative estimate of air flow rates.

e) Collision and coalescence of droplets.

f) Methods for fine droplet collection.

III) Among the tests in the droplet laboratory were the following:

a) Performance analysis of different atomizers.

b) Development of a rotary atomizer with very uniform droplet sizes and complete immunity against clogging.

c) Production of an extremely uniform droplet size train for experimental purposes.

d) Measurement of efficiency in droplet collision and coalescence.

e) Effect of electrostatic charging on final droplet collection.

IV) Among the tests with the turbine model were the following:

a) Shapes of the blades.
b) Different rates of air flow.
c) Control for maximum performance.
d) Droplets adsorption by hitting the turbine parts was only simulated numerically.

Many meteorological profile measurements were collected and some have been made specifically for the Tower's conditions. Measurements were made for wind speed, direction, temperature and humidity to at least one kilometer height. From the measurements, skilled meteorologists produced 24 hour profiles of typical days, for each month of the year. Another model defined all characteristic synoptic conditions of the climate in the region necessary for estimating the power output of the Towers. The climatic conditions are still the least reliable factor. They have the largest contribution to the overall standard deviation of the electricity cost estimate which was estimated to be about $\pm 20\%$.

Recently, satellite weather measurements were utilized in a preliminary way to help analyze different sites in different parts of the world. The available data are at 5 different tower elevations, every 3 hours, every day, for 10 years. The data have been worked out for a 1.125 x 1.125 degree grid.

1.10.6 The reliability of predictions from different models - Each one of the subsystems of the Energy Towers processes, occurring inside and outside the tower, has different scaling rules. All of them are very well known. Well established engineering practice has adapted safety factors which provide a very wide margin of security to applications such as structures. The development team used very conservative approaches in the design of the specific components.

The remaining uncertainties in the estimates are mainly due to variability in unit costs and the inaccuracies in climatic statistics. It has been assumed by computation that the anticipated cost of electricity production has a standard deviation of $\pm 20\%$ and behaves like a normal population (see section 5). This can be reduced to about 10% by a proper preparatory work.

1.10.6 Local power output maps

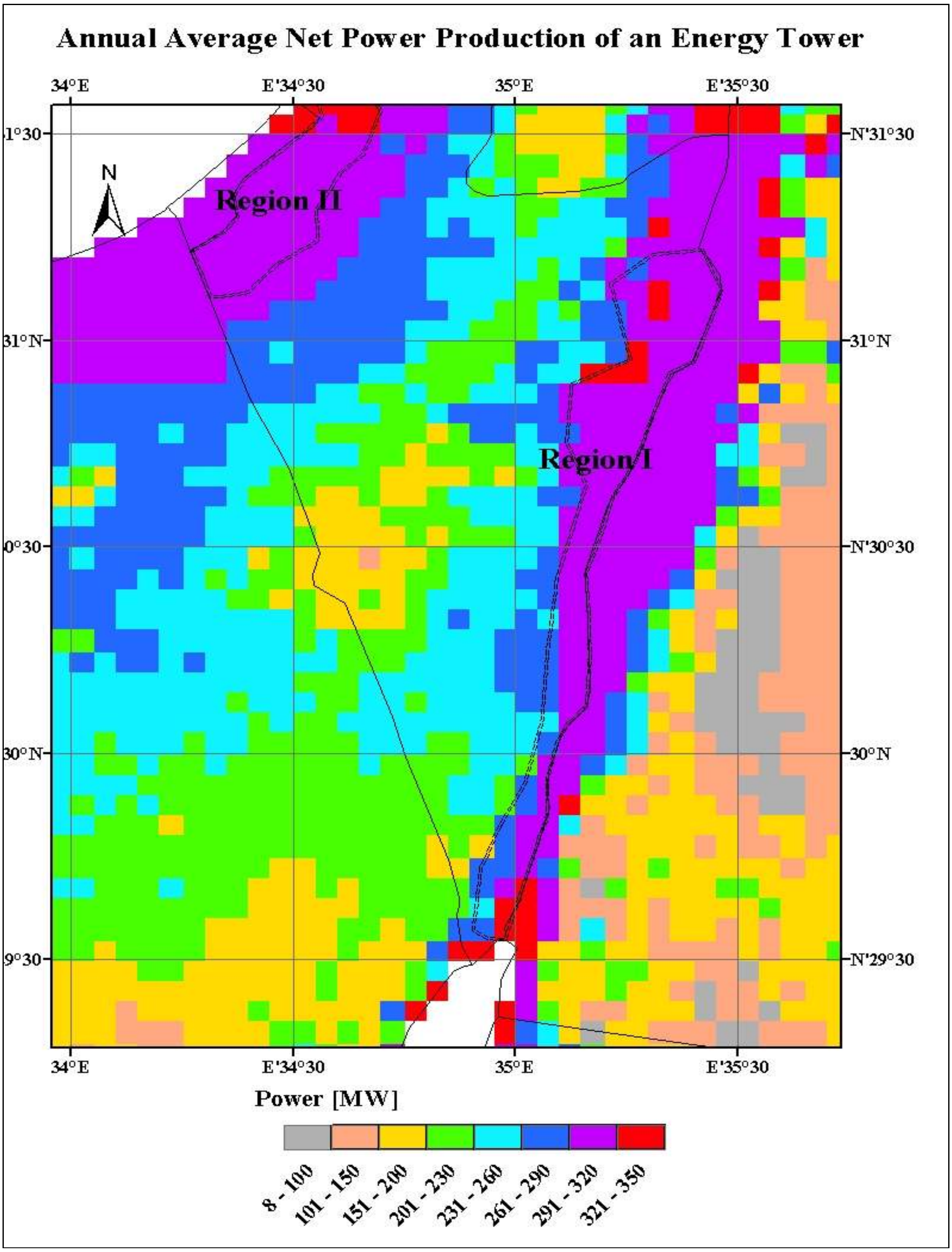

Figure 15a - Mapping of the net output from a standard design Tower in the South of Israel (5x5 km area units)

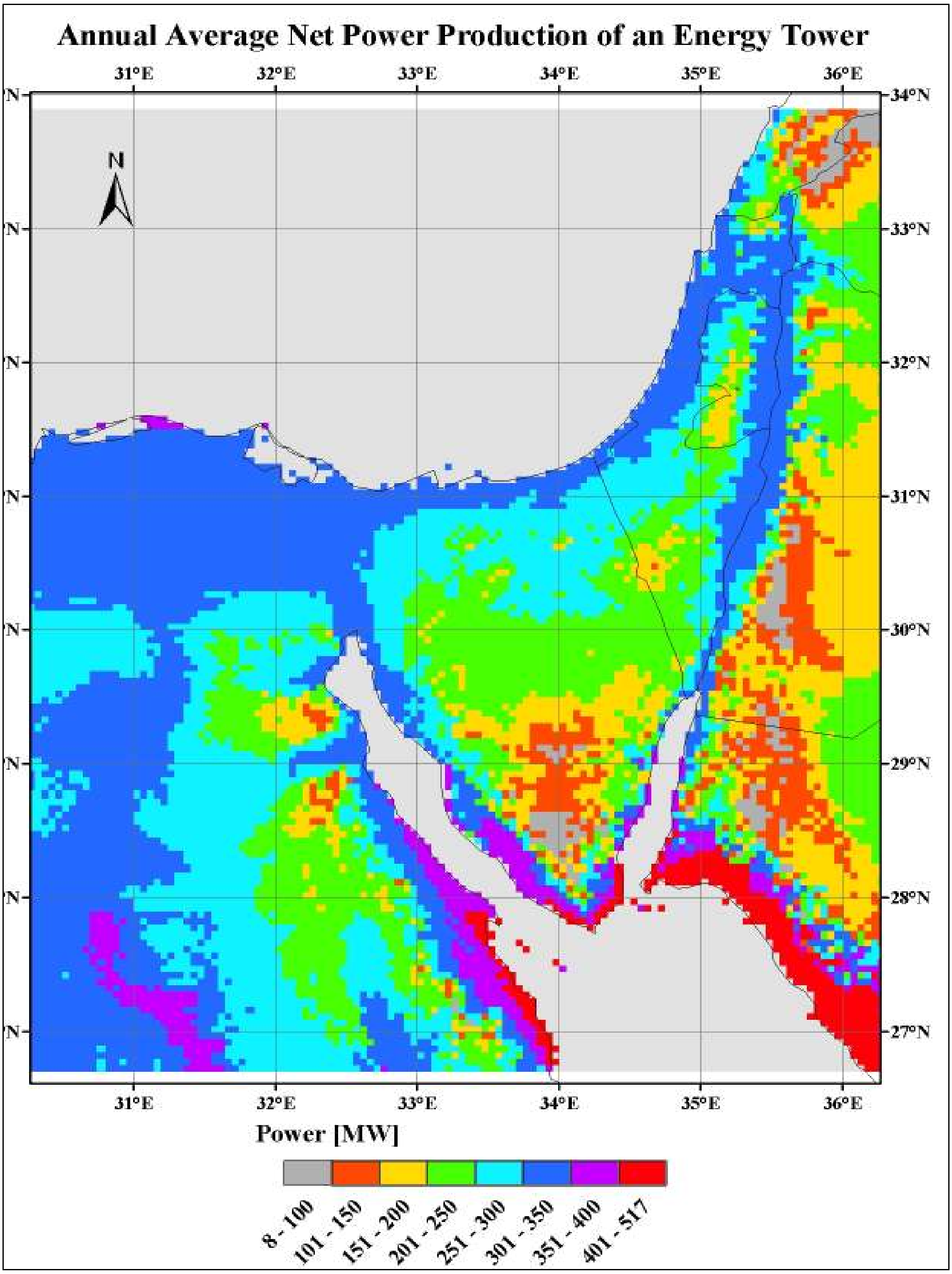

Figure 15 b - Mapping of the net output from a standard design Tower in Israel and its neighbors (5x5 km area units)

2. The economy

Following are estimates for a tower of the following dimensions in the Southern Arava Valley, near Yotvata, 40 km north of the Bay of Eilat, 80 m above sea level.

Table 18 - Main dimensions and performances

Optimal vertical cylinder height	1200 m
Total height	1280 m
Diameter of main shaft	400 m
Distance from the sea	40 km
Elevation above sea level	80 m
Net average power	371 MW
Installed turbine capacity	1374 MW
Installed pumping capacity	589 MW
Annual deliverable electricity (95% availability)	3.09×10^9 kWh
Annul water spray	About 600 M m^3

Table 19 - Investment cost following standard conservative design

System	***Nominal investment [M$]***	***Nominal investment plus interest during construction [M$]***
Water supply	146.3	159.8
Structure	267.5	292.3
Turbines and generators	364.5	398.1
Infrastructure	43.5	47.5
Others	29.2	31.9
Total	**851**	**929.6**

Investment cost of an updated design utilizing technological improvements

The major variables in this table are the direct power system connection to about 2/3 of the pumping gear and reduced construction cost. Largest is the reduction in steel prices and second, the reduction in the computed loads on the structure. The unit cost of steel reduced initially from 2000 $/ton to 1400. The resulting cost investment cost is enumerated in the table above. However, later steel prices went up, and the cost per ton is now close again to $2000. The compensation is that "Alstom" estimated that the water supply, turbines and generators will be 30% cheaper than the development team estimated. A similar reduction in the estimate was with respect to the construction (by late Prof. Eidelman in reinforced concrete Tower and a similar reduction by Prof. Yair Tene in steel structure).

The range of costs found for natural gas combined cycle, nuclear power stations and coal power stations were reported above (table 6a). This information is from a brochure named "*Projected Costs of Generating Electricity - Update 1998*", published by the "Organization for Economic Co-Operation and Development and International Energy Agency (OECD/IEA), 1998. The electricity production costs were estimated for power stations that will be operational in the years 2005-2010. The costs were taken from actual projects in 22 countries and normalized to a 75% capacity factor and either 5% or 10% discount rate. The results are given in table 6a. The energy production cost was then estimated again in the early part of 2007 also by OECD in table 6b. The cost range for the Energy Towers was taken from figures 8a and 8b and from table 7. In the following table 20, the original production cost in 1996 are taken as the minimal opportunity price to then we have added 7 cents to receive the overall income. These days the cost of gas was tripled and the cost of oil more than doubled, so that the production cost plus 7 cents must be considered conservative.

For the Energy Towers, the cost of operation and maintenance has been assumed to be 12 $/kW/year or 0.556 cent/kWh, which is relatively high.

The investment in construction was assumed to be 20% for the first year, 20% for the second year, 30% for the third year and 30% for the fourth year, respectively.

Thus, we can see the minimum mark up of price one can expect above the electricity production cost.

The main observation is that the cost of production of electricity from Energy Towers is less than the average characteristic cost of electricity from coal, gas and nuclear power. There

has been for quite a while a wide cost overlap between the Energy Towers and the major sources of power. However, these days the cost of electricity from nuclear, coal and gas is significantly higher. Notably, to get the total value of Energy Towers, one has still to add the value of a by-product and the earning due to elimination of different externalities.

Despite the fact that all countries use the same energy technologies and the same fuels, electricity prices vary widely. Therefore, there will be many places in the world where the electricity from the Energy Towers will be highly attractive and in some less attractive.

Besides the reduction of electricity production costs, the towers have a built-in capacity for "pumped-storage" and will eliminate the penalty from greenhouse gas emissions and other environmental damage. It has been estimated that these alone will add in order of 7 ¢/kWh to the tower's benefits. Adding them to the replacement prices (in the two right columns of the following table 20 we will get the range of incomes received for the electricity from an Energy Tower).

Table 20 - Possible price for electricity from Energy Towers, including the value of pumped storage and some bonus for clean energy

Source	***Range of net electricity production cost + benefit of 7 ¢/kWh***		***Characteristic average prices taken from table 6a***	
	5% discount	10% discount	5% discount	10% discount
Nuclear + benefit	10.31	12.05	3.31	5.05
Coal + benefit	11.07	11.49	4.07	4.99
Gas + benefit	10.98	11.47	3.98	4.47
Energy Towers production cost for comparison	1.68-3.93	2.51-6.42		

It is worth repeating: since table 6 a was written, the price for electricity from fossil fuel has been significantly increased.
The Energy Tower's advantage is very obvious.
Strictly speaking, the possible price for electricity could become even larger than in the above table when it is composed of the following 5 different sums:

1. The replaced electricity production cost;
2. The bonus for clean energy;
3. The built-in capacity for pumped storage;
4. The profit required for the conventional electricity sources to meet a certain IRR. As an example, adding 5% IRR to a coal fired power station, requires an increase in price of about 1 ¢/kWh. An increase of 5% to the IRR by gas stations, will require about 0.3 ¢/kWh addition to the price;
5. Other benefits that will be enumerated in the next chapter. However even without this addition, just the replacement cost the clean energy bonus and pumped storage, will lead to a very attractive economy of the Energy Towers.

For the complete list of the potential benefits see table 22.

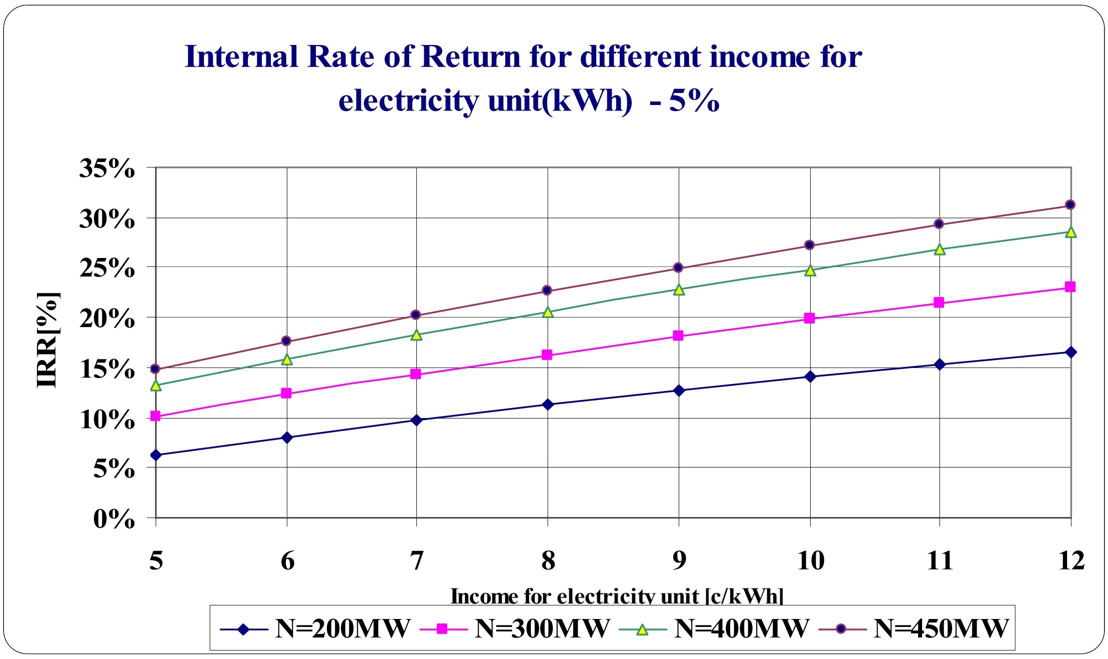

Figure 16a - Internal Rate of Return for Energy Towers - 5%

851 million dollars initial investment under the conditions of South Arava; 4 years construction; 30 years life project; 0.556 ¢/kWh

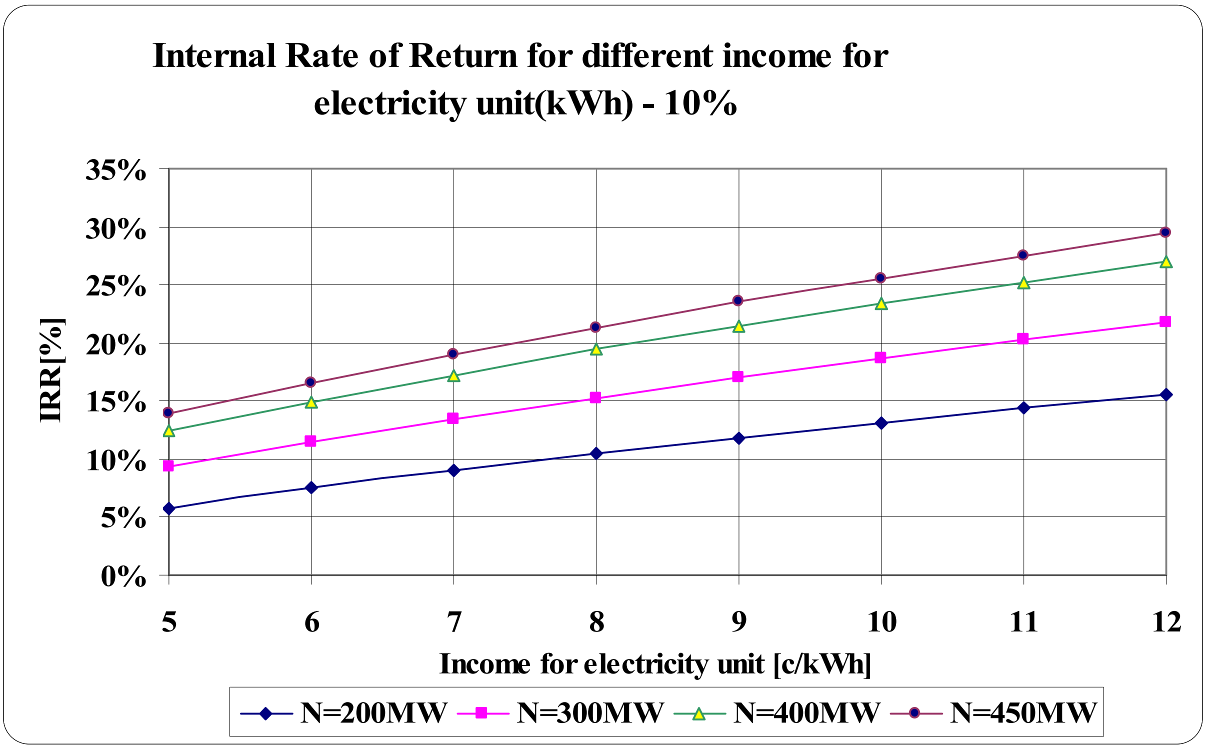

Figure 16b - Internal Rate of Return for Energy Towers - 10%

851 million dollars initial investment under the conditions of South Arava; 4 years construction; 30 years life project; 0.556 ¢/kWh

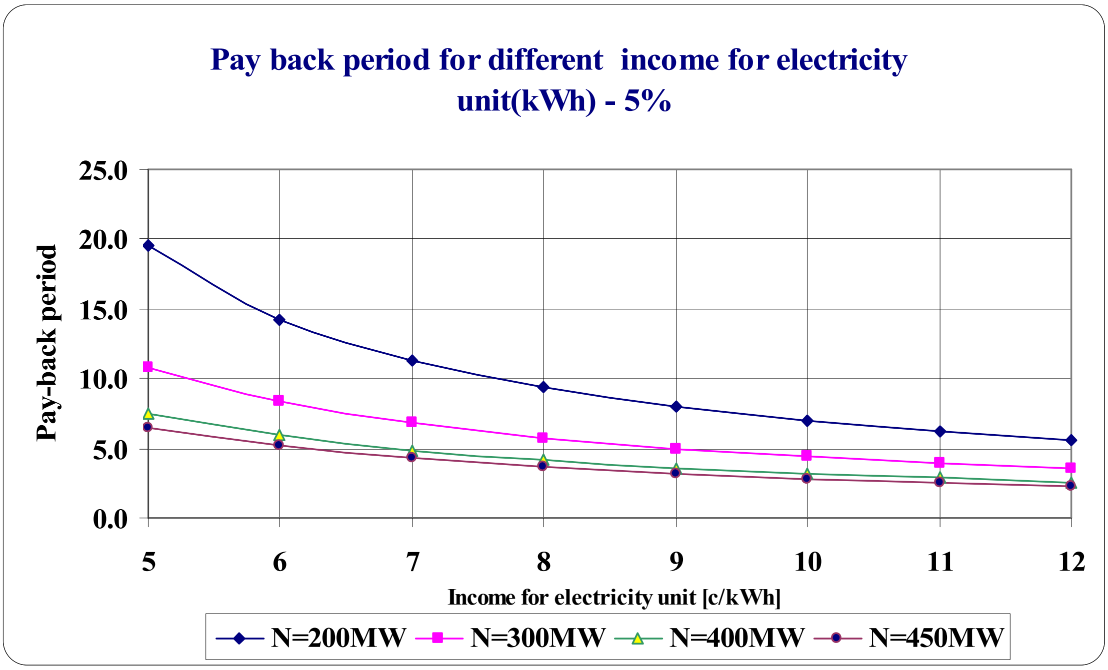

Figure 16c - The Pay Back Period as a function of the income per kWh (i=5%)

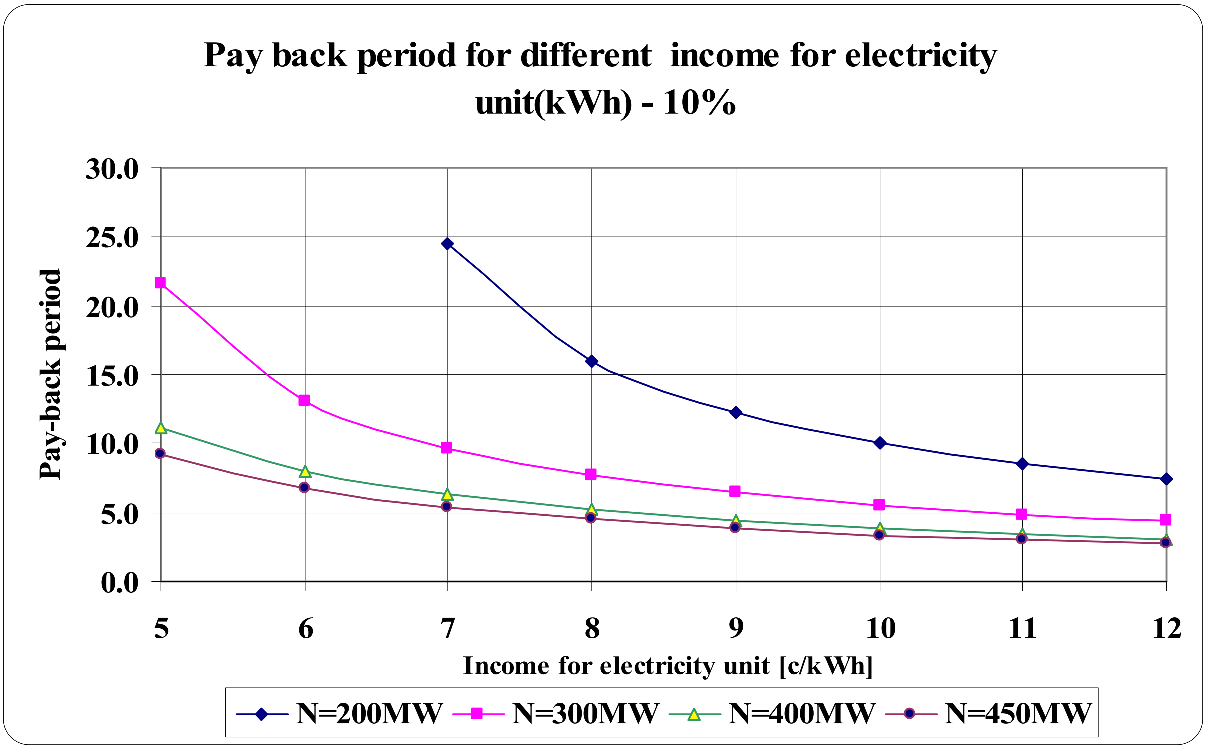

Figure 16d - The Pay Back Period as a function of the income per kWh (i=10%)

The difference between the sum of all 5 components and the production cost of electricity in the Energy Towers will determine the opportunity income to the Towers and the IRR and payback period, present value or another economical yardstick.
To get a general impression, let us assume that we get 1011 ¢/kWh North of Eilat. The Internal Rate of Return there will be 23-25% for 5% interest rate and 22-23% for 10% interest rate. The return period becomes 4 to 3 years for 5% interest rate and 4.5 to 5 years for 10% interest rate.
A preliminary proposal by the Israeli Authorities was paying 10 cents or more for kWh. If we consider 10-12 ¢/kWh, we get the following North of Eilat for a 1200X400 m Tower.

Table 21- The economic performance of the Energy Towers with the possible income

	5 %	**8 %**
I.R.R.	23% to 27%	22% to 25%
Payback period	4.5 years to 3 years	4 years to 3 years

3. Fringe benefits and by-products

The extra-economical benefits of the Energy Towers, many of which we have discussed in the above, may be divided into three groups:

A) Replaced costs such as pumped storage and greenhouse tax (components 3.1 and 3.2 in the following).

B) Direct income to the project from built-in products (components 3.3 to 3.5 in the following).

C) Benefits of a macro-economic nature for which the project may or may not be compensated.

These comprise about a dozen benefits, including some of the following:

GROUP A

3.1 Pumped storage

An example of built-in pumped storage as shown above has a potential average income up to 1.89 ¢ /kWh, in the Southern Arava, in Israel. Mention also should be made of the ability to guarantee minimum power during certain hours of the day, in a given season, which equates with savings at the national grid level (see section 1.8 and figures 4 & 11).

3.2 The overall environmental contribution

The external communal costs of operating fossil fuel and nuclear power stations are significant. However, there are wide differences in the estimates of these costs. The most commonly encountered cost range has been considered here: 1-2 ¢/kWh for combined cycle with natural gas, and 6-7 ¢ for coal or oil operated power stations.

"Energy Tower" technology introduces a competitive alternative to energy derived from fossil fuel sources. Non-dependency on fossil fuels has far reaching implications from economic, political and security points of view. The implied threat to oil suppliers that their product is no longer indispensable for the survival of developed and developing economies, would possibly help world peace. The true communal external cost of using fossil fuel is far higher than 1-2 ¢/kWh. For coal burning, estimates for the communal external costs, such as the impact on human health and ecosystem damage may reach 5-7 ¢ kWh. However, here we might accept the bonus provided by the government in each country. As an example, in Israel it has been decided about approximately 2 ¢/kWh. However, we have shown that there would have been a justification for several tens of percent.

GROUP B

3.3 Desalination

Desalination of sea water in combination with the Energy Towers can save a large part of the initial investment. Even countries such as the UK, traditionally thought to be immune from regular water shortages, are presently investigating the construction of desalination plants, as global warming is already having an impact on water security. Desalination is most effective when using Reverse Osmosis which is the preferred method today. Analysis of an operational Energy Tower shows savings of nearly half the investment and about 1/3 of the energy outlay, as a result of drawing from desalination and using common equipment. Characteristically, 88 ¢/m^3 desalination was reduced to 53 ¢/m^3, meaning a 40% saving. There are savings on the water intake, conduit of sea water and return of saline brine at outflow. There is a further saving due to high pressure pumps for about half the water because of the reused end brine. Furthermore, there is no need for energy recovery from the end brine. There is also the possibility of further savings due to pre-treatment, before pumping up the Tower.

As an illustration of these, a 388 MW net average power station was computed to produce $3.4x10^9$ kWh /year. Desalination of $200x10^6$ m^3 of water will require no more than $700x10^6$ kWh - some 20.6% of the total energy. This capacity can be installed gradually in small modules without the need for a major initial investment.

Advances in desalination technology are expected to reduce costs and energy outlay. The most recent bid showed a cost of 52.7 ¢/m^3. **The chances are that, in combination with the Energy Towers, the final cost of desalinated water will be no more than 30¢/m^3. Israeli agriculture could then afford it, for practically all crops.** A country such as Morocco, if it were to invest in this technology, might well find itself in the curious position of being able to export not only electricity, but also water to Europe during the summer months, generating foreign exchange.

There is an added potential benefit for combining desalination and electricity delivery. Water production can be used for the equivalent of a very large capacity seasonal "pumped storage". A base line supply of electricity can be obtained almost without any additional cost.

The ability to reduce desalination cost, and especially in arid lands is a technological breakthrough that may solve one of the world's most crucial environmental, economic and political problems.

In the example mentioned above, North Africa could install Energy Towers to supply all Europe's electricity needs (see paragraph 1.6 above) and, at the same time, produce water many times the volume of the Nile's flow. This would allow agriculture to flourish in countries such as Morocco Tunisia, Libya, and Algeria and Egypt. The economic development of North Africa, presently constrained by lack of water and energy, could foreseeable provide a market for European industry and help regional cooperation and stability, by displacing immigration to Europe.

Similarly, Southern California and Mexico would be in a position to provide all the electricity needed for their immediate requirements, and become net energy exporters to the rest of the U.S.A. Energy Tower technology could also resolve once and for all California's Energy and looming water crises. Desert areas such as Peru and Chile - some of the driest parts of the world - could well be positioned to provide all the electricity and water needs of South America.

The Washington Post stated (April 17, 1999) that: **"only 2.5 % of the earth's water is fresh water of drinking quality. In many parts of the world, drinking water is being consumed faster than it can be replaced by precipitation. The United Nations warns that fresh water shortage poses the biggest obstacle to producing enough food for a burgeoning world population. Today 31 countries are short of water. Many others, like the U.S. and China, have shortages in certain parts. By the year 2025, the number of countries with a shortage of fresh water will grow to 48. The need for fresh water to produce food for a projected 8.8 billion people will grow by 17-55%, depending on the degree of efficiency achieved, according to Ismail Sergeldi, Chairman of the World Commission on Water for the 21st Century"**.

Energy Tower technology makes the prospect of cheap water production possible in the countries that suffer most from a shortage of water.

The potential site for an Energy Tower that has been discussed in greatest detail has been that of a position in the Arava Valley, which lies between Israel and Jordan. An Energy Tower in this valley could replace the idea of the Red-Dead Sea Canal, between Aqaba and Eilat and the Dead-Sea. <u>Such an Energy Tower could be constructed as a joint Israeli-</u>

Jordanian co-operative project. It could produce well over 10,000 MW average power or nearly 100 billion kWh /year, and provide water to replenish the dying Dead Sea. These figures compare favorably with the 85-90 MW, or 750 million kWh/year, that would be generated by the Red-Dead Sea Canal. The investment would be $ 2,300 per average kW in the Energy Towers as compared to nearly $ 30,000 per average kW, for the Canal. The electricity cost will be in the order of less than 4 ¢/kWh assuming normal market conditions, compared to more than 10 fold for the Red-Dead Canal. Such a project could have a marked effect on the Jordanian economy, providing both water and energy at a competitive price. Jordan suffers as it has no oil reserves and a scarcity of water. Sharing the project between Israel and Jordan could fulfill international objectives regarding the Middle East Peace process. Water shortages in the region are a constant source of tension and instability. These are admittedly not the fundamental cause of conflicts in the Middle East, however, disagreements over water do not contribute to calming the situation.

The advantage of the Energy Towers over the Red-Dead Canal is also that it eliminates at least three most terrible environmental threats of the Canal. (Polluting the Dead Sea by desalination chemicals precipitation of fine gypsum crystals that paint the water white and salinization of the groundwater along the Arava Valley).

Energy Tower technology could provide a solution to this otherwise intractable problem. The cost of investing in an Energy Tower is insignificant, when compared to the cost of a war, or the cost of the ongoing Palestinian conflict. Furthermore, development of the nascent Palestinian Authority's Economy will be impossible without access to both cheap, reliable water and cheap energy. An Energy Tower constructed near the Gaza Strip could provide a much needed boost to the Gaza section of the Palestinian Economy, and would provide a much needed source of foreign exchange, locally produced energy and a reason for cooperation.

An Energy Tower constructed in the Arava Valley could be financed in part by Palestinian development funding, with the aim of providing long term secure supplies of electricity and water.

Without secure power sources and reliable sources of cheap water, the Palestinian Authority will never be able to stand on its own feet and compete economically.

The project would, as outlined above, serve as a model for cooperation between Israel and Jordan. The constant source of tension related to water shortages that presently exist between Syria, Lebanon, Jordan, the Palestinian Authority and Israel, would disappear. Israel could recover its agriculture and heal the state of its aquifers, which have been over pumped, and are in danger of being rendered saline due to the ingress of seawater import of salts by the Lake of Galilee, and recharge of sewage water. Energy Towers would also enable the development of Israel's Southern desert areas which are about 60% of Israel's area. As was mentioned in the above it would also be able to replace fossil fuel by bio-fuel.

3.4 Prevention of salinity in large irrigation projects

The largest irrigation projects in the world are in the process of gradual destruction due to salination. Examples of land lost from agricultural use may be noted along the ***Colorado River, the Murray-Darling River in Australia, the Orange River in South Africa, around the Indira Gandhi Canal in Rajasthan, India, etc.***

The process occurs as a result of the evaporation of the irrigation water and the return of the drainage water to the source, but with the drainage water having a higher salinity due to evaporation. Sometimes the salinity is adversely impacted by soil salts being leached from the soil by the drainage water. These salts keep re-circulating many times through the soils and gradually build up. There are several adverse effects:

a) A progressive reduction in crop yields.

b) Destruction of soil fertility.

c) Loss of large parts of the water volume due to salinization.

d) Increased investment in irrigation infrastructure and drainage systems to compensate for leaching.

The solution is straightforward. **Drainage water needs to be intercepted so that after irrigation it cannot directly return to the river or aquifer from which it was drawn. Analysis shows that for each cubic meter of brackish water which is intercepted, it is possible to gain about 0.5 m^3 of usable water downstream at the water source.**

Until now, the obstacle to this logical solution was the very large infrastructure and concomitant investment required. Decision makers have always preferred to postpone this spending. The problem develops slowly, and political processes tend to drive decision makers to address short term problems.

The large expense is principally due to the very long and large canal infrastructure which is needed in most cases to divert and separate the saline run-off from the water source. The typical cost of transferring the brackish water to a disposal site is about 0.1-0.15 ¢/m^3/km. For example, the distance needed to be covered by such a diversionary system for the Indira Gandhi Canal would be in the order of some 1000 km at a cost of more than 1 \$/m^3. It would cost over 3-3.5 billion dollars /year, an unacceptable financial burden.

There are several ways to reduce the volume of the brackish water for disposal:

a) Evaporation ponds which are relatively expensive if properly built.

b) Concentration of the brackish water using spray lines, which incidentally use the same technology as that proposed for the spray heads of an Energy Tower.

c) Desalination, if there is a market for desalinated water. This requires a certain level of agricultural sophistication and the political will to invest in such a project.

In a desert or arid climate, the preferred location for an Energy Tower, spraying of brackish water through the Tower would be the preferred method of reducing the volume of water to be disposed of. Furthermore, this water can then be economically desalinated, as outlined above. The results would be two-fold:

a) Reduction of the water volume to be disposed to some 3-5% of the original volume.

b) A gain of up to 10 kWh (with 1.2 km Tower) for each cubic meter which is evaporated.

By using just 3 ¢ net income/kWh, the net earning would be 30 ¢/m^3 intercepted and the final reduction in disposal cost is 95-97% leaving a cost of only about 5 ¢/m^3 for brine disposal, even for a distance of 1000 kilometers.

Thus, desalination of the water by using Energy Tower technology protects the land from further salination by stopping contamination of the water source and turns out to be of economic benefit, and not merely an expense.

It is difficult to determine how to apportion the value of this ecological accounting, in addition to the easily calculated benefits of electricity generation. If an Energy Tower were constructed in an area affected by agricultural salination, it is feasible that the Power Company could be compensated financially for the removal of saline agricultural run-off. If compensation were in the order of ***10 ¢/m³ for waste water removed from the water cycle, this would amount to 1.1-1.3 ¢/kWh of additional benefit.***

India is a very attractive area for application, since over a billion people and possible double can be supplied by 6,000 kWh/year (see table 16). Also, the Indira Gandhi irrigation project in Rajasthan can be saved, and economically significant volumes of desalinated water could be produced for Gujarat and Rajasthan.
These two additional benefits: desalination and prevention of salination would also solve the ecological disaster that is presently unfolding around the Salton Sea in the Imperial Valley of Southern California.

In order to be able to preserve a body of water such as the Salton Sea, at least three elements need to be feasible:

a. It must be economical and feasible to divert to the ocean concentrates of the soluble salts that are presently accumulating in the Salton Sea.
b. It must be economical and feasible to provide sufficient cheap fresh water to both maintain the sea at an acceptable level, and to provide excess capacity for irrigation purposes.
c. It must be clear that the maintenance of the salt water body - Salton Sea, in this case, will cost no less than fresh water, at the rate of at least the evaporation from the water body.

In view of different possible alternatives, there may be a choice of the targets for this specific project. In any case, at present there is no competition with the Energy Tower for the purposes of sea water desalination and brackish water concentration in order to produce electricity and reducing the cost of salt disposal to the ocean.

3.5 Aquaculture

A kilogram of fish grown in ponds requires about one kg dry food as compared to 5kg of food plus some 2 liters of fuel for a kilogram of beef (2 kg for kg poultry and 3 kg for kg hog meat). Thus, fish has the lowest requirements in kg dry food, for each kg of final product. A growing demand for fish is causing over-fishing with serious environmental ramifications and rising prices.

In the South of Israel, there are at least three obstacles to large scale fish farming despite the high expertise developed there.

a) There is a shortage of cheap land near the sea.

b) The cost of pumping water inland is prohibitive.

c) Pollution of the Eilat-Aqaba Bay has become a limiting factor for marine farming, due to the excretion of some 2/3 of the original food fed to the fish. This is also a problem in other regions where intensive marine farming is practiced.

The combination of fish farming with an Energy Towers solves all three problems in an elegant manner. The water which is sprayed into the tower is used first in fish ponds. This water is filtered before spraying to prevent nozzle clogging, and thus helps partially clean the water. If handled properly, the higher density of the disposed brine from the Tower will be able to flow from the outflow pipe along the sea floor and eventually by diffusion reach a density equivalent to that of sea water. Alternatively, it will sink to the greatest available sea depth and will gradually fill this lowest part. The process of diffusing and mixing will dilute any pollutants present by a factor of thousands. (A more detailed explanation exceeds the level of this brief presentation). The Density Gradient is well understood, due to extensive research conducted in connection with solar ponds.

The Eilat chapter of the Israel Oceanographic & Limnological Research Institute has helped to estimate the potential for fish farming from one tower. This was found to be in the order of 160,000 tons for one full scale Tower, compared to less than 3000 tons today. (Assuming the annual amount of sea water spray to be 600 million cubic meters, dividing by 365 days and retaining the water in a delay pond which is just one meter deep, will give us on the average 100 kilogram fish per square meter. The problem remains how to control the amount of water over time and have the right combination of ponds for the different growing stages of the fish). The typical projected fish price was estimated to be 5-6 $/kg, generating economic activity of some 500-600 million dollars annually. **Charging just 0.5 dollar /kg of fish for the water supply and disposal of waste would bring an income of about 2 ¢/kWh to the Tower. For a conservative estimate we have assumed one quarter per kg and for the potential of 160 000 tons fish it adds up to only 1 ¢/kWh.**

Another estimate for the reimbursement to the energy company for aquaculture services is 10 ¢/m^3 of water or 60 million $/year, or nearly 2 ¢/kWh.

The development of fish farms away from the seashore is presently economically impossible. Without the towers, there would be no economic rationale for pumping such vast amounts of water inland. A significant initial investment in the conduits for bringing water in and taking water back and the mechanisms needed to cleanse the water ejected from the ponds, would render such a project prohibitively expensive, despite its ecological attractiveness.

Fish ponds using the sea water of one Tower will use an average of up to 1.5 million m^3 daily. If a pond is 1 m deep, this means an area of about 150 hectares ($1.5X10^6$ m^2), or gross area not more than $2X10^6$ m^2. This whole area can be placed between the inner diameter of the Energy Tower structure which is about 800 m less than 2 km in diameter. This ring occupies an area of about 2.1 km^2. This amounts to about 660 m^2 per million kWh per year. The diameter of the outer circle can be increased if needed for spray collection and can be decreased in case the fish pond area does not have to be that big.

A PRTIAL SUMMARY OF THE PRODUCTS OF ONE FULL SCALE TOWER

Electricity	*3 x 10^9 kWh/year*	*i.e. for 500,000 people at 6000kWh/year/person at Western European levels*
Water	*200 million m^3*	*i.e. 400 m^3/capita/yea (by using 20% of the electricity)*
Fish	*160,000 ton*	*i.e. 200 kg fish/capita/year*

The global potential (assuming half the global supply of electricity using Energy Towers) is about 130 million tons of fish, more than the entire present volume of global fishing and pond fish growing.

3.6 Cooling of thermal power units

The water shipped out of the tower and back to the sea could be used for cooling thermal power stations. It thus permits a wider choice of sites for power stations which are still being operated by fuel or even for solar power stations. The main saving is in the cost of land which can reach over 2 ¢/kWh and cost savings associated with provision of cooling water.

3.7 Pre-cooling of compressed air for gas turbines operation

The air that comes out of the tower is cooler than the ambient air, often by 15 centigrade or more. The air fed into the gas turbines is compressed first. The pre-cooling of this air adds considerably to the net power of the turbine due to higher air volume and therefore less energy needed for final compression. The measured improvement is nearly 1%/degree centigrade. Alternative cooling methods require an investment increase of over 10% in the gas turbine station.

3.8 More energy recovery and optimization

There are still other possible ways to recover some energy. For example, using the concentration differences between the end-brine and the original sea water.

Optimizing the combination of products has a very large potential to increase the overall profitability.

3.9 Growing crops to replace gasoline and diesel fuel for transportation

Providing much water in a large desert area creates an opportunity that provides an unexpected solution for another branch of energy use.

So far, we have discussed 6 added benefits, all of which potentially could increase an Energy Tower's income. The following are some added benefits of a macro-economic nature.

GROUP C

3.10 Reduction in fuel imports

For coal to produce the energy of a 388 MW net average power, 1.27 million tons/year of coal have to be imported to Israel, at a cost of 60-80 million dollars a year. This would be the foreign exchange saving made by the construction of one standard design Energy Tower in the Arava Valley. The average methods of energy production also require oil distillates and natural gas, which would increase the projected cost savings. It has to be remembered that the net energy output in Israel is only 0.57 of the installed capacity.

Some years ago, the Israeli government granted 15% of the investment to any power station using local renewable energy sources. In other jurisdictions, this has approached 30% for import saving. ***This benefit can be estimated to be equivalent to 0.7-1.5 ¢/kWh. More generally, it can be considered as one of the major macro-economic benefits.*** Some of these savings in the past have been able to be passed on directly to the project's investors.

3.11 Compliance with limits for power use and Kyoto Protocol

At the end of 1997, the Kyoto Convention formulated the requirement that greenhouse gas emissions be reduced by the year 2010, to roughly the level of the year 1990. The international community has been slow to activating the protocol or to enforce it, as the implementation, using present technologies, risks causing an economic slow-down. Since Kyoto, the Marrakech convention reconfirmed the Kyoto protocol which has now been signed by 158 countries.

The Energy Towers alone could gradually provide an acceptable solution for nearly 2/3 of the necessary reduction in greenhouse gases due to electricity production. Assuming a 2.5% annual increase in electricity demand and 2% power station replacement, the additional use of fuel for electricity will reduced by 4.5% per year. At resent there are some international mechanisms to sell rights of greenhouse gas emission, so that a real profit may be drawn.

A project carried out in the U.S.A. showed that meeting the Kyoto Protocol's requirements could mean raising electricity prices from an average of 6-7 ¢/kWh to 11¢/kWh. This will happen if Energy Towers are not implemented, as other forms of renewable electricity generation developed to date provide expensive electricity.

3.12 Possible future environmental contribution

There are the obvious direct contributions by the Energy Towers in replacing the use of fossil fuels for producing both electricity and providing bio-fuel for transportation. The Energy Towers could, in all probability, solve some of the worse desertification processes. However, it might be that they can actually act to reverse in a direct way some of the global warming effect and have a positive feedback in the sense that as the globe is warmed up, their performance is increased.

The estimated radiation incidence over the equatorial belt and over the two arid belts north and South of the equator is 15-30 times the heat which is transferred by the Hadley Cell Circulation. What is the main cooling effect and how can it be intensified?

The hot and humid air above the equatorial belt rises and in the process cools close to half a centigrade per 100 meters. As it cools the vapor condenses to water droplets and at higher elevations to ice crystals. The vapor is the most effective greenhouse gas. Thus, the cooling effect takes place in the upper atmosphere, above the equatorial belt, because there the air is not as cold and at an elevation of several kilometers it is also free of vapor or nearly so.

Above the arid land, the warming effect is not as effective because the air is warmer and as it rises the cooling is a whole centigrade per 100 meters.

It is therefore quite possible that earlier humidification of the air improves the cooling effect by enhancing the Hadley Cell Circulation and this is what is anticipated by the Energy Towers activity.

The second effect is the irrigation of desert area and the change in its libido. The third effect is simply that as the air warms up the output of the Towers increases. The fourth effect is that plantation in desert areas increases the absorption of carbon dioxide from the atmosphere.

3.13 Protection against price fluctuations

It can be proven that if Y is the overall economic product of the country, which is partly a function of the fuel price P, then the overall economic damage caused by price fluctuation is expressed very closely by

$$\frac{1}{2}\frac{\partial^2 Y}{\partial P^2}\sigma_p^2 \quad ,$$

where Y is the yield relative to the product at the average fuel cost and P is also the fuel cost relative to the average fuel price. σ_p^2 is the variance of the price fluctuation with time, also in relative terms.

It can be proven that when the economy works close to optimal condition, the entire term is negative, reducing the economic product yield. Moreover, it can be shown that the second derivative is larger than one unit. The computed variance of oil prices since 1972 is at least 0.24. Thus, the damage caused by price fluctuations can be considerable.

3.14 Avoiding the need for strategic reserves and other strategic expenses

The strategic need for fuel is extremely high. Very large stores of fuel need to be maintained. Wars are being .launched in order to protect fuel interests, and we have conceivably seen only the first of such wars at the start of this millennium. It has been estimated that the security component of the cost of gasoline approaches 70 ¢/gallon compared to the nominal cost of the product, which at the time of writing is around 30 cents.

3.15 Industry and export

The renewable source of energy provided by the Energy Tower concept, desalination and fish growing, could serve as a basis for new industry, tens of thousands of new work positions and huge export volume - including exports of water, electricity, fish, and agricultural products. Even if Israel will be able to export only 20% of the overall Energy Tower product, it would mean 20 billion dollars per year!

3.16 Natural gas for transportation

One of the most interesting gains is the ability to divert use of natural gas reserves to transportation. The technology for internal combustion motors is really available and efficient. Fuel cells could also be used. Once we have an abundance of electricity for all our uses that is completely clean and renewable, it makes no sense to burn natural gas for electricity.

3.17 Cooling of the globe beyond just reducing the amount of the greenhouse gasses

Moistening the air that flows towards the equator increases the air temperature when it rises above the equatorial strip, and thus, one gets a better cooling by radiation to space. Irrigation of desert lands also adds to this cooling effect.

3.18 Positive feedback increases the performance of the Energy Towers when the air warms up

3.19 Technological improvements to "Energy Towers"

Nearly a dozen technological improvements have been pinpointed that could in future lead to even better cost effectiveness ratios than those presented here. These could reduce the cost of electricity by up to 30%.

While it is highly recommended to continue development before implementation, there is no need or justification to postpone or delay the commercial application for more development, as the technology is already cost effective, and competitive.

3.20 Summary of added benefits

Table 22 - Summary of added benefits

GROUP A	
Environmental saving by Israel government	1-7 ¢/kWh 2 ¢/kWh
Pumped storage	Up to 34% or 2 ¢ / kWh
GROUP B	
Desalination	0.3 ¢/kWh
Salinity prevention	1.1-1.3 ¢/kWh
Fish farming	1.1-2 ¢/kWh
Cooling water of thermal power stations	2 ¢/kWh
Pre-cooling of air for gas turbines	1 % /centigrade cooling
Recovering energy by using the osmotic pressure difference between the end brine and the original sea water	1 ¢/kWh
Growing crops producing clean liquid fuel	? (we have no figure)
GROUP C	
Avoiding fuel import	0.7-1.5 ¢/kWh
Complying with limits to power use	Very high
Protection against fuel price fluctuation	Very high
Strategic savings	Very high
Industry and export	Very high
Replacing oil with natural gas for transportation	Very high
Dealing with sale of rights for pollution	About 2 ¢/kWh

One cannot add all the values in every case even if they have been quantified. However, it is noted that under many circumstances the economic justification, at least at the communal levels, could be double that of the direct income from electricity production. Strategically, the dependence on fuel imports and fuel price fluctuations can be fatal.

Following are three more notes:

a. As a corollary to the above, Energy Towers provide a potential solution to some of the most pressing environmental problems confronting humanity today.

b. The Energy Towers could become the most important recent political contribution, on a global scale, and in the Middle East. Solving the Middle East problem is going to be necessary, to avoid future conflicts in the area.

c. By eliminating electricity subsidies in Israel, at least 1.5 billion dollars could be saved annually.

In Israel, an Energy Tower could feasibly be constructed every two years, so that within 16 years, the entire electricity needs of the country would be provided through this technology. Similar calculations can be made for the USA, and for Europe, assuming the construction of Energy Towers in nearby arid countries such as Morocco, which would then become energy exporting nations.

4. Environmental problems & gains

In designing the Energy Towers we have identified about a dozen environmental problems. The exact number depends on the exact classification of these problems.

Salinity problems

1. Salt water leakage from the ponds and spray collection areas
2. Runaway of concentrated salt spray
3. Return of brine to the sea

Problems caused by the very structure

4. Shadow
5. Visual disturbance
6. Blocking of animal movement
7. Hitting flying birds
8. Interference with aviation
9. Occupying area

Functional disturbance

10. Acoustic noise
11. Electronic noise
12. Outflow of cold air
13. Possible reversal of global warming (which is not a problem but an asset)

Reactions to the above list is first of all by two basic statements.

I. - Despite the long list of problems mentioned in the above, the installation of the Energy Towers solves so many extremely serious environmental problems that the balance is unusually positive;

II - Despite the above remark, we feel obligated to do everything possible to solve or minimize the weight of each of the above mentioned environmental problems.

Following are several very brief remarks with respect to the mentioned environmental problems.

Problem 1 - The solution is by well known and very reliable nature. An important point is that most of the installation is concentrated very near the Red Sea Bay and saline areas. There is no long distance conveyance of sea water (which exceeds 200 kilometers in The Peace Valley program between the Dead Sea and the Red Sea. There is no landscaping using sea water.

Problem 2 - This problem called for a special research over more than five years with the development of new simulation programs on droplets behavior; it included also full scale experiments to learn about both the formation of the droplets, their coalescence, adsorption and precipitation we can say that the problem has been perfectly solved meeting the most difficult standards.

Problem 3 - The solution was based on a very thorough set of studies related to the solar ponds. There we have learned about density flow o heavier, more concentrated sea water. The brine can be placed on the sea floor and allowed to flow on the slope towards the deeper parts. The Red Sea has at least three very deep parts with a tremendous storage volume. Moreover, there is a tide twice a day from the Southern straights. The inflow then reaches 40,000 m^3/sec. This is an excellent leaching mechanism which occurs well below the active part nearer to the sea surface. Notably there is an upflow of saline water from the sea bottom anyhow.

Problem 4 - There is nothing we can do about it.

Problem 5 - This is a subjective argument and there are those who do not see this as a problem, and even some that think it adds to the enjoyment of the landscape. There may be an effort to ask architects and art people for special treatment of the tower's shape and possible other uses, all the way to a small city of several thousands inhabitants on the circumference of the Tower.

Problem 6 - There is very little that can be done, besides making opening in fences and structures to make animal transport more possible.

Problem 7 - Bird's experts have suggested:

i. Lighting the chimney will prevent most chances for collision between the birds and the structure;

ii. By increasing the diameter of the top entrance to twice the diameter of the cylindrical part the air velocity reduces to one half;

iii. A very dense structure is placed over the top entrance in order to support the water supply and spaying system. This could provide a foothold for flying birds that have a tendency to be sucked in;

vi. There are very few birds flying at these elevations and those that do usually make use of air updrafts. However, the air around the Tower is usually in a state of a down draft.

Problem 8 - The chimney can be considered as another mountain which is marked in the maps and can also be equipped with signaling means to warn the planes.

Problem 9 - The necessary area is anywhere between 1/24 and 1/8 times the area needed for the same output in the best solar systems. If we do not need an extra area around the structure to precipitate the last traces of saline spray then the area needed by solar stations is 24 times larger or more. This area is not larger than the one needed for conventional power stations run by fuel.

Problem 10 - a) Acoustic experts predict that there will not be a disturbing noise coming off the Tower;

b) It is possible to install an anti noise by microphones installed at the air outlets. Amplifiers will produce noise waves at 180 degrees phase difference. These will neutralize any troubling noise.

Problem 11 - There cannot be an electronic noise because it is built like a grounded Faraday cage.

Problem 12 - This is a real problem that has 3 sub-items:

i. The cold and humid air may turn the air more convenient for human life and for some plant micro climate

ii. The cold humid air layer my carry with it pollutants and stabilize them densely close to the ground layer. It is therefore of absolute importance not to allow any source of pollution within this layer.

iii. The earlier humidification of the air by the installation of Energy Towers will have a positive effect on reversing to some extent the climate warming effect.

Problem 13 - This is not a problem; it is in all probability a great asset. We have shown that the heat transfer by the Hadley Cell Circulation is about one part in 20 of the solar radiation absorbed on the equatorial belts plus the two arid belts north and South of it. It is quite obvious that this is a tremendous cooling effect in association with the Hadley Cell Circulation. It works as follows. Where equatorial air rises, the air expands and cools. At a certain elevation above the global surface, the water vapors start condensing. There the rate of air cooling reduces from about a whole centigrade every 100m to only half a centigrade. Thus, the air goes up and remains relatively warm. The more humid the air in the equatorial belt, the warmer is the air at top heights and the better is the heat loss to space.

The most effective greenhouse gas is the water vapor. At the high air elevation above the equatorial belt (say some 10 km height), the air becomes practically vapor free, and then it easily cools by radiation to space.

Very interestingly - the moisture added to the air by the Energy Towers then enhances the rate of heat loss to space. Moreover, if we produce very cheaply desalinated sea water and irrigate the arid belts, we add to the rate of humidification within the equatorial belt, bringing up a warmer air.

In conclusion, the application of the Energy Towers and its by-products will act as a reversal to the global warming. This is a very exciting additional benefit of this new technology.

5. Is there a need for a pilot plant and what is the design stage?

This issue has already been discussed in the above.

Several working rules were followed by the development team:

a) To avoid insofar as possible dependence on new technologies or new materials and to use, if possible, only proven and widely used technologies.

b) To check by all means available that all crucial elements were investigated in more than one way and, wherever possible, by more than one team.

c) To encourage reviews by outside professionals at all stages of the development process.

d) To ensure that all estimates and decisions were conservative.

As a result, there is a great confidence in the estimates for each subsystem and for the overall success of the system as a whole.

Some of the reviews, performed by highly qualified engineers, expressed the opinion that there is actually no need for a pilot plant. Some reviewers suggested building a small but commercially viable power station. As explained above, this last suggestion was preferred also by the Mutual India-Israel Steering Committee. Possible dimensions of this demonstration plant were given in section 2.4 for a 6.5 MW and 10 MW. Later ideas suggested a larger unit, capable of generating up to 50 MW.

A work program was prepared for the pilot plant and this will now be revised for the larger demonstration plant. Two elements are required from this demo-plant by the operating committee:

- The capability of covering at least the operating expenses from electricity sales;
- To show that measured parameters of performance are sufficiently close to the computed ones, to be within an accuracy of ± 10%.

The whole work program consisted of several parallel activities:

a) Full scale planning and quotations from suppliers.

b) Planning of the demonstration plant.

c) Undertaking the necessary statutory process.

d) Legal and patent activities.

e) Site data collection.

f) World climate survey and search for more sites.

A *parallel effort should be made to continue the scientific efforts to further refine various design elements, to use the knowledge and technological advances, which has been developed recently in related applications, etc.*

During the first year to year and a half, general design and specifications will be prepared so that quotations can be obtained from qualified contractors, prior to initiating construction.

In the following table 23, we have initially assumed an extremely high error in estimating the cost of a certain component - $\pm 50\%$. The weighed average standard error turns to be $\pm 20\%$. Even increasing significantly the error in the climatic data getting far beyond 40% error instead of 20%, the increase in the standard deviation is not more than to 24%. After the first 1-1.5 year, the weighed average standard error will reduce from 20% to almost 10%, or even less, mainly due to much higher reliability in the unit prices by contractors and more accurate climatic data.

Table 23 - Estimate of standard deviation of electricity production cost

Subsystem	Weight	Error	Error following first stage Design and bids
Structure	0.3	$\pm$ 30%	$\pm$ 10%
Water supply	0.3	$\pm$ 30%	$\pm$ 10%
Turbo-generator	0.3	$\pm$ 30%	$\pm$ 10%
Others	0.1	$\pm$ 30%	$\pm$ 10%
Climate data	2	$\pm$ 25%	$\pm$ 15%
Computation	2	$\pm$ 10%	$\pm$ 5%
Weighed standard error		$\pm$ 21.7%	$\pm$ 10.9%

Following is table 24 with an anticipated probability of a cost estimate deviation of one, two and three standard errors or more. Accordingly, we can see the possible deviation in the actual cost. It is evident from these figures that there is an extremely low probability that an Energy Tower's economic performance will ever go into the red.

Table 24 - Changes in the electricity production cost in Eilat, Israel, (¢/kWh) due to upwards errors in the cost estimates for today and after the first stage

Probability for a larger error	**50%**	**15.87%**	**2.28%**	**0.135%**
Deviation in terms of a number of standard deviation	*0*	*1*	*2*	*3*
Today - Estimated standard deviation of electricity production cost = 20%				
Deviation from estimate	*0*	*20%*	*40%*	*60%*
Electricity production cost [c/kWh] at 5% discount rate	2.47	2.86	3.24	3.62
Electricity production cost [c/kWh] at 10% discount rate	3.88	4.54	5.20	5.87
Stage 1 - Estimated standard deviation of electricity production cost = 10%				
Deviations from estimate	***0***	***10%***	***20%***	***30%***
Electricity production cost [c/kWh] at 5% discount rate	2.47	2.66	2.86	3.04
Electricity production cost [c/kWh] at 10% discount rate	3.88	4.21	4.54	4.88

It is significant that the possible income highly exceeds the maximum required income of 5.87 ¢/kWh under a 10% discount rate and at 60% upward deviation of the costs estimates which today has a probability of only 0.135%. After the first stage (1-1.5 years), the standard deviation reduces from 20% to 10% and the maximum production cost for the same conditions reduces from 5.87 to 4.88 ¢/kWh.

Clearly, there are sites where the production costs will be much lower than those in Eilat and the chances for the Energy Towers to turn uneconomical in such circumstances are negligible.

We have already discussed in the above the reasoning behind working on a pilot plant first. It was shown to be an unjustified initiative.

Attached is a brief table of the designed stages and task performers towards the design of the full scale tower.

Table 25 - List of groups in the preparatory work plan

Work group	Main Performers
1.Review and translation of research records	Sharav Sluices
2. Data collection and review research to date, translation and design target definition	Sharav Sluices + Engineering Company
3. Development and perfection of numerical tool for different evaluations (flow, output, wind forces, etc.)	Sharav Sluices
4. Preparation of an improved global atlas; development of a climatic model based on satellites site measurements and other geographical and economical data	Sharav Sluices
5. Measurements of climate parameters for a whole year: temperature, humidity, wind velocity per one site; collection of geologic, topographic and hydrologic data of the site	Sub-contractor + Engineering Company
6. Optimization of design and operation of the Tower	Sharav Sluices
7. Evaluation of environmental problems and solutions for specific sites	Sharav Sluices + Environment experts
8. Design of water supply and spraying system	Engineering Company
9. Design of the construction and erection method	Engineering Company
10. Design of turbine system and generators	Engineering Company
11. Design of control systems	Engineering Company
12. Cost estimates and economic evaluation	Engineering Company
13. Quality and reliability assurance	Engineering Company + Sharav Sluices special team
14. Statutory process	Sub-contractor + Sharav Sluices
15. Marketing, management, financing, legal and promised prices	Europartners
16. Inspection of items 8, 9, 10, 11, 12	Sharav Sluices

The cost of this stage has been estimated to be about 7 million dollars for three potential sites. With the associated business activities and some reserves, it has been extended to 10 million dollars over not longer than 2 years.

6. **Some organizational notes**

The development of this project took place at the Technion--Israel Institute of Technology, in Haifa. The head of the development team was Prof. Dan Zaslavsky, formerly the Chief Scientist of the Ministry of Energy, Water Commissioner and later Dean of the Faculty of Agricultural Engineering. His last public task was for three years ending on the 31 of August 2007 as the chairman of the Israeli national commission for R and D. He was in charge of issuing a thorough report of the state of research and development and professional training in Israel. A similar precious piece of work has been published only in 1984.

The intellectual property remains the property of "Sharav Sluices Ltd." which used to be a subsidiary of Dimotech, which is, in turn, a subsidiary of the Technion Foundation for Research and Development. Dimotech has transferred its whole share to Prof. Dan Zaslavsky. 10% of the company "Sharav Sluices" belongs to an American company called "Tower Power".

Patents have been requested in 15 countries where installation seems most feasible.

"Sharav Sluices Ltd." is looking for strategic partners and venture capitalists to erect the full scale power station in order to enter the commercial stage. The commercial stage should commence in about 1.5-2 years after the initiation of design stages, with a maximum of 5 years to completion of the erection of the first full scale tower.

List of terms

Downdraft

An air flow directed downward.

Dry adiabate

The change in the gas temperature by changing the pressure with no heat exchange with the environment and no vapor condensation or liquid evaporation.

Greenhouse gas emission

The greenhouse effect is trapping the heat and not letting it be radiated outside. It is agreed that gases like carbon dioxide helps capturing the global heat and prevents its cooling. Methane is some 55 times more efficient as a greenhouse gas, at least for a period of a couple of decades after it's emitted into the atmosphere.

Most people, and even some scientists, are not aware of the fact that water vapor is a very efficient greenhouse gas may be the most efficient. The cooling effect is obtained when air warms up and rises up. The cooling is about one centigrade every 100 meter rise. When the air is saturated with vapor, on rising, the vapor condenses into water droplets and the air cools only about half a centigrade every 100 m. Thus, on rising high enough, the air remains practically free of vapor and it is still of relatively high temperature. This process comes above the equatorial belts and leads to the most effective cooling effect. It radiates out nearly 95% of all the solar radiation absorbed over the belts around the equator, from 35 degrees latitude South to about 35 degrees latitude North, including both the equatorial belt and the two desert belts - South and north of it. Thus, a better saturation of the air with water vapor near the ground may create an early vapor condensation and bring up a warmer air to improve the cooling effect.

Interestingly, if we could irrigate the deserts without the need to burn fuel in order to desalinate sea water, the plants grown there would take away carbon dioxide from the air.

Kilowatt (kW)

Thousand Watts power (expressed by kW).

Kilowatt hour (kWh)

A total work done which is the product of power rate by the time.

Kyoto Protocol

The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases.

The Kyoto Protocol now covers more than 160 countries globally and more than 60% of countries in terms of global greenhouse gas emissions. It calls for the reduction of greenhouse gas emission to few percents less than the level in 1990. This must be performed before 2012.

Megawatt (MW)

Million Watts or thousand Kilowatts.

Pascal

A pressure unit in dynes per square centimeter. One gram is nearly 10 dynes. So, one Pascal is equivalent to the pressure of to one part in ten thousands of an atmosphere.

Photovoltaic cells

Plates or films that produce electrical current when put under the radiation of the sun.

Pumped storage

A volume of water stored in an elevated reservoir and which is released to flow down and provide energy when there is peak demand of electricity.

Reynolds number

A dimensionless term VD/ν, where V - fluid velocity; D - a typical dimension; ν - the kinetic viscosity. Reynolds number is widely used for dimensional analysis of fluid flow where the viscosity of the fluid plays a role.

Solar collector

An instrument which has an area surface that absorb solar radiation to use it as heat or electricity.

Solar thermal electricity production

Heat up an area or body by radiation of the sun to higher temperatures, creating steam or air flow and producing a working machine that in turn, generates electricity.

Updraft

An airflow directed upward.

Watt (W)

A unit describing a rate of energy output. The unit is called a "power".

Wet adiabate

The change in air temperature by changing the pressure with no heat exchange with the environment, the presence of liquid droplets that are evaporated or get more condensed liquid.

List of figures

Figure 9 - The Hadley Cell Circulation with two arid belts - Climatic zones in Europe, Asia, Africa and Australia. The yellow and bright red areas marked by the letter "A" are desert or arid lands

Figure 10a - Climatic zones in Europe, Asia, Africa and Australia. The yellow and bright red areas marked by the letter "A" are desert or arid lands

Figure 10b - Climatic zones in America. The yellow and bright red areas marked by the letter "A" are desert or arid lands

Figure 11 - The power distribution over the year
[near Eilat, Israel]

Figure 12 - Cumulative volume of spray droplets (right curve for on-off charging regime; left curve for continuous charging)

Figure 13 - Differences in cumulative volume between the on-off electrical charging regime and the continuous charging. Note a 20% value reduction taken off the droplets smaller than 280 micros diameter. The original share of these droplets was over 60% and is now a little over 40%

Figure 14 - Schematic view of the turbine

Figure 15a - Mapping of the net output from a standard design Tower in the South of Israel (5x5 km area units)

Figure 15 b - Mapping of the net output from a standard design Tower in Israel and its neighbors (5x5 km area units)

Figure 16a - Internal Rate of Return for Energy Towers - 5% 851 million dollars initial investment under the conditions of South Arava; 4 years construction; 30 years life project; 0.556 ¢/kWh

Figure 16b - Internal Rate of Return for Energy Towers - 10% 851 million dollars initial investment under the conditions of South Arava; 4 years construction; 30 years life project; 0.556 ¢/kWh

Figure 16c - The Pay Back Period as a function of the income per kWh (i=5%)

Figure 16d - The Pay Back Period as a function of the income per kWh (i=10%)

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