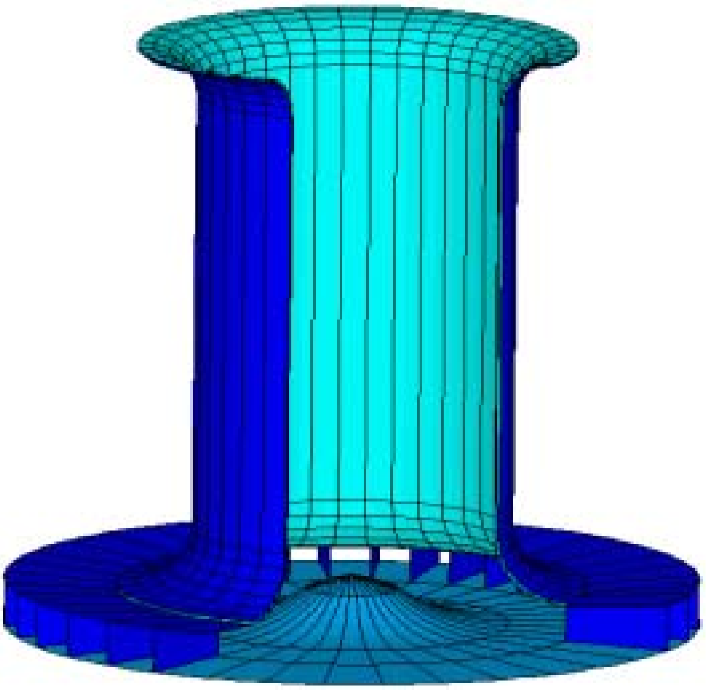
ENERGY TOWERS

for Producing Electricity and Desalinated Water without a Collector



Israel - India Steering Committee

The Chief Scientist Office - Ministry of National Infrastructures
The State of Israel
and
TIFAC--Technology Information, Forecasting and Assessment Council
Department of Science and Technology , Technology Bhavan
Government of India

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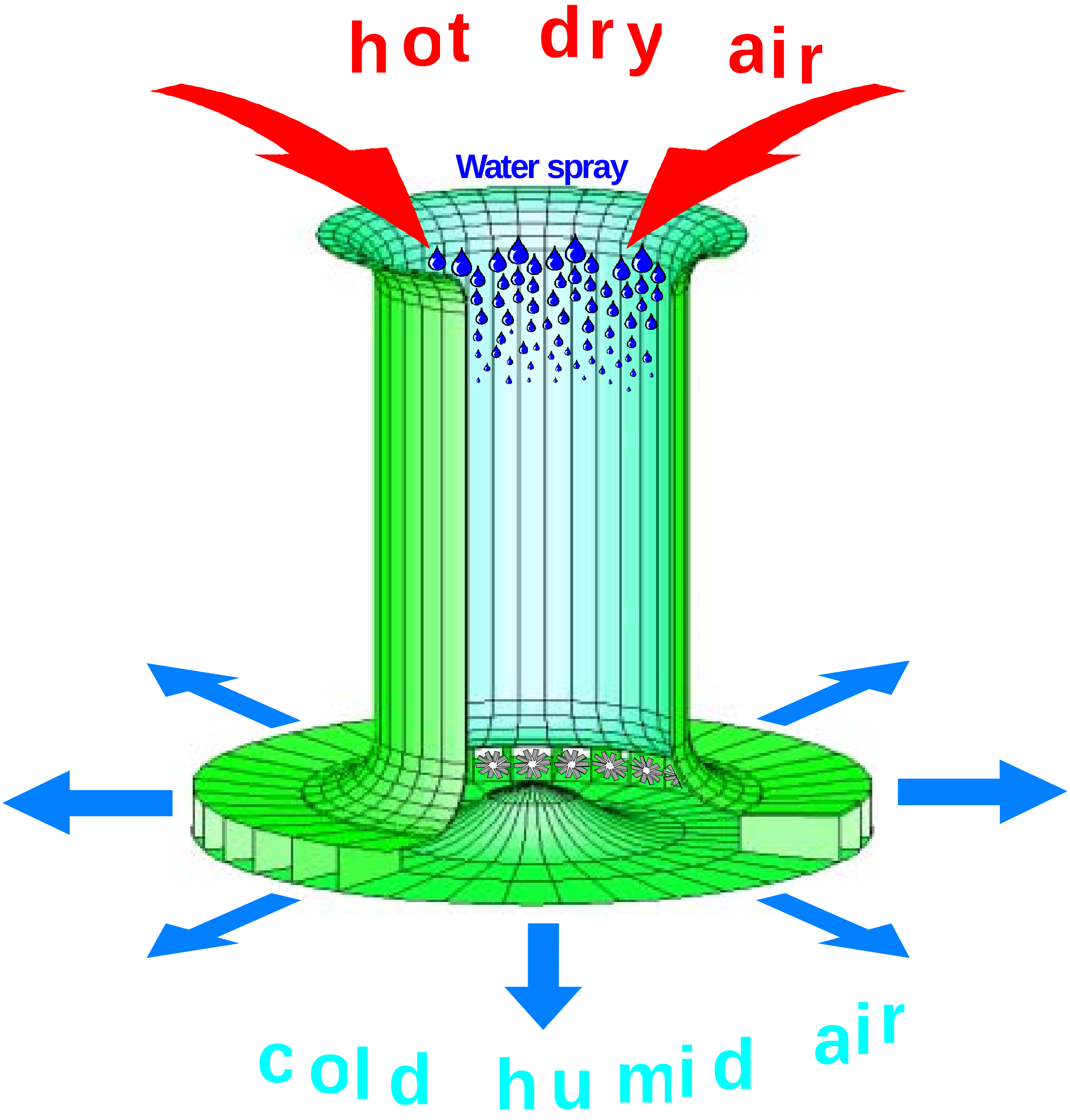

Figure 1 - The Energy Tower principle

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Executive summary

Name

“Energy Towers” is the name of a technology which was developed at the Technion--Israel Institute of Technology, to produce electricity in arid lands, taking its predicament - a lot of hot and dry air - and turning it into an asset.

Over and above the age old sources of wind, hydro-power and bio-mass, the “Energy Towers”, as far as we can judge, is the most economically promising technology of all the technologies which are being developed to produce environmentally clean electricity using renewable sources. Moreover, it does not require a solar radiation collector and it works continuously day and night. It is also capable of producing very large quantities, an order of magnitude more than all the electricity produced today around the world, or even when the whole world would consume at the level of Western Europe.

The principle

A vertical hollow shaft will be constructed in heights larger than 400 m and diameters larger than 100m. Optimal dimensions can reach four to five hundred meters in diameter and over 1000 m in height. Water (usually sea water or brackish water) will be sprayed at the top opening. The water will partially evaporates, cooling the air.

The cool air is heavier and will sink down, producing an effect which is opposite to the effect which happens in common chimneys. When properly designed, the air will flow at high rates, moving turbines and electricity generators through openings near the shaft’s bottom.

Proof of the physical principle and the technologies

The basic principles have been repeatedly reviewed by top outside experts. The reviews indicate that the physical principles have been fully confirmed, including the calculation of net electricity output. It has also been assessed that the Energy Towers can be built mostly by proven technologies. Furthermore, the unusually large dimensions of the shaft may not seem to pose any serious technical problems.”

Renewable energy without the need for a solar collector

The most outstanding feature of the Energy Towers is that like wind energy, hydropower and biomass it needs no collectors in order to capture the solar radiation.

This fact leads towards several very important results:

- There is a very significant cost saving.
- A commercial power station will operate 24 hours a day. By contrast, best solar thermal units work only 6-8 hours a day. Storage of energy would further reduce the efficiency and add to the cost of the solar methods.
- In the Energy Towers, there is a minimal need for backup by fuel or expensive storage.
- The land area needed is no more than twice the area for a conventional power station, but only one tenth of what is needed for all other solar technologies.

Economy

The expert review committee, nominated by the Israeli Ministry of Energy, found that there is a wide favorable economic margin compared with electricity from conventional fuel sources (coal or natural gas) even without including any external community costs due to environmental damages by fuel burning.

The projected electricity production cost with optimal dimensions in Eilat, in the south part of Israel, was found to be 2.47 ¢/kWh at 5% discount rate and 3.88 ¢/kWh with 10% discount rate (for 30 years and 4 years station construction). In a most recent evaluation by the group of professionals who have prepared a business plan, the electricity cost of the Energy Towers is slightly less than the average representative electricity costs of coal fired and natural gas combined cycle stations. The range of possible costs widely overlaps the costs from the new technology. However, several added benefits for the Energy Towers can economically outweigh even the best available conventional power sources. The production cost reduces in sites with better climatic conditions.
Eilat is not the best site on the earth. There are sites where the electricity production cost reduces to 1.68 ¢/kWh at 5% discount rate and 2.51 ¢/kWh at 10% discount rate.

Compared with other solar technologies

The Energy Towers projected cost of electricity is the lowest among all renewable sources with the exception of some large hydro power stations under very favorable conditions.
As an example, electricity from photovoltaics cost in the order of 30-40 cents per kWh. The investment per average kW from photovoltaics is in the order of $50,000 as compared with $2,300 per average kW from the Energy Towers. The investment for an average kW for a coal fired power station is $1,800-$2,000 (at about 2/3 capacity factor). The projected cost of electricity from the best solar thermal technology under development is 12-15 cents per kWh for only 6-8 hours a day.

The “Energy Towers” potential

In Israel, the potential is to provide all the electricity for the year 2020 and much more (in order of 50 billion kWh per year in the Arava). In India, the Energy Towers’ potential may provide electricity to over half a billion people at the West European level of consumption. In the world, there are about 40 lands which have good conditions to install Energy Towers. The theoretical potential found in a recent global estimate for Towers with an average output of 200-600 MW was found to be (conservatively) 230,000 billion kWh per year. The present global consumption is mere 8,000 billion kWh. If 6 billion people consume electricity at the level of Western Europe, the total consumption will be in the order of 32,000 billion kWh. With modern long transmission lines, electricity can be provided to the majority of the global population.

Other benefits

- *Pumped storage*

A built in capacity with no energy losses and very small investment may improve the economy by more than 30% (in the order of 2 cents per kWh over and above the average tariff that can be obtained in many sites).

- *The use of clean renewable energy will avoid the penalty for greenhouse gas emission or gain the equivalent compensation.*

These first two benefits are expected to range between 2 and 3 ¢/kWh practically in all or most sites.

- *Desalinization*

Desalinization of sea water can be incorporated into the Tower, and it can be installed gradually in small modules. The projected investment is 1/2 and the energy outlay is 2/3, compared with conventional Reverse Osmosis. The cost saving in sea water desalination can reach 45%. With about 20% of the Tower's energy, in its base line dimensions, it is possible to desalinate 200 million cubic meters of water per year.

- *Sea fish growing*

Alleviating environmental and economic problems by using the water en-route to the Tower, each Tower has a potential of $\$90\mathrm{X}10^{6}$ up to $\$450\mathrm{x}10^{6}$ fish production per year (15,000 to 75,000 tons per year).

- *Elimination of salinity now destroying some of the largest irrigation projects*

This is by utilizing the brackish drainage water to produce electricity (about 10 kWh for each cubic meter of evaporated water) and by disposing of the brine.

- There are some more benefits. Among them: cooling water for thermal stations; air cooling for gas turbines; bonus for eliminating the greenhouse gas emission; avoidance of fuel import; immunity against fuel cost rise and fluctuations; no need for strategic fuel reserves; improved balance of payment etc.

- *Reliability*

The cost of electricity production was computed in a highly reliable fashion. Furthermore, the future plan of work intends as a first stage to obtain quotations from suppliers, thus reducing even further the uncertainty in the projected electricity production cost.

Authorities' attitude

After reviewing the project, the Government of India suggested to the Government of Israel that the two countries join forces, and together, with the developing company "Sharav Sluices Ltd.", undertake completion of the project. A joint Steering Committee for India and Israel was formed, and meetings took place in Jerusalem between May 21st to May 24th, 2001. The recommendations were:

One) To build a demonstration plant with an average output between 6.5 and 10 MW, that may be later used to produce electricity and the prices obtained to cover at least the running expenses.

Two) The Indian delegation suggested that the Indian Government may provide 50% of the total investment which was initially estimated at 100 million dollars.

Three) Consequently, the demo-plant will be erected in India (probably in the State of Gujarat or Rajasthan).

1. Main story

1.1 Brief history

The project started in 1982. Prof. Zaslavsky's interest was aroused when working on the engineering of the so called stratified, or density gradient, "solar ponds" with "Ormat" in the northern end of the Dead Sea. He became convinced that renewable energy for electricity would be more efficient and, in all possibility, more economical if it did not require the installation of a solar radiation collector. There is no theoretical proof of this; but, so far, there is no practical exception.

The oldest forms of energy used by man are renewable (wind, hydro-power, bio-mass), and do not require the use of a structured solar collector. The construction of a convective Tower with air downdraft, as described here, is another possible source of this type.

Prof. Zaslavsky of the Technion--Israel Institute of Technology in Haifa, later found out that Dr. Philip Carlson had used the main principles required to implement and develop such an idea. He has been granted a U.S. patent in 1975. Several very important improvements were added by the Technion team headed by Zaslavsky to reduce the cost effectiveness ratio by a factor of about 1:7.

The project was supported mainly by the Israeli Ministry of National Infrastructures (formerly the Ministry of Energy), by financial contributions of the American Technion Society - Baltimore Chapter, different research foundations and primarily by the Technion itself. The Israeli Electric Corporation followed the project's progress, reviewed it and helped financially and professionally.

Scientists and engineers of 5 departments, including 13 professors and 8 engineers with Doctorate degrees, participated in the project. Nearly 20 theses for higher degrees were involved. All in al, over 100 men-years were spent on the Energy Towers development.

A patent was requested in 15 countries and already approved in some, and close to be formally confirmed in other countries.

The first expert reviewing committee included 12 members. This committee was nominated by Prof. Haim Eilata and Gur Arieh Eitan, then the Chief Scientist of the Ministry of Energy and the head of R&D division, respectively(early 1983). All their conclusions were positive.

In 1994, the Israeli Minister of Energy nominated a 7 member expert committee, headed by Prof. M. Sokolov of 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 wide experience in erecting different types of power stations; and the head of the R and D division of 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. 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 over more than one year and 18 special brochures were prepared for the benefit of the reviewer. The committee conclusions' were:

- All physical principles were proven and re-proven beyond doubt.
- The project can be built completely by proven technologies.
- There is a wide economic advantage compared to the conventional sources of energy.
- There are several know-how gaps that could be bridged with good chances to further improve the economy.

Much work has been done since. Different aspects of the idea were confirmed and re-confirmed and significant improvements were made. At the request of the Israeli Ministry of National Infrastructures, a 13 volume documentation of about 2500 pages was prepared by the development team. The net deliverable output was estimated by different teams using 8 different computation methods. The differences were no more than 2-3% over a range of parameters.

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

A mutual Steering Committee convened in Jerusalem a year later, on May 21-24, and came to the following main conclusion points of action and decisions:

One) Both governments of Israel and India should take action to promote the project for the benefit of the two countries;

Two) A demonstrable 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 the running expenses from future electricity production;

Three) The development team estimated that the dimensions of the demo-plant should be about 400 m height and 150 m diameter. The investment needed for all the preparatory activity to the point where the full scale commercial erection could be initiated is about 100 million dollars. Of course, this includes the cost of demo-plant erection which would cost about half of this sum.

Four) A site should be chosen for the development and for the full scale commercial unit. Extra benefits of the Energy Towers should be utilized as many as possible, without loosing sight of the main purpose of producing cheap and reliable electricity.

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

Six) More comprehensive agreement on rights should be prepared at a later stage when the large sum financing becomes a reality.

The company "Energy Towers" which was registered and it owns the intellectual properties is actively involved in searching for investors / strategic partners.

1.2 Themes for project consideration or review

An interested reviewer should probe into several series of questions in order to form an educated opinion, however, it should be kept in mind that a complete judgement must utilize a multiple number of experts. The detailed review work is long and costly. It is, therefore, recommended that before undertaking a very expensive test, maximum use of former reviews and existing evaluation should be made.

<u>Question series 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: sources of the energy which is the famous Hadley Cell atmospheric circulation that produces the world's arid land and carries in the order of $2\text{-}4X10^{16}$ kWh heat per year; the thermodynamic principles; the transformation from heat to mechanical energy; climatic conditions 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; measurement and computation of energy loss coefficients; experimental coefficients of the rate of evaporation of water sprays; geometry of the air flow in the shaft; the type of turbines and method of their control; different areas' proportions; water supply design and pumping energy; water spraying method and collection of salt spray, spray excess and distribution over the top entrance, etc.

The answers to these questions fill several volumes of different computation methods, wind tunnel tests and actual tests in the Tower. They require several optimization decisions. Unfortunately, many attempts to compute the net deliverable power made by reviewers were intuitive, and short of physical and engineering reasoning.

<u>Question series no. 2</u> - Available technologies

The policy of the development team was to avoid, if at all possible, the need to develop new basic technologies. With the exception of one case, this rule was maintained. A superficial review led some to think that the dimensions of the structure pose a serious problem. This is not necessarily the case. The one problem where the team came closest to walking on untreaded ground was the clearance of the unevaporated spray of brine droplets from the air. This problem could have turned to become an impasse. All engineering decisions were made in a conservative way. Rules of dimensional analysis were used when necessary, having different scales for different processes. Finally, commonly used factors of safety were used here as well.

<u>Question series no. 3</u> – What are the environmental problems which are being eliminated and what others are created

An absolute determination was arrived at in this case. There are at least three major environmental problems which will be reduced by the Towers: environmental damages due to the use of fuel and conventional power stations; water shortage and salinity damages due to over-pumping, and over-fishing. There are 10 environmental problems which are created by the Energy Towers erection and use. The overall conclusion is extremely positive by any measure. However, this did not prevent the development team from handling and overcoming the most important parts of the 10 specific environmental problems posed by the Tower. Among them: salinization by water spray; sea water leakage from the canals; effect of returning brine into the sea; cold and humid wind; visual pollution; noise; disturbance to air traffic; disturbance to free movement of animals; sucking nomad birds into the tower and shadow projection around the Tower. The really most serious problems are the first three, and they can be eliminated by a proper design.

<u>Question series no. 4</u> - What is the economy of this technology, measured by common economic yard sticks, compared to the economy of conventional energy sources without any ideological reasoning or support

The economic justification was based on electricity production and sale only. Electricity from the Towers is competitive with conventional electricity from coal and natural gas. However, added benefits may more than double the income over and above the opportunity prices for the electricity. The internalization of the communal external costs from environmental damages and strategic problems add another dimension to the economic evaluation. Some items add to the commercial value of the Towers and some have a national importance of a macro economic nature. There is always the question of risk in investing in general, and in new technologies in particular. This risk can be estimated. Furthermore, one can minimize it by being prudent. We have attempted to determine the cost for heights from 300 to 1400 m shafts and for various diameters, and also estimated the risk that the cost of electricity production will be larger than projected. The risk is small and it becomes even smaller after the first stage in the suggested work program.

<u>Question series no. 5</u> - The potential of the technology in Israel and around the world and possible marketing

How much hot and dry air is being provided, and what part of it can be exploited; how far can the electricity be shipped from the lands where it can be produced; to what extent do the Energy Towers need backup by conventional fuel, etc. The new electricity demand in different parts of the world put another upper bound to the potential marketing extent.

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

The development has been essentially completed, and preparations should be made to start erecting the first commercial unit.

In order to answer some of the questions in this category, a very detailed work program was prepared with 7 major work groups and some 70 different tasks. The original plan of work was to design a full scale, to do the statutory effort necessary to allocate sites for both pilot plant and the early commercial units. The work included also further improvement of the technology and marketing efforts.

Some experts considered the erection of a pilot plant (scale 1:7) and above 1 MW average output as redundant. The Israeli-Indian Steering Committee has decided upon a 1:3 demonstration plant to proceed to the full scale commercial unit. The demo-plant is defined by its residual value that justifies at least by its future electricity production and the electricity sale. The size of this demo-plant was estimated in a preliminary way to be of 400 m height and 150 m diameter and a net energy power above 6.5 MW and up to about 10 MW.

The first stage of the work program includes the design, specifications and quotations by qualified contractors. By then, the deviation of the electricity production cost from projections, would become even smaller.

1.3 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 three decades it has been studied extensively due to its effect on aviation. It is often referred to as “wind shear”. The “Energy Towers” technology is an attempt to contain the process inside a tall and large diameter hollow shaft with an open top and openings around the bottom (see figure 1). The 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. The cooled air is denser. As an example, air cooled by 12 centigrade is approximately 4% heavier than the ambient air. 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 moves 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 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 south part of the Arava Valley in Israel (1200 m tower, 40 km away from the sea and 80 m above the sea level is given in figure 2.

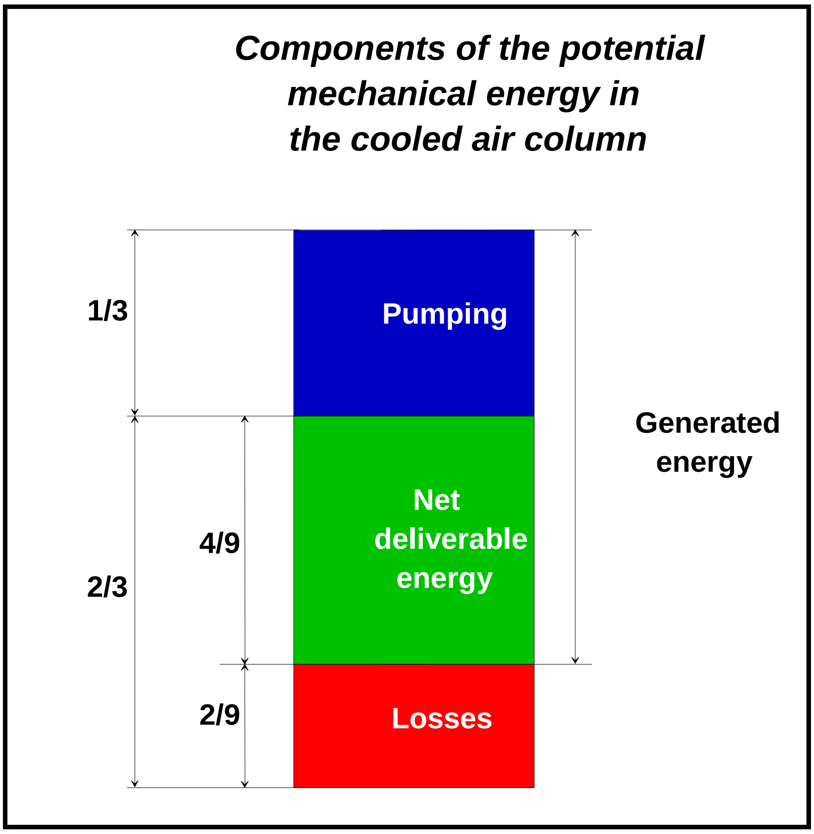

Figure 2 - Components of the mechanical energy

Using several independent methods of analysis, a medium size model (21 m high), experiments and wind tunnel models, 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 south Arava, north of Eilat, the mechanical energy is divided about 4/9 for electricity delivery, 3/9 for pumping and 2/9 energy losses as the air flows through the shaft. (See figure 2).

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 only on the Tower height H_c . T_{max} is the outside air temperature at the shaft bottom and T_{min} is the outside air temperature at the shaft top. The whole efficiency term of turning heat to mechanical energy is roughly equal to $0.7\frac{H_c}{30000}$ where H_c (the shaft's effective height) is in meters. 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 about 1.2%.

The following explains the futility of the updraft chimney, called the “Solar Chimney”, promoted by Prof. Schlaich of Stuttgart, Germany. Assuming 50% efficiency of a solar collector, which is needed to heat the air in the updraft case, the overall efficiency would be at best 0.6% The value was actually measured by Prof. Schalich’s team in south of Spain. From about 2000 kWh per 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 will be less. If the solar collector cost is only 50 dollars per square meter, or 5 dollars per year per square meter, then the contribution of the collector alone to the electricity cost is 42 cents per kWh - a hopeless case.

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

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

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 [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) plus the recovered energy of the non-evaporated sprayed water (E_{Ri});
- ρ is the average air density [kg/m^3];
- F is the energy loss coefficient [-].

This formula is a result of an analysis showing that the term $\frac{2}{3}$ E_{net} in parenthesis gives the theoretical maximum possible 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 be expressed by:

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

Interestingly, the ratio N/Q is

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

independent on 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 per cubic meter of air or per unit weight of sprayed water.

While equations 1 and 2 can be proven analytically, the loss coefficient has been the subject of extensive experiments in wind tunnels, and subject to several independent efforts of Computational Fluid Mechanics (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 6 kWh per cubic meter of sprayed water. It is closer to 9 kWh per cubic meter of evaporated water.

Great efforts have been made to estimate each one of the parameters in equation 1. 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 in reality, higher than the power at the average conditions. F - the energy loss coefficient, 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, and 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 ratio of outlet areas (A_D) to the cross sectional area of the Tower (A_C) squared.

It may be enlightening to some reviewers that regardless how high is the loss coefficient F, it is impossible to obtain a negative figure for N, the deliverable power from equation 1. 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.

The fundamental question is whether the produced electricity exceeds the electricity consumed for pumping. There is no general answer to this question. It has to be checked in each case. As an example, in the base line design, 40 km from the Eilat Bay, 80 m above sea level, we get positive net deliverable energy and every additional 100 m elevation of the tower base above sea level, will reduce the net deliverable electricity by about 5%.

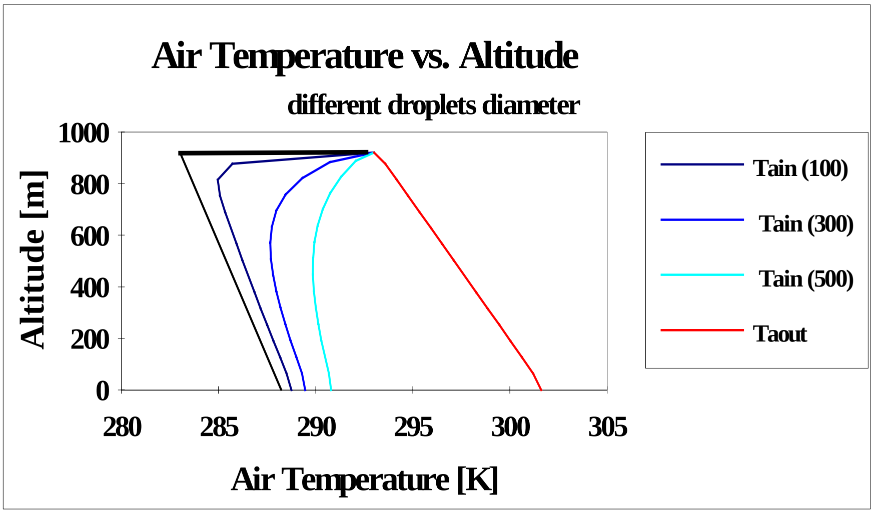

Figure 3 - Temperature change with elevation (Left - inside air, Right - outside air)

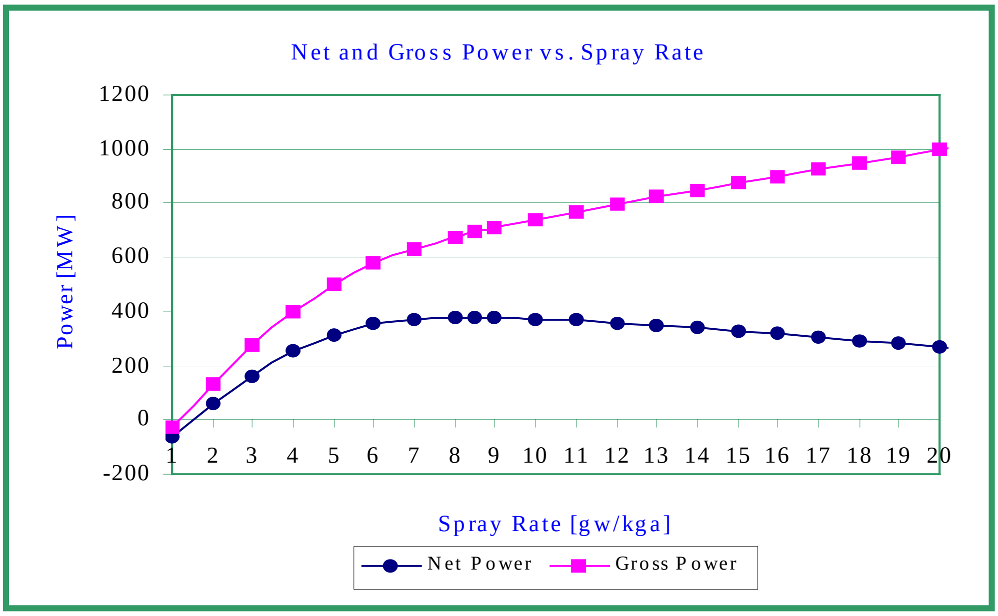

Figure 4 - Gross and net power vs. spray rate in grams of water per kg air

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 adiabat or about one centigrade over 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 approximately 0.5 centigrade per 100 meters.

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 between smaller droplets for better cooling, and larger droplets for lower energy spending for pumping and spraying. 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. The gross power is extremely important because it can be used when pumped storage is utilized. For an explanation, see section 1.5. 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 come close to the upper line in figure 4. This is a dramatic advantage over other forms of renewable energy sources which have no way of conforming the supply to the demand. It is a built-in capacity of the so called “pumped storage”. The economic value of this quality is nearly 2 cents per kWh under the conditions of south Arava and the electricity tariffs in Israel.

In summary, it is necessary to optimize the Energy Towers by choosing the right size droplets and the right amount of excess water spray. 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 $\frac{1}{3}E_{net}$.

Finally, 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 modern techniques of computerized fluid dynamics. The cylindrical symmetric computations and the three dimensional computations employed a turbulence model $(k-\varepsilon)$. We obtained practically the same results using all eight methods. Recently, a new more advanced grid has been composed to compute more complicated cases of tower operation which may be especially useful for cases with strong outside wind and for regulating 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.

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.

b) Choice of optimal aperture area of the turbines.

c) Choice of optimal slowing ratio (AR) due to diffuser sizes and opening angles downstream from the turbines.

d) The shape of the top air inlet to minimize the high energy losses which are possible in the presence of outside wind.

e) Choice of optimal height and diameter of the Tower.

Figures 5 and 6 show the average net output and the annual energy output as a function of the tower net cooling height H_C and the diameter D_C for a slowing ratio AR=2. The site is 40 km north of Eilat and 80 m above sea level.

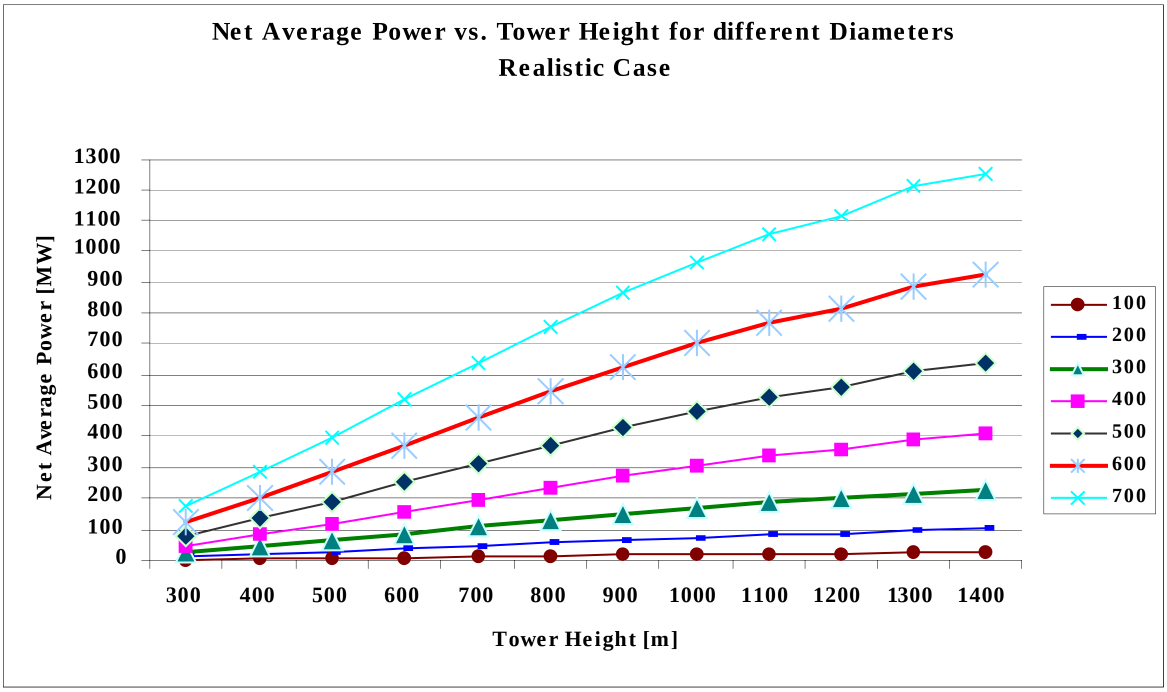

Figure 5 - Net average power vs. tower height for different diameters (AR=2)

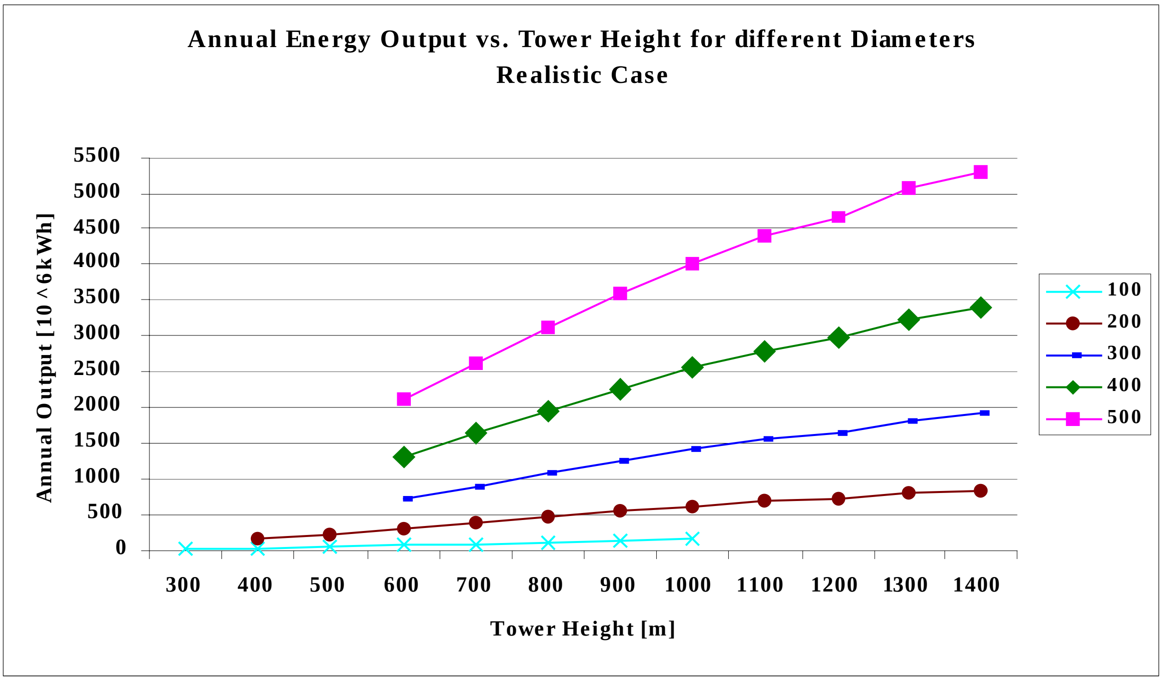

Figure 6 - Annual energy output vs. tower height for different diameters (AR=2)

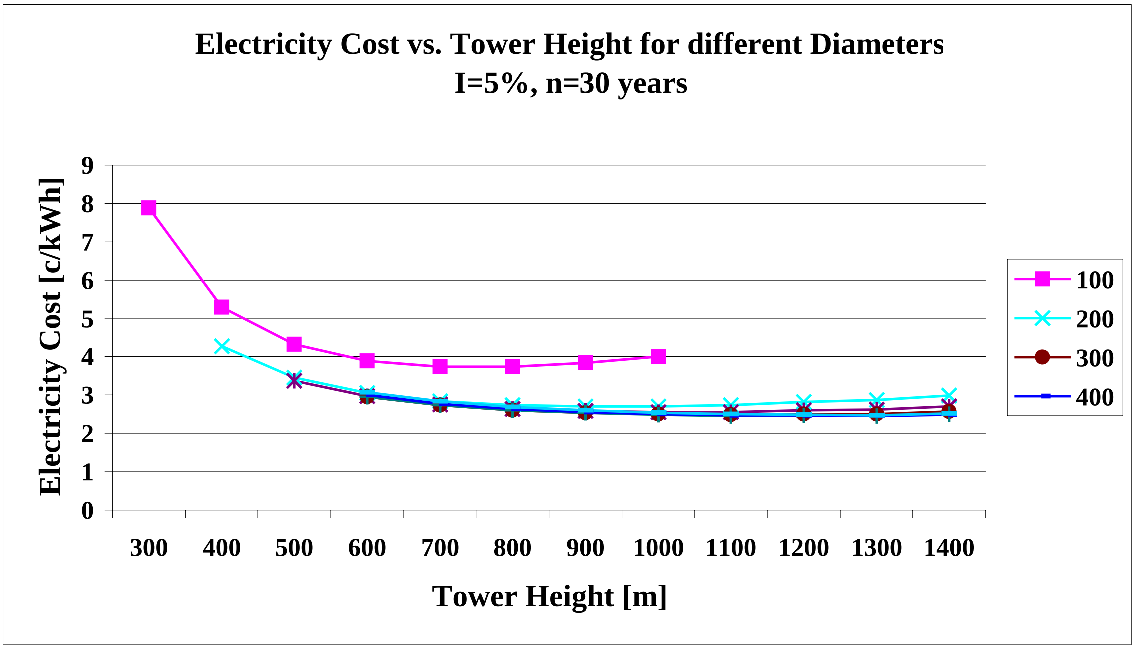

Figure 7a - Electricity production cost from Energy Towers with 5% discount rate

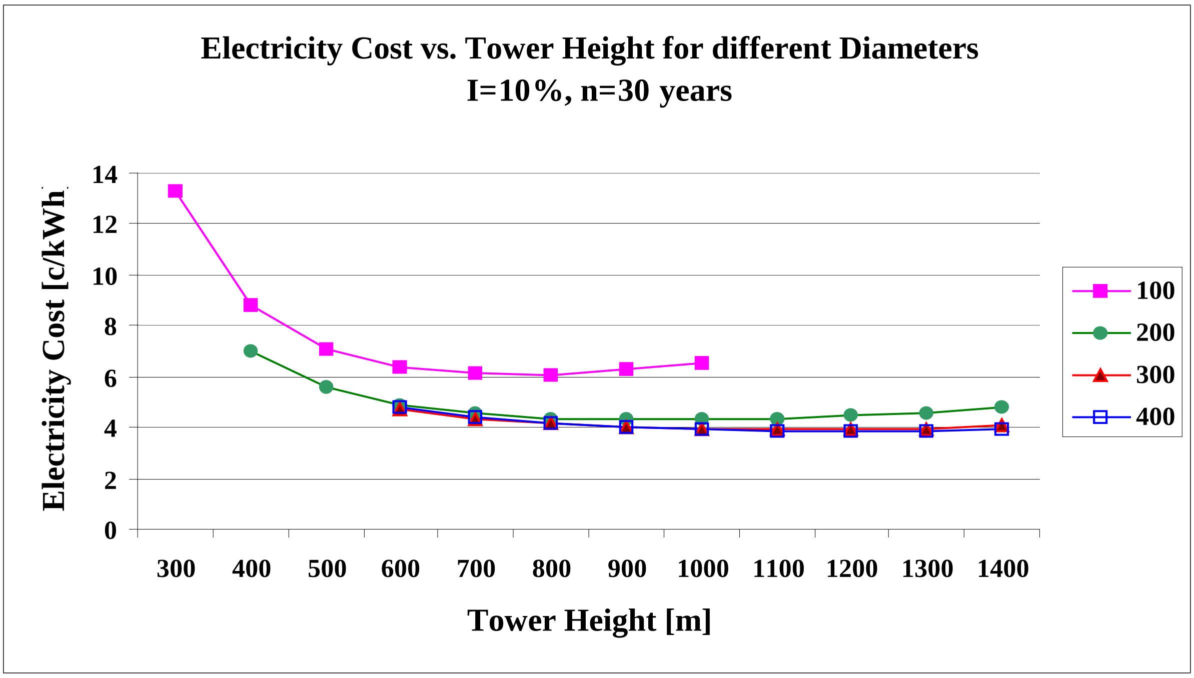

Figure 7b - Electricity production cost from Energy Towers with 10% discount rate

Tables 1 and 2 show the computed net deliverable power and the annual net electricity delivered. 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

		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

		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

		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

		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

		Height (m)											
		300	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**
Diameter (m)	**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

1.4 The electricity costs

In figure 7a, one can see the estimated cost of the deliverable electricity with 30 years projected life, 5% interest, 9.1% interest during construction and about 0.556 ¢/kWh operation and maintenance expense. 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 7 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 7b.

An interesting relation between the rate of water spray and energy production can be inferred from equation 3. For a 1200 m tower, one cubic meter 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 height, the production of electricity per cubic meter of water spray is also about one half. Therefore, the cost of water supply and pumping is relatively smaller for a taller tower.

All the above lead to the choice of very large tower dimensions. In fact, the average cost of electricity drops from over 4.5 cents per kWh for 20 MW average power and slightly over 3 cents per kWh for 40 MW average net power. This is at 5% discount rate. The production costs increases to 3 cents per kWh for 20 MW and about 5 cents for 40 MW average net electricity capacity.

The rough dimensions of the demo-plant were estimated from these tables. The requirement was that the net average output should be higher than 6.5 MW and it should not exceed 10 MW. This requires the following dimensions and electricity costs at 10% discount rate.

6.5 MW	316 x 150 m	10.44 ¢/kWh
	445 X 100 m	8.1 ¢/kWh
10 MW	400 X 145 m	7.61 ¢/kWh
	550 x 115 m	6.8 ¢/kWh
	620 x 100 m	6.3 ¢/kWh

It becomes obvious that at the investment which does not exceed 22 million dollars, a 6.5 MW station can be built and 29 million dollars for a 10 MW station. There is no competition by other solar methods even at such small towers.

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 meters.

At the optimal dimensions, the cost of electricity is 2.47 ¢/kWh with discount rate of 5%, and 3.88 ¢/kWh at 10% discount rate. This competes with every known technology, with the possible exception of very large hydropower projects, especially cheap combined cycle projects with closely available natural gas sources. (See the following table 6).

Table 6 - 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

Sensitivity tests show that the increase in fuel costs and reduced interest rates will make the Energy Towers more and more competitive. The cost of gas makes 53-77% of the electricity in the above table. Gas costs are expected to be doubled. 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.

There is a very wide overlap between the projected costs of electricity from the Energy Towers and the leading fuel burning sources of electrical power including nuclear power.

The gross disadvantage of the Energy Towers, at least in their early application, is that they are not as economically attractive at small dimensions and small investments.

The gross advantage is that in addition to income from electricity sale, other benefits are expected, in most cases, these benefits will add to 2-3 ¢/kWh, and in some cases even twice as much.

1.5 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 rising air cooling with moisture condensation is about half a centigrade 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 a latitude between 15 degrees and 35 degrees north or south. The descending air warms up, this time a full centigrade every 100 m. High pressure air belts are formed. Finally, the air turns back towards the equator picking up moisture and heat again.

The areas of air descent turn into arid lands. The hot and dry air forms the desert; it is not the desert that makes hot and dry air.

Figures 8 and 9 show the belt of deserts and arid lands painted yellow and bright red. There are several estimates of the heat transfer which results from the Hadley Cell circulation.

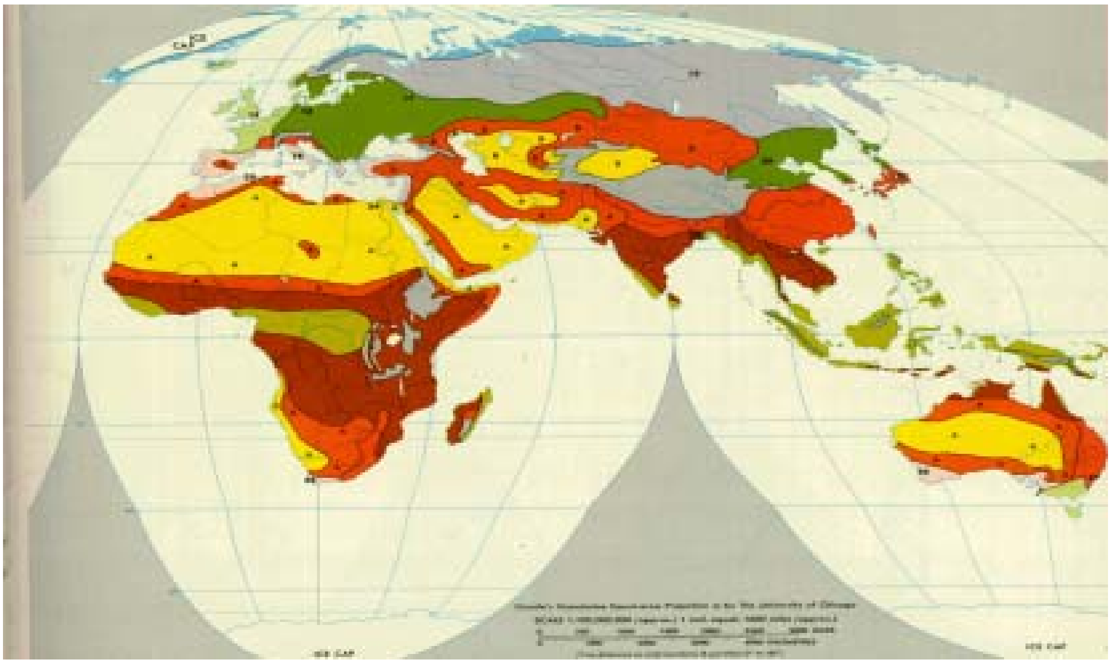

Figure 8 - Climatic zones in Europe, Asia, Africa and Australia. The yellow areas and the bright red areas marked by the letter "A" are desert or arid lands

Figure 9 - Climatic zones in America. The yellow and bright red areas marked by the letter "A" are desert and arid lands

One estimate is over 17 million 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 per year. A typical rate of air descent is one centimeter per second. Assuming a cooling rate of 10-12 centigrade, a similar heat supply is estimated.

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 2-4x10^{14} kWh per year. Assuming the future use of all human beings of 5000 kWh per year per capita, this theoretical quantity is sufficient for 40-80 billion people ! An order of magnitude greater than the population of the globe.

Recently, the development team has prepared an estimate of the world potential using a satellite set of measurement data (ECMWF) over 10 years, every hours, and at several elevations. In this somewhat simplified and conservative computations only data of 1200 m above the local ground level were taken into consideration and distances from a water source and elevation above a water source. The computation was made for a base line design tower of 1200 m height and 400 m diameter. The results are summarized in table 7, and are organized in power groups of 50 MW average output from 200 MW and up to 600 MW. The total annual power at this table is about 2.3 X 10^4 kWh/year, about 1% of the heat flow through the Hadley Cell circulation.

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]**
600-550	69	173	839	1.68-1.78	2.51-2.69
550-500	233	583	2,679	1.78-1.90	2.69-2.90
500-450	1,017	2,542	10,579	1.90-2.05	2.90- 3.16
450-400	2,248	5,620	20,923	2.05-2.24	3.16 - 3.49
400-350	4,167	10,418	34,221	2.24-2.48	3.49-3.91
350-300	5,989	14,973	42,627	2.48-2.80	3.91- 4.47
300-250	8,597	21,492	51,775	2.80-3.25	4.47- 5.25
250-200	13,137	32,843	64,733	3.25-3.93	5.25 - 6.42
Total	**35,457**	**88,644**	**228,376**		

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.

The assumptions are very conservative in several ways, first, each value from the satellite data represents 1.125x1.125 degrees or about 125x125 km. In such a square, it is possible to find points of output much higher than the average one. As an example, the local results in the south Arava were 370 MW net deliverable output, while the representative value from the satellite was only 210 MW.

The summary results at the bottom of table 7 are of extreme interest. The world potential, assuming 200 MW as a the low economic limit, is 230,000 X 10^9 kWh/year, sufficient for 46 billion inhabitants at the level of Western Europe.

Another very interesting outcome is the highly reduced projected costs of electricity production in some categories. Theoretically, there can be built some 756 towers at costs lower than 1.9 cents/kWh at 5% discount rate, and below 2.9 cents/kWh at 10% discount rate (!)

There are some 40 areas where conditions seem very good for the installation of Energy Towers. As the elevation above sea level increases by 100m the net power reduces by about 5%. A longer distance from the sea will increase the cost of the water conduits. However, several or even many towers can be planned around one very large aqueduct, reducing the cost of the water supply per tower.

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

Following is the total potential for different regions.

Table 8 - Regional potential of Energy Towers

Region	***200-600 MW average net output***		***300-600 MW net average output***		**6,000 kWh/year per capita**	**10,000 kWh/year per capita**
	Annual energy	**Number of towers**	**Annual energy**	**Number of towers**		
	10^9 kWh/year	*[-]*	*10^9 kWh/year*	*[-]*	*10^6*	*10^6*
North Africa	46412	18140	14251	4018	2375	-
South Africa	17256	6850	5932	1685	989	-
India	16086	6487	4407	1548	734	-
Saudi Arabia	8780	2580	6072	1089	1012	-
Persian Gulf	6884	1715	6440	1543	1073	-
California & Mexico	27182	10956	4748	1442	-	474
Chile & Peru	23653	8385	9542	2730	1590	-
Australia	111783	5004	907	289	151	-
Spain , Italy Greece	3320	1666	-	-	-	-

The last two columns show the number of people that can be supplied all this electricity from the Energy Towers at 6,000 kWh/year/capita or at 10,000 kWh/year/capita.

An exciting example of the possible application of the Energy Towers would be installations throughout North Africa. Some 1685 Energy Towers could be installed with total electricity in the order of $5.9X10^{12}$ kWh per year. This is at a station with at least 300 MW and up. This electricity could be provided to Europe, supplying up to 990 million people with their complete electricity. It is interesting that the sky space assumed to provide sufficient hot air for one tower was only about 400 square kilometers. The total desert area necessary for 1685 towers is not more than 674,000 square kilometers. Very small indeed, compared with the desert area in North Africa - 7,256,000 square kilometers.

The economic success and market penetration of the Energy Towers will depend very little on backup units. It 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 it can be in excess of 1-2 cents per kWh. For coal or oil it may reach 5-7 cents per kWh. There are predictions of large escalations in liquid and gas fuel costs before the end of the decade. As an example, Germany passed the “Infeed Law” for payment of over 10 cents per kWh for clean renewable sources. Spain determined recently a payment of about a quarter ECU per kWh for clean renewable energy. Other European countries are following in different ways.

The cheapest solar technology cannot project electricity cost today for less than 12-15 cents per kWh. While there are great expectations for a price reduction, this is still to be proven. The direct use of solar energy cannot supply the huge needs of electricity today. Solar energy is operational only 6-8 hours a day. Energy storage is possible; however, it is still expensive and inefficient. Electrical batteries are 60-70% efficient and the production of hydrogen and reproducing electricity in fuel cells is 50% efficient. Thus, these two methods of storage nearly double the cost of electricity during 2/3 of the day.

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 backup. Having 1/4 of the time 12 cents per kWh and 3/4 of the of the time 4 cents per kWh will produce an average cost of 6 cents per kWh that seems to be reasonable. However, the solar component is still at least 3 times more expensive than the electricity from fuel.

1.6 Pumped storage and base load

Figure 10 shows the net power output over the year and a characteristic daily cycle for each month, in South Arava Valley in Israel. The annual amplitude is about ± 0.6 of the annual average power. In the figure 10 example, the minimal daily average is about 120 MW and the maximum daily average is 480 MW. The overall average in this example is about 300 MW. The daily cycle has an amplitude of ± 80-100 MW. The peak potential production is about twice the average (610 MW compared with 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.

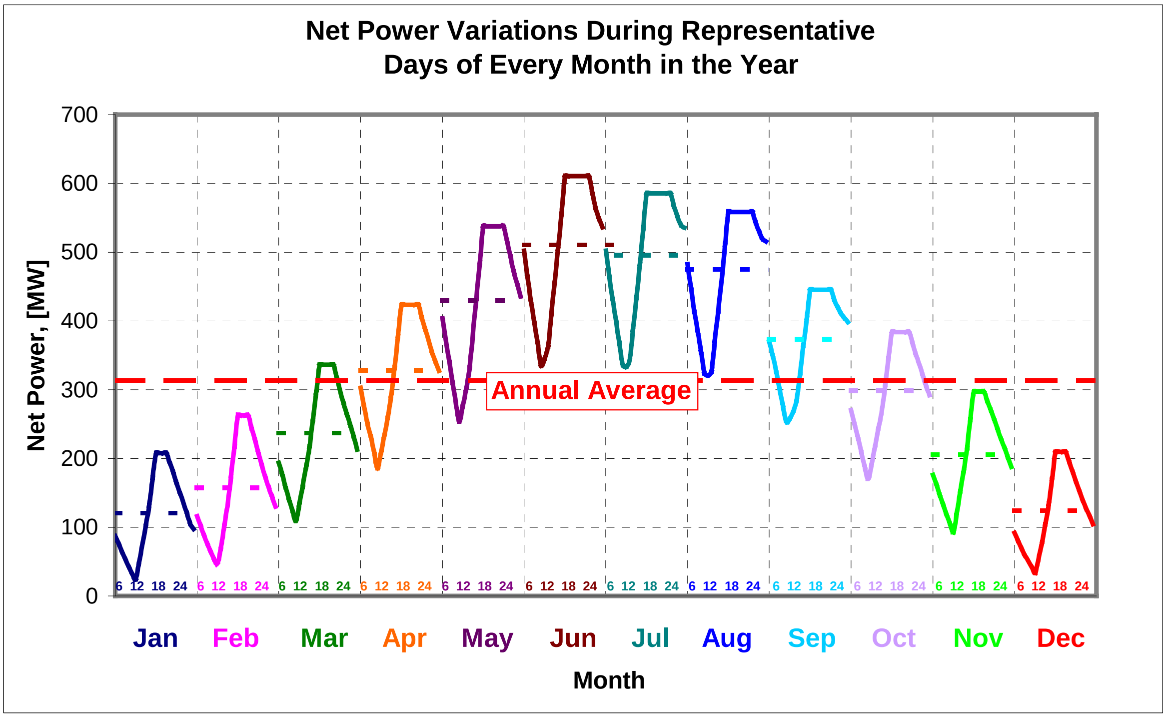

Figure 10 - The power distribution over the year

One should install the pumping gear for the maximum daily average with an operational reservoir built at an elevated site for the maximum daily average when possible. An alternative way is to install the operational reservoir on the tower itself near the top. Thus, more electricity can be delivered at hours of high demand while more pumping can be done at hours of low demand. (See the explanation to figure 4 above).

During months where the climatic conditions are less favorable, there is a great excess of pumping capacity and thus the power spending for pumping can be done mostly at hours of low electricity demand and low return for electricity delivery.

Contrary to conventional pumped storage, there is no energy loss and no need for investment in pumping and generation gear.

By the Israeli electricity tariff for 1996, the net economic gain was found to be 33.7% if full advantage is taken of the built in pumped storage. In actual terms, it was in the order of 2 cents per kWh.

There may be a certain optimal installed capacity which is lower than the peak production capacity. It can lead to a further significant reduction in electricity cost, and at the same time, a reduced difference between the summer peak and the winter hours. There is even a way to supply a base load if necessary. This happen if the installed capacity of the pumping gear and the generation gear does not exceed the winter average. The structure and some infrastructure elements have a full cost. 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 as they are presented in this brochure.

Finally, it is possible to vary a product using the electricity as an electricity storage mean. The outstanding example is desalinized 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 thus increase, and the net deliverable electricity for general need comes closer to a base load.

In summary, there are ways to improve significantly the economy of the Energy Towers specific to each electrical grid.

There is a serendipitous aspect to the Energy Towers operating in arid lands. The usual increase 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.

1.7 Different parts of the system

1.7.1 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 of the air entry at the tower’s top.

The whole spray system is supported on a special structure close to the top of the shaft. It creates some resistance to the air flow which adds about four percent to the energy loss coefficient. The sprayers are available on the market. On-off control of the individual atomizers, or groups of them, should produce the exact overall spray rate as well as even distribution over the shaft’s top even during changes in the prevailing wind.

1.7.2 Spray collection - the excess spray must be taken from the air that comes out the bottom. If 6 kWh are produced for each cubic meter of sea water which is sprayed then 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 in a special area where it can be collected and later returned to the sea. No solid salt will be released.

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 per square meter per second.

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 droplets smaller than 300 microns, or even 400 microns, before the air is out. This allows precipitation speed of 1.2-1.6 meters per second.

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 per one million kWh per year (by comparison it takes 200-300 m for a conventional coal station and over 5000 m^2 is projected for the best future thermal solar stations or photovoltaic cells).

1.7.3 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 on the runner blades angle and the guide vanes angle. The so called “solidity” of the turbine (the ratio of blades area to the overall aperture area) is high, typically with 8 blades and 30 guide vanes. A two speed turbine seems to be the best choice. 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.

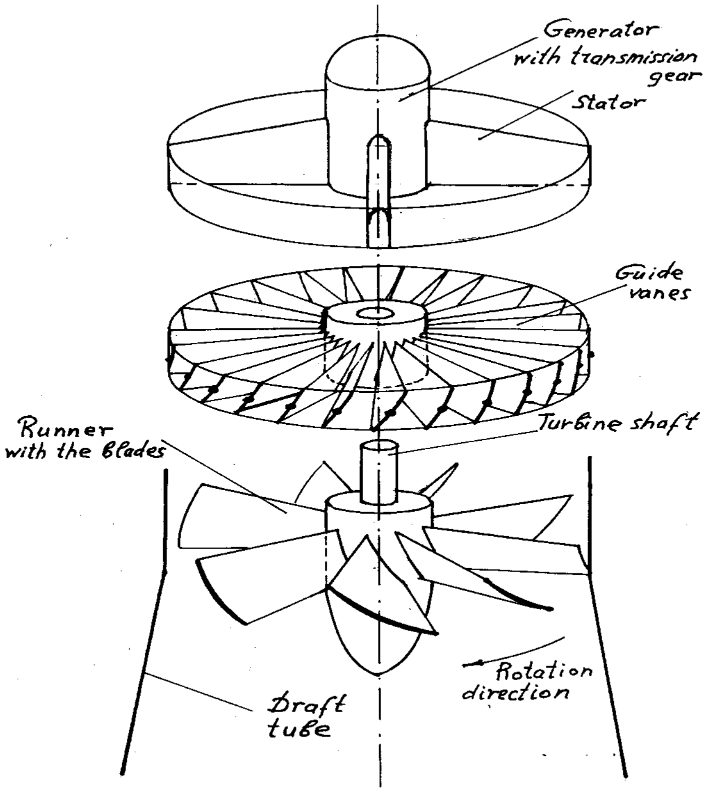

Figure 11 - Schematic view of the turbine

The typical turbine would be 30 m diameter. 100 turbines would be arranged in two tiers 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.

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} , 2/3 of which can be used optimally. The turbines in the Energy Towers are shrouded.

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 percents of the power are also saved.

1.7.4 <u>*The structure*</u> - at least three designs of the tower were made of reinforced concrete. This may be the preferred choice in places where a high elevation operational reservoir for the pumped storage cannot be installed. It may then be installed on the tower itself.

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 frame geometries and arrived at very similar structural weights and costs.

Although the Energy Towers may be 3 times taller than the tallest office building in the world, it was the opinion of all experts, without exception, that it would be much simpler to build.

A significant part of the structural cost is the diffusers, which are needed to reduce the energy losses of the turbines and thus the factor F of energy losses in equation (1) 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.

There is still much potential to reduce the investment in 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 $\rho V^2 / 2$ (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 it is expected under extreme wind storms. The estimated coefficient was 0.3-0.4. It is considerably less than half the coefficient assumed in the building codes.

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

The phenomenon of “wind shear” which causes aviation disasters is caused by rain shed 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/sec and the jet blast diameter can reach one kilometer.

Many experiments were made by the development team in three 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.

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 is contrary to intuitive thought comparing the air flow in the tower to the drain in the bath tub.

Different geometries were studied over the years.

Hot air model of the diffusers was studied in paralleled by a numerical analysis. The stratified flow inside the diffusers has been simulated by heated air instead of cooled air.

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 to the shaft walls.

d) Qualitative estimate of air flow rates.

e) Collision and coalescence of droplets.

f) A method for fine droplet collection.

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

a) Performance of different atomizers.

b) Development of a rotary atomizer with very uniform droplet sizes.

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

d) Measurement of efficiency in droplet collision.

e) Effect of electrostatic charging on final droplet collection.

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. In estimating the power output of the towers, the climatic conditions are still the least reliable factor. They could range as much as ±10%.

Recently, satellite weather measurements were utilized in a preliminary way to help analyze different sites in different corners 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.

1.7.6 *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 that the anticipated cost of electricity production has a standard deviation of $\pm 20\%$, and behaves like a normal population (see section 6).

2. The economy

Following are estimates for a tower of the following dimensions in the south Arava, near Timna, 23 kilometers north of the Eilat Bay and 80 m above sea level.

Table 9 - Main dimensions and performances

Optimal vertical cylinder height	1200 m
Total height	1280 m
Diameter of main shaft	400 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

Table 10 - Investment cost following standard conservative design

System	***Previous nominal investment [M$]***	***Present nominal investment [M$]***	***Nominal investment plus interest during construction [M$]***
Water supply	335	146.3	159.8
Structure	472	267.5	292.3
Turbines and generators	434	364.5	398.1
Infrastructure	43.5	43.5	47.5
Others	29.2	29.2	31.9
Total	**1313.7**	**851**	**929.6**

Investment cost following an updated design utilizing technological improvements

The major changes in this table are the direct power system connection to about 2/3 of the pumping gear and due to the reduced construction cost. First is the reduction in steel prices, and second, the reduction in the computed loads on the structure. The unit cost of steel reduced from 2000 U.S. dollars per ton to 1400. The resulting cost investment is enumerated in the table above.

The range of costs found for natural gas combined cycle, nuclear power stations and coal power stations, from an updated 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 is repeated here. The electricity production costs were estimated for power stations that will be operational in the years 2005-2010. The costs are taken from actual projects in 22 countries and normalized to 75% capacity factor and either 5% or 10% discount rate. Table 11 is identical with table 6 above. The cost range for the Energy Towers was taken from table 7.

Table 11 - Summary of electricity costs predicted for 2005-2010 with a 75% load factor,

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

For the Energy Towers, the cost of operation and maintenance is assumed to be 12 dollars per kW per 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.

The main observation is that the cost of electricity from Energy Towers is smaller than the average characteristic cost of electricity from coal, gas and nuclear power, and that there is a wide cost overlap between the Energy Towers and the major sources of power today.

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 replacement of electricity production costs, the towers have a built-in capacity for “pumped-storage” and will eliminate the penalty from greenhouse gas emission and other environmental benefits. It has been estimated that these will add 2-3 ¢/kWh to the tower’s benefits.

Adding 2-3 cents to the electricity production costs, one gets the following table of possible prices for the electricity from the Energy Towers, which are still competitive with the common electricity sources.

Table 12 - Possible price for electricity from Energy Towers, including the value of pumped storage and some bonus for clean energy

Source	***Range of prices in ¢/km***		***Characteristic average prices***	
	5% discount	10% discount	5% discount	10% discount
Nuclear	4.47-8.75	5.90-10.96	5.31-6.31	7.05-8.05
Coal	4.48-8.64	5.74-10.61	6.07-7.06	4.99
Gas	4.33-10.91	4.36-11.44	5.98-6.98	6.47-7.47
Energy Towers	1.68-3.93	2.51-6.42	2.47	3.88

The Energy Tower’s advantage is very obvious.

Strictly speaking, the possible price for electricity should be even larger than in the above table when it is composed of the following 4 different sums:

One) The replaced electricity production cost;

Two) The bonus for clean energy;

Three) The built-in capacity for pumped storage;

Four) 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.

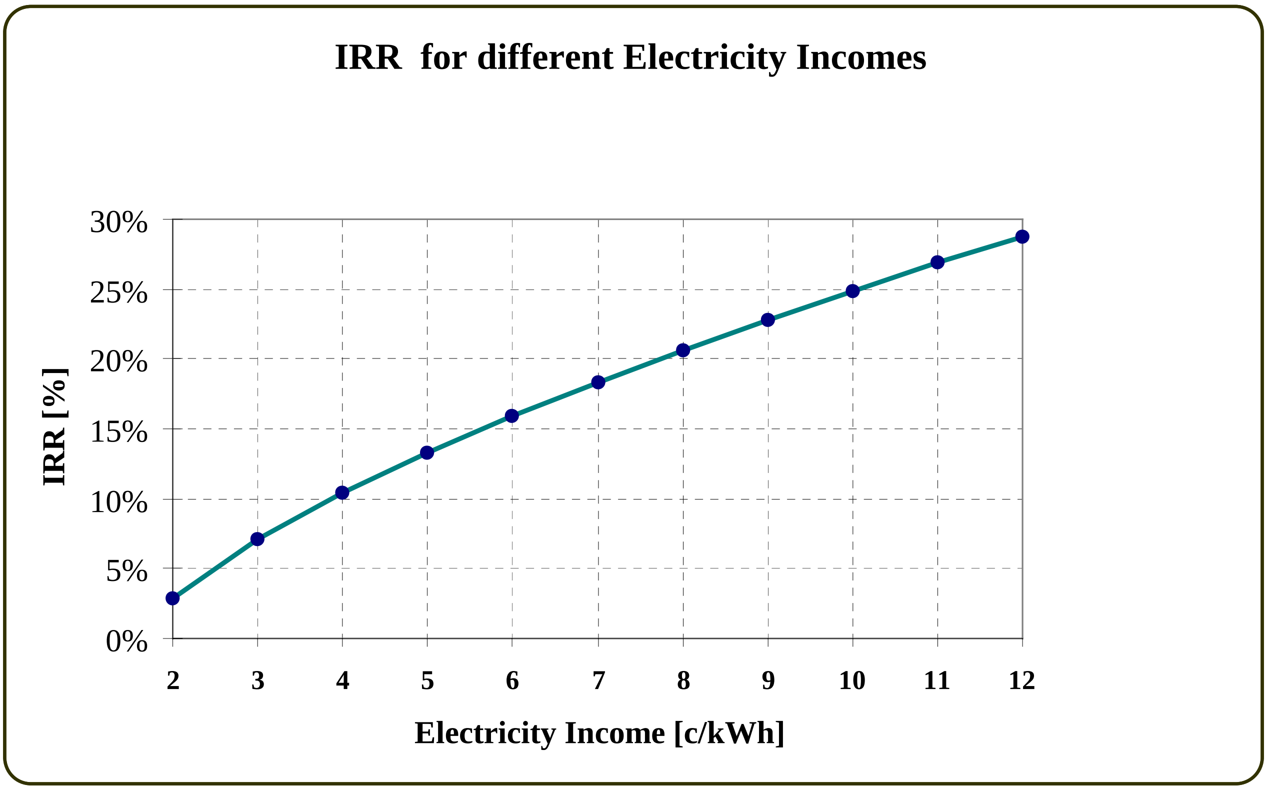

Figure 12 - Internal Rate of Return for Energy Towers 851 million dollars initial investment under the conditions of south Arava; 4 years construction; 30 years life project; 0.556 ¢/kWh operations and maintenance

Following is a table of possible income for the electricity production in the Energy Towers under the conditions of south Arava Valley in Israel and accordingly the Internal Rates of Return (IRR), net present value and payback period.

Table 13 - The economic performance of the Energy Towers with the possible income

Discount rate		*5% discount rate*				*10% discount rate*			
	Units	**Coal**		**Gas**		**Coal**		**Gas**	
1.Possible income	c/kWh	5.98	9.14	5.15	11.36	6.24	12.11	4.86	11.57
2. NPV	M$	1373	2608	1048	3475	469	1637	195	1530
3. Pay back period	years	6.5	3.8	7.9	3.0	8.4	3.3	13.7	3.5

The range of IRR for possible incomes between 5 cents per kWh is between 13% - 28% before tax.

3. Benefits of the Energy Towers in addition to electricity sale production

The extra benefits of the Energy Towers are divided into three groups:

A) Replaced costs such as pumped storage and greenhouse tax.

B) Direct income to the project.

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

They add up to about a dozen benefits. Following are some of them.

GROUP A

3.1 Pumped storage

The idea of built-in pumped storage was explained above with the possible average income up to 1.89 cents per kWh. Mention should be made also about the ability to have a guaranteed minimum power during certain hours of the day, which is of a great saving in the national grid (see section 1.6 and figure 4).

3.2 Overall environmental contribution, or the Kyoto Protocol

The external communal costs of operating fuel fed power stations are very significant.

There are wide differences in their estimates. The reasonable choice were 1-2 cents per kWh for combined cycle with natural gas. It is 6-7 cents for coal or oil operated power stations. It is, however, only gradually that these communal external costs are internalized. Most recently, in November 2001, the Kyoto Protocol was reconfirmed in Morocco and signed by 158 countries.

GROUP B

3.3 Desalination of sea water

Including sea water desalination into the Energy Towers scheme can save a large part of the initial investment. This is especially effective with Reverse Osmosis which is the preferred method. A detailed analysis showed savings of about half the investment and about 1/3 of the energy outlay. Characteristically, an 88 cent cost per cubic meter desalination was reduced to 53 cents per cubic meter, a 40% saving. There is saving on the water intake, conduit of sea water and return of end brine. There is a saving of high pressure pumps for about half the water because of the reduced end brine. There is no need for energy recovery from the end brine. Also there can be a saving in the water pre-treatment.

As an illustration, a 388 MW net average power station was computed to produce 3.4×10^9 kWh per year. Desalination of 200×10^6 cubic meters of water will require not more than 700×10^6 kWh, 20.6% of the energy. This capacity can be installed gradually in small modules without the need for a serious initial investment.

Advances in the desalination technology are expected to reduce costs and energy outlay. Projections are as low as 50 cents per cubic meter or less. The most recent bid showed a cost of 52.7 ¢/kWh. The chances are that, in combination with the towers, the cost will be 30 cents per cubic meter. Israeli agriculture could then afford it.

There is an added potential benefit of combining desalination and electricity delivery. It can be shown that the water production can be used as 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 desalinization cost is a technological breakthrough that may solve one of the most crucial environmental, economic and political problems in arid lands.

In the example mentioned above, North Africa could install Energy Towers to supply all Europe's electricity need, (see paragraph 1.5 above), and at the same time, to produce water many times the volume of the Nile's flow. North Africa could then become a food store for Europe. The economic development of North Africa will provide a market for European industry and help regional cooperation and stability.

Similarly, South California and Mexico could provide all the electricity to this part of the continent, and unlimited amounts of water to desert regions. Peru and Chile could provide all the electricity to South America and every quantity of fresh water.

It is not possible to estimate how much of the economic benefits should be credited to the towers. If 5 cents is charged per cubic meter for $200x10^6$ cubic meters per year, it would amount to 10 million dollars income per year or 0.3 cents per kWh added income.

The Washington Post stated (April 17, 1999), that **"only 2.5 percent 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, reducing poverty and protecting the environment. Today 31 countries are short of water. Many others have shortages in certain parts, like the U.S. and China. By the year 2025, the number of countries with water shortage 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"**.

What a wonderful coincidence that the Energy Towers technology makes cheap water production possible in the countries that suffer most from water shortage.

Another example of the Energy Towers' application is in Jordan Rift Valley, which should replace the repeatedly rejected old idea of the Red-Dead Sea Canal. Between Aqaba and Eilat and the Dead-Sea. It is possible to produce over 50,000 MW average power or 50 billion kWh per year. This is instead of 85-90 MW or 750 million kWh per year from the Red-Dead Sea Canal. The investment per kW is $ 2300 in the Energy Towers as compared to nearly $ 30,000 kW (yes, more than ten fold). The electricity cost will be in the order of less than 4 cents per kWh at normal market conditions, compared to more than 10 fold.

Two great advantages of the Energy Towers project are:

One) It can be built in stages. One stage may consist of a 350-500 MW unit, with an investment of 0.850 to 1.210 billion dollars;

Two) It is possible to produce desalinated water at or above sea level, for less than 50 cents per cubic meter. In the proposed Red-Dead Sea Canal, the cost of desalinated water was at best more than 1.5 dollar per cubic meter.

The project could and should serve as an exemplary model for cooperation between Israel and Jordan, while the Read-Dead Canal as well as Med-Dead Canal were repeatedly rejected by every Israeli professional team. At present it is pursued as an exclusive Jordanian project despite tremendous anticipated damages to the existing economical activities and to the environment.

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 salinization. Examples are along the Colorado River, the Murray-Darling River in Australia, the Orange River in South Africa, the Indira Gandhi Canal in Rajasthan, India, etc.

The process is due to evaporation of most of the irrigation water and the return of the drainage water to the source with all the salts preserved. Sometimes more salts are added from saline layers that are leached by the drainage water. The salts keep re-circulating many times through the soils and gradually build up. There are several results:

a) Progressive reduction in crop yields.
b) Destruction of soils.
c) Loss of large parts of the water volume due to salinization.
d) Increase in irrigation systems and drainage systems because of increased leaching requirements.

The solution seems to be straight forward. The drainage water must be intercepted so that it cannot return to the river or aquifer involved. Analysis shows that for each cubic meter of brackish water which is intercepted, it is possible to gain 0.5 cubic meter, downstream at the water source.

Until now, the obstacle to this straight forward solution was the very large investment required. The decision makers always preferred to postpone this spending, being sure that the final disaster would not occur during their watch.

The large expense is due to the very long and large conduit which is needed in most cases. The typical cost of transferring the brackish water to the disposal site is about 0.1-0.15 cents per cubic meter per kilometer. As an example, in the Indira Gandhi Canal, the distance is in the order of 1000 kilometers and the cost more than one dollar per cubic meter. It would amount to spending over 3-3.5 billion dollars per year.

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 by spray lines which must use the Energy Towers technology or a similar one.
c) Desalination, if there is a market for desalinated water. It requires a certain level of agricultural sophistication and often a very difficult change in the local politics.

The desert climate brings to mind spraying the brackish water inside the Energy Towers. The result would be two fold:

a) Reduction of the water volume to be disposed to some 3-5% of the original volume.
b) Gain up to a 10 kWh (with 1.2 km Tower) for each cubic meter which is evaporated.

Using just 3 cents net income per kWh, the net earning is 30 cents per intercepted cubic meter and the reduction in disposal cost is 95-97% per cubic meter leaving a cost of only about 5 cents for brine disposal to a distance of 1000 kilometers.

The project of saving the water source and land becomes an immediate benefit instead of a large initial expense.

Again, it is difficult to determine how much can be charged to the benefit of the electricity production installation, and what is the value of saving these projects. If the authorities would compensate the Energy Towers by just 10 cents per cubic meter taken away, it would amount to 1.1-1.3 cents per kWh additional benefit.

India becomes a very attractive area of application, not only that 3/4 of a billion people can be supplied each 6,000 kWh/year. (See table 8). The Indira Gandhi irrigation project in Rajasthan can be saved. A lot of desalinated water could be produced for Gujarat and Rajasthan.

3.5 Fish farming

A kilogram of fish grown in ponds requires 1.5-2.5 kg of food as compared to 5kg of food plus some 2 liters of fuel for a kilogram of beef. 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 of fish farming despite the high expertise developed there.

a) Shortage of cheap land near the sea.

b) Very high cost of water pumping to the required distances and elevations where land is available.

c) Very serious pollution of the Eilat-Aqaba Bay due to the excretion of some 2/3 of the original fish food.

The combination with the Energy Towers solves all three problems in a very satisfactory way. (The detailed explanation exceeds the level of this brief presentation). The water which is sprayed into the tower is used first in the fish ponds. The pollution problem is solved in a way which will not be elaborated on here. However, it is intrinsic to the incorporation with the tower.

The Eilat chapter of the Oceanographic & Limnological Research Institute has helped to estimate the potential of fish farming from one tower. It was found to be 15,000 tons annually by once through water use and up to 75,000 tons with 5 times water circulation and aeration associated with one tower. The typical projected fish price was estimated at 6 dollars per kilogram bringing this economic activity around one tower to 90-450 million dollars annually.

Charging just 0.5 dollar per kg of fish for the water supply and disposal, brings the income up to 1.1 cent per kWh. The development of fish farms away from the sea shore is economically impossible without the towers because it requires a huge initial investment in the conduits bringing water in and taking water back.

3.6 Cooling of thermal power units

The water shipped out of the tower and back to the sea could be used for cooling other 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 cents per kWh. Solar thermal power stations will also require cooling.

3.7 Pre-cooling of compressed air for gas turbines

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 less energy needed for compression. The measured improvement is nearly 1% per centigrade. Alternative cooling methods require an investment increase of over 10% in the gas turbine station.

So far, we have discussed 6 added benefits directly related to the Energy Towers income. Following are some added benefits of a macro-economic nature.

GROUP C

3.8 Saving fuel import

The equivalent for coal to produce the energy of a 388 MW net average power Tower is 1.27 million tons per year or 60-80 million dollars a year.

The Israeli government has recently granted 15% of the investment to a power station using local energy sources. In other times and other places this has reached 30%. This benefit can be estimated to be equivalent to 0.7-1.5 cents per kWh. More generally, it can be considered as one of the macro economic benefits.

3.9 Alleviation of limits for power use

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 is slow in activating a concrete protocol to enforce it. However, it is bound to come soon. A more recent convention in Marakesh, Morroco reconfirmed the Kyoto protocol and was undersigned by 158 countries.

The Energy Towers alone can provide a solution for nearly 2/3 of the necessary reduction in greenhouse gas (leaving unsolved the fuel burning by transportation and the emission of methane from garbage piles).

3.10 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 is expressed very closely by

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

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 not too far from optimal, the whole term is negative, reducing the economic product yield. Moreover, it can be proven that the second derivative is larger than an unity. The computed variance of oil prices since 1972 is 0.24. Thus, the damage can be quite considerable.

3.11 Avoiding the need for strategic reserves and other strategic expenses

The strategic need for fuel is extremely high. Very large fuel storage has to be maintained. Wars are being launched in order to protect fuel interest.

3.12 Summary of added benefits

Table 14 - Summary of added benefits

GROUP A	
Environmental saving	1-7 cents/kWh
Pumped Storage	Up to 34% or 2 cents / kWh
GROUP B	
Desalination	0.3 cents/kWh
Salinity prevention	1.1-1.3 cents/kWh
Fish farming	1.1 cents/kWh
Cooling water of thermal power stations	2 cents/kWh
Pre-cooling of air for gas turbines	1% added up power for 1 centigrade cooling
GROUP C	
Improved balance of payment	0.7-1.5 cents/kWh
Alleviation of limits to power use	Very high
Protection against fuel price fluctuation	Very high
Strategic savings	Very high

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 in the communal levels, can be easily doubled beyond the direct income from electricity. Strategically, the dependence on fuel import and fuel price fluctuations can be fatal.

3.13 Technological improvements

Still, there are nearly a dozen technological improvements that can lead to higher energy output and lower investment. Realistically, these can reduce the cost of electricity up to 30%.

While it is highly recommended to continue the development, there is no need or justification to postpone the commercial application until more development will be obtained.

4. Anticipated markets

Notably, the world climate is in a process of change. Southern Europe may become hotter and dryer. The "Energy Towers" technology has a positive feed-back, in this respect, becoming economically more attractive in cases where the electricity demand increases for operating irrigation and for air conditioning increases.

Based on current energy consumption (as shown in figure 13) and expected growth rate (2.5% per annum according to IEA) energy consumption is projected to grow in arid areas suitable for introducing to the Energy Tower by around 53 billion kilowatt/hour annually. In order to meet this demand it will be necessary to construct power stations with an average total capacity of nearly 10,000 MW installed each year over the next two decades. Note that this estimate does not include new power stations that are required to replace old stations. The annual output energy from a typical Energy Tower is 3.09 billion kWh.

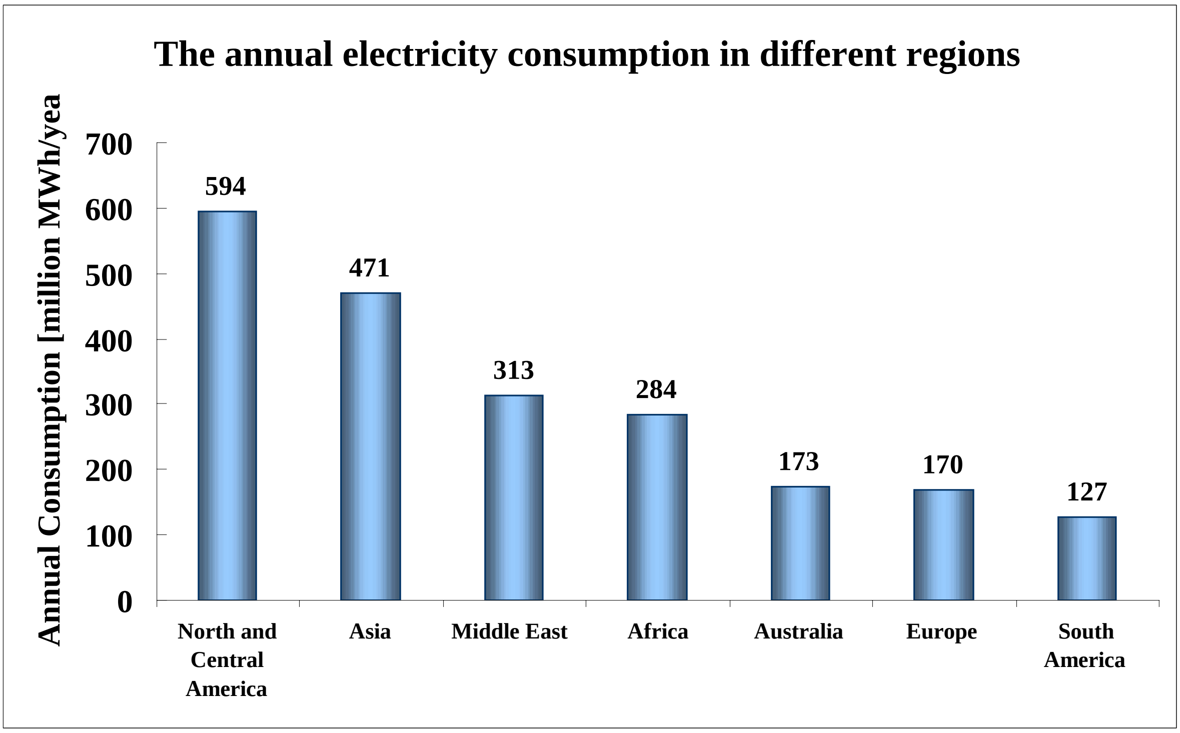

Figure 13 - The annual electricity consumption (in 1998) in those areas where Energy Tower is most efficient Source: EIA, Table 6.2: "World Total Net Electricity Consumption, 1989-1998".

Notes to figure 13:

** The consumption in North & Central America relates to Mexico and the following states in U.S: California, Arizona, New Mexico, Nevada, Colorado and Oklahoma.*

** Notably, the potential market would more than double by adding long enough transmission lines for the electricity and realizing even a part of the additional benefits mentioned above.*

Hence, full provision of the potential growth is at least 17 units of Energy Towers per year or an investment rate of the order 14 billion dollars or more.

As the technology advances, it is possible that even some other European countries around the Mediterranean, such as Italy, Greece and Turkey will be appropriate for the introduction of Energy Towers.

We have already mentioned the example of North Africa. It would be possible to erect, over the time, towers to produce nearly all the electricity needs of Europe. Water desalinization could be performed for

the local use. North Africa could become the agricultural storehouse for Europe's fresh agricultural supply. The additional income from energy and agriculture would permit the economical advance of North Africa and thus, also producing a larger market for the European technology.

The overall market is immense. It is measured in investments of more than a trillion dollar.

The rate of penetration with time is very difficult to estimate. We can assume initially only one tower with an investment of not more than one billion dollars. Within 2 years we can expect an initiation of another tower and then not less than one tower per year. Eventually in few years it can reach the rate of at least 2-3% of the market every year.

In view of the fact that no other electricity source competes with the Energy Towers, with the possible exception of very large hydro-electric towers, it is more reasonable that the market share of the Energy Towers will soon exceed 10% of the market. Another effect could be that the low cost will widen the areas where Energy Towers could be economically attractive.

A recent estimate of the increase in the electricity production (“World Energy Outlook”; International Energy Agency; 1998), predicts 3% annual growth rate between 1995 and 2000, adding from 13204 TWh per year to 27326, i.e. some 564 X 10^9 kWh per year. It is equivalent to the addition of about 65000 MW average installed power annually.

Clearly, installed power must also compensate for power stations that have finished their technical life. This could easily reach 2-3% of the existing power capacity, i.e. over some 300 TWh per year. The total added business directly to Energy Towers could easily exceed 10 billion dollars a year and reach several tens of billion dollars a year in newly installed stations.

The whole economy described in the above demonstrates that the project is extremely attractive even with only one commercial tower.

The extreme gap between the anticipated annual marketing and the real marketing potential makes it possible to use first only the most attractive sites from every possible point of view.

As an example, a site in Gujarat - India, with an average net output of 430 MW, will have an anticipated electricity production cost of 2.12 and 3.28 cents per kWh at 5% and 10% discount rates, respectively. If the computation is as conservative as in the Israeli southern Arava Valley, the actual net average output could be 70% higher, and the production costs less than 1.7 cents per kWh at 5% discount rate, and much less than 2.5 cents per kWh at 10% discount rate.

5. The need for a pilot plant and the design stage

Several working rules were followed by the development team:

a) To avoid as much as possible the dependence on new technologies and to use, if possible, only proven and widely used ones.

b) To check as much as possible, by all the means available to the team, all cardinal answers in more than one way and if possible by more than one team.

c) To welcome reviews by outside professionals.

d) Wherever in doubt, to make sure that the estimates and decisions are on the conservative side.

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

Some of the reviews, performed by highly qualified engineers, expressed the opinion that there is 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 Steering Committee. Possible dimensions of the demonstration plant were given in chapter 1.4 for 6.5 MW and 10 MW.

A work program was prepared for the pilot plant and it will be revised for the demonstration plant. Two things are required from the demo-plant:

1) To be capable of covering at least the running expenses from electricity sale;
2) It will be possible to show the measured parameters of performance are sufficiently close to the computed once, say, within accuracy of ± 10%.

The whole work program consists 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.

g) **A *parallel effort should be made to continue the scientific efforts to refine different design points, to use the know-how which has been developed so far for other applications, etc.***

The important point is that during the first year to a year and a half, general design and specifications will be prepared so that quotations could be obtained from qualified contractors.

In the following table 15, obviously we have assumed initially an extremely high error in estimating the cost of a certain component ± 50%. The weighed average standard error turns to be ± 20%. After the first 1-1.5 year, the weighed average standard error will reduce from 20% to almost 10%.

Following is a table (table 16) with the anticipated probability to have 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’s obvious that there is an extremely low probability that the “Energy Towers” economy will ever turn negative.

Table 15 - Estimate of standard deviation of electricity production cost

System	*Weight*	*Error*	*Error following first stage*
Structure	0.3	± 50%	± 10%
Water supply	0.3	± 50%	± 10%
Turbo-generator	0.3	± 50%	± 10%
Others	0.1	± 50%	± 10%
Climate date	1	± 20%	± 15%
Computation	1	± 10%	± 5%
Weighed standard error		± 20%	± 10.4%

Table 16 - Changes in the electricity production cost in Eilat (Israel)(cents/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%**
Deviations from estimate	*0*	*1*	*2*	*3*
Today - Estimated standard deviation of electricity production cost = 20%				
Standard deviation	*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 of table 13 exceeds the maximum required income of 5.87 ¢/kWh under 10% discount rate and at 60% upward deviation of the costs estimates which has today the 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 Tower to turn non-economical are negligible.

6. Some organizational notes

The development of the project took place in 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.

The know-how is the property of a company “Sharav Sluices” Ltd., a subsidiary of Dimotech, which is in turn a subsidiary of the Technion Foundation for Research and Development.

Patents have been requested in a large number of countries where installation seems most feasible.

“Sharav Sluices” Ltd. is looking for strategic partners to perform the demonstration plant and full scale design stage and enter the commercial stage. The commercial stage may commence about 3 years after the initiation of the pilot and design stage if work is undistributed. The Steering Committee estimated it to be 5 years. The construction of the first commercial power station may take 4 years.

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