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Contribution to the Utilization of Solar Energy

Utilisation de l'énergie solaire

Beiträge zur Nutzung der Solarenergie

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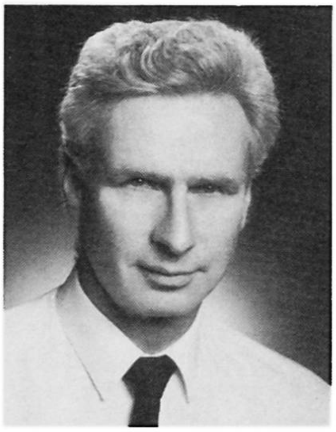

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SUMMARY
The long term energy supply to the world population represents the greatest political and technical challenge that mankind has ever faced. For this and other reasons, it is mainly the Third World which will have to make use of solar energy. This description of two solar energy plants, which were developed from structural engineering projects, is an example of how civil engineers can help solve the energy problem.

RESUME
L'approvisionnement en énergie est un des plus grands défis politiques et techniques que l'humanité n'ait jamais eu à affronter. Les pays en développement ne pourront pas renoncer à l'exploitation de l'énergie solaire. L'exemple de deux centrales solaires montre que les ingénieurs des structures peuvent également contribuer à la solution de ce problème.

ZUSAMMENFASSUNG
Die langfristige Energieversorgung der Weltbevölkerung ist eine der grössten politischen und technischen Herausforderungen, vor der die Menschheit je stand. Besonders in der Dritten Welt wird man dabei nicht auf die Nutzung der Sonnenenergie verzichten können. An zwei Solarkraftwerken, die aus Arbeiten im konstruktiven Ingenieurbau entstanden, soll gezeigt werden, dass auch Bauingenieure sinnvoll zur Lösung dieses Problems beitragen können.

1. WHY SHOULD WE DEVELOP RENEWABLE ENERGY SOURCES?

A mere look at the developing countries, which have neither oil nor substantial raw materials, makes it quite clear that the long term energy supply to the world population represents the greatest political and technical challenge which has been posed to mankind so far.

The energy requirement can be stabilised only in the event of stagnation of world population. According to experience, this is possible, if one rules out the use of force and occurence of catastrophes, only with a higher standard of living in the developing countries, which again can be achieved only with a higher energy consumption. One must therefore accept that till the stabilization of the world energy consumption, the total energy requirement will have to increase substantially until it reaches asymptotically a limiting value, which corresponds to the equilibrium population - living standard - consumption. We must therefore produce much more energy in the coming years, so as to be able to reach sometime a limiting value of consumption.

All predictions indicate that in the coming decades the increase in the energy consumption would be much more than the possible exploitation of new energy resources, so that the need for oil and coal would constantly increase, and the reserves would be rapidly depleted. The decisive question is, when would it be possible to reverse this trend, so as to preserve (or prolong the availability of) the valuable fossile primary energy source on the one hand, and on the other, preventing it to become too expensive on account of shortage, as in that case, the development of new energy sources (which again require energy) would be impossible to pay for. Over and above this, lies the concern about the increasing CO_2-content of the atmosphere and the concommitant danger of instability of the earth's weather, which reminds one of the need to exercise restraint in burning fossil fuels.

It is thus obviously very important, at this juncture, when we can afford the time and money, to exploit or develop as quickly as possible additional energy sources of all kinds: new fossils, nuclear and renewable.

Let us assume that immediate exploitation of solar energy as a renewable energy source has very bright chances of success. For this purpose a large land area with bright sunshine and also energy and money for the construction of powerhouses are needed. All these pre-requisites are available in the desert areas of the earth. It is hence clear that for the sake of long-term supply of energy we must seek cooperation with the desert-oil-countries. If we are able to convince them, that even after their oil reserves are depleted, they could, with this help of our technology, continue to remain the suppliers of energy to the world, then they would not hesitate to sell their oil at a reasonable price. In that case, not only we, but particularly the developing countries, too, have a chance to economically and productively tide over the inevitable time gap till the perfection of the technology to yield the new energy sources is achieved.

If the politicians succeed in paving the way to such cooperation, and further in stopping the spending of money for purchase of arms by all countries, not only would the material future of the mankind be assured, but also personal and international peace. This common venture could gradually lead to the dissolution of nations in favour of unifying humanity and as a result, all personal irritations and frustrations of affluent societies would vanish.

2. SOLAR POWER PLANTS WITH METAL MEMBRANE CONCAVE MIRRORS

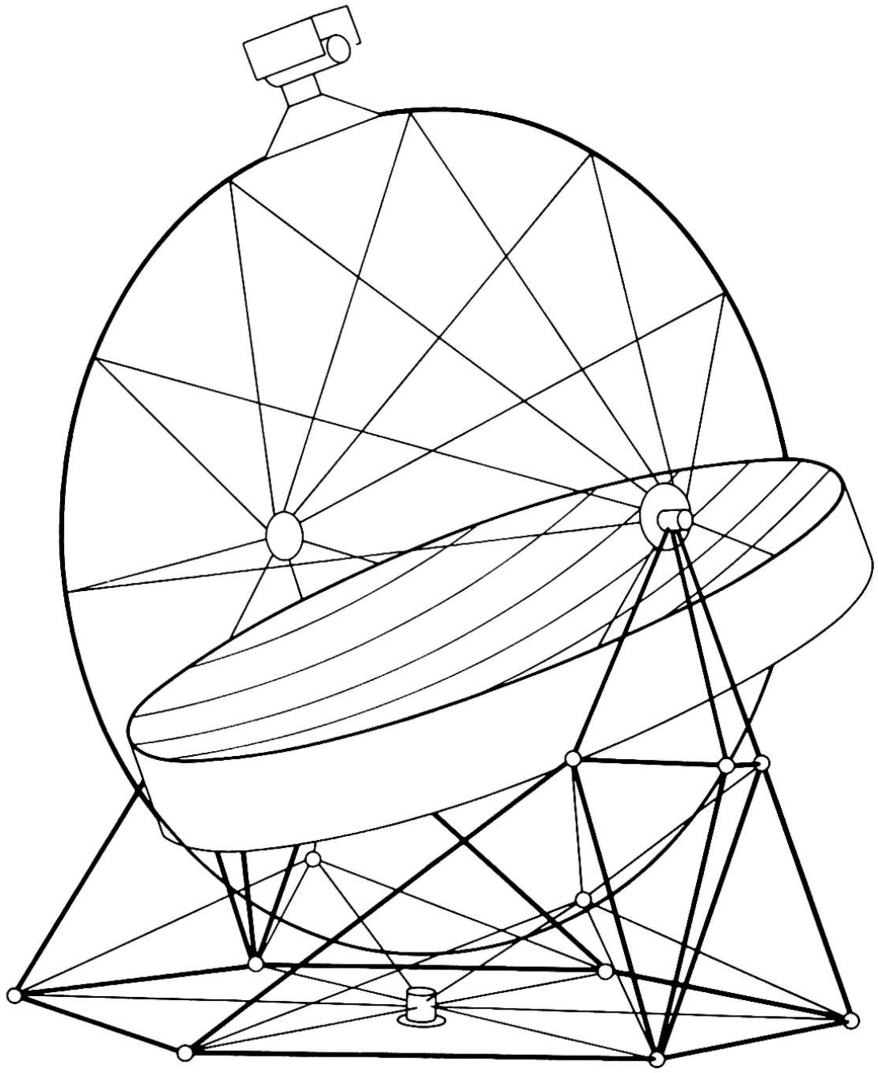


Fig. 1

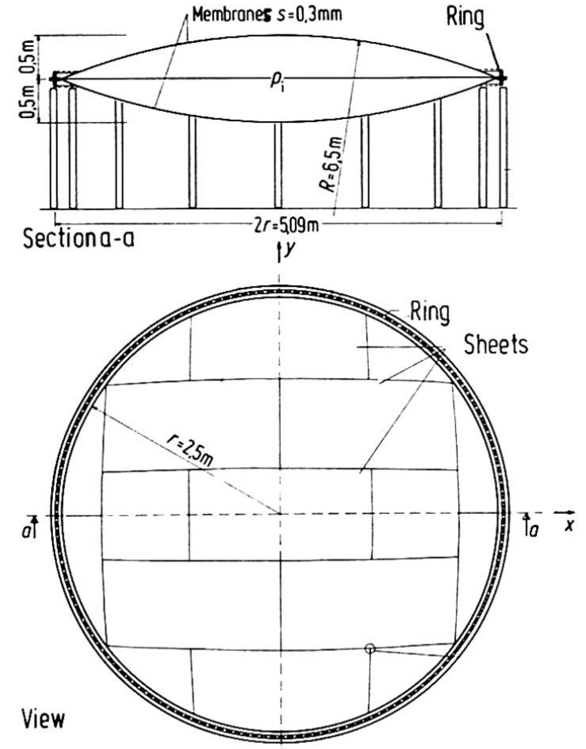
A 50 kW Solar Power Plant with a vacuum stabilized metal membrane mirror supported by a steel truss structure on rails. It carries an energy converter consisting of a Stirling engine with a receiver and a generator (see also Fig. 6)

2.1 Metal membranes in structural engineering

For wide span roofs cable net or membrane structures are used. Whereas cable nets need an additional cladding and therefore tend to be rather costly, with membranes the problem of manufacturing a double curved surface from plane material arises. Since such light weight structures need to be prestressed in any case for stability, their surfaces got to be curved anticlastically in case the prestress is introduced from their borders or synclastically if pneumatic pressure is applied. Membrane roofs are therefore today manufactured by joining small pieces of plane material along their borders following a cutting pattern similar to the method clothes are sewed. Textile materials with plastic coating are used because they are not sensitive against small errors in the cutting pattern and they permit the whole membrane after its fabrication in the shop to be folded and packed for shipment to the site. However, the disadvantage of these textiles is their short lifetime in natural climate and their little resistance against mechanical injuries. Therefore again and again the use of metal membranes for roofs has been proposed. They avoid these disadvantages but on the other side, they cannot be folded. Double curved metal membrane roofs therefore are to be assembled completely on site. Of course, all methods applying cutting patterns fail there due to high costs and possible inaccuracies.

We therefore tried to make use of the high plasticity of metal in forming such surfaces. [1] [2].

For demonstration a pneumatic cushion was built. Out of 0.3 mm thick stainless steel strips two circular sheets were welded - the description of the welding machine newly developed for that purpose, the welding and testing of the seams would be a paper in itself - and clamped between two rings of 5 m diameter. After pressurerizing the space in between the two sheets, they expanded into shperes with about 50 cm depth on either side, which reduced only slightly after depressuration (Fig. 2). Load tests showed that only a small pressure is needed under typical service load for roofs and it became obvious that such roofs can span large areas with a minimum of material.



During the tests, out of pure routine, the contour lines were also registered by geodesic means. They emerged that the inaccuracies and wrinkles of the sheets due to welding disappeared already at low pressures and that the contour lines soon became exact circles. Obviously such precision was not at all required for structural purposes because tensile structures do not have the problem of instability due to imperfections.

Fig. 2 A pneumatic metal membrane cushion.

2.2 The principle of metal membrane concave mirrors

In meditating on such superfluous precision the idea emerged to invert the above described process with the aim of producing concave mirrors. For that it was only necessary to apply the two sheets to a drum and to evacuate the interior (Fig. 3).

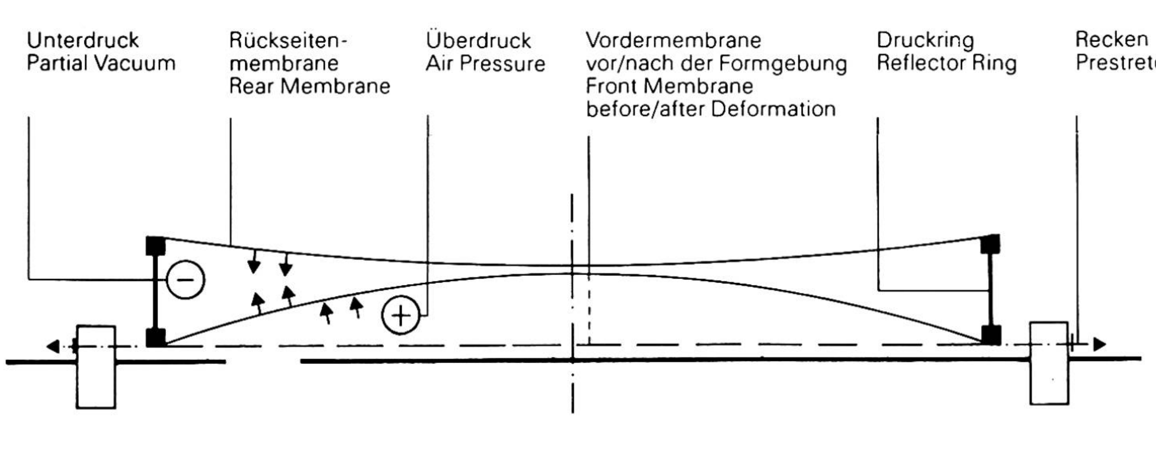


Fig. 3 Forming concave mirrors by prestretching and pneumatic loading of metal sheets

Obviously there is a need of such mirrors for antennas and for solar energy exploitation with concentrating systems. In the latter case mirrors are formed today mainly by a facette-type addition of small plane mirrors which are mounted on steel truss structures.

Several prototypes of membrane mirrors for solar application were produced and tested during the last years (Figs. 4 and 5). They demonstrated that with this method very large solar mirrors or reflectors can be built economically.

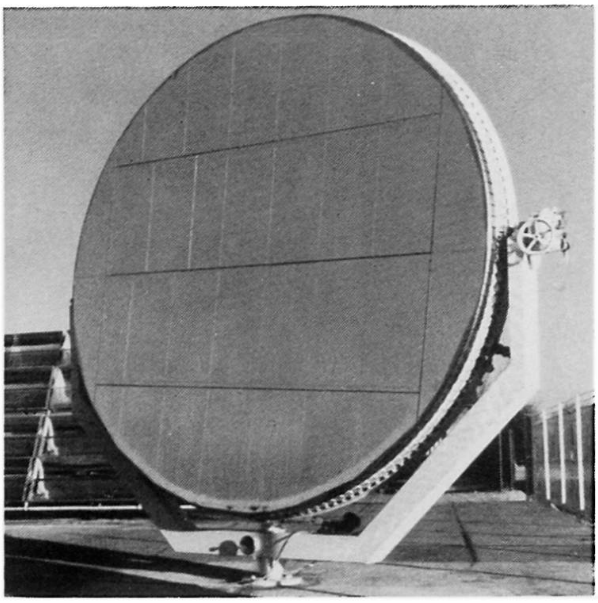


Fig. 4 Prototype of a membrane concentrator, 5 m diameter

Fig. 5 A solar furnace for brick burning

2.3 50 kW Solar power plants

As a means of generating electricity from solar energy, high-temperature energy conversion with concentrating systems has a very promising future. Therefore on the basis of the above described investigations and tests the German and the Saudi Arabian Research Ministries (BMFT and SANCST) jointly decided to sponsor the development and construction of two 50 kW solar power plants with such metal membrane mirrors or reflectors (Figs. 1 and 6). These reflectors have diameters of 17 m and are suspended and supported on rails in such a way that they can track the sun. The reflectors have energy converters, which convert the concentrated solar heat into electricity, suspended at their focal points. The shape of the membrane is kept constant by a partial vacuum in the interior between the reflector membrane, the rear membrane and the outer ring. On the surface of the reflector membrane mirror glass is bonded.

The energy conversion system (ECS) consists of a Stirling engine with a receiver located at the focal point of the reflector; the reflected solar rays heat the working gas (hydrogen) of the engine. There is a generator coupled directly to the engine. The ECS has its own control system which monitors all essential operation data. A central control system calculates and controls tracking, monitors the Stirling control system, processes wind data and indicates malfunctions.

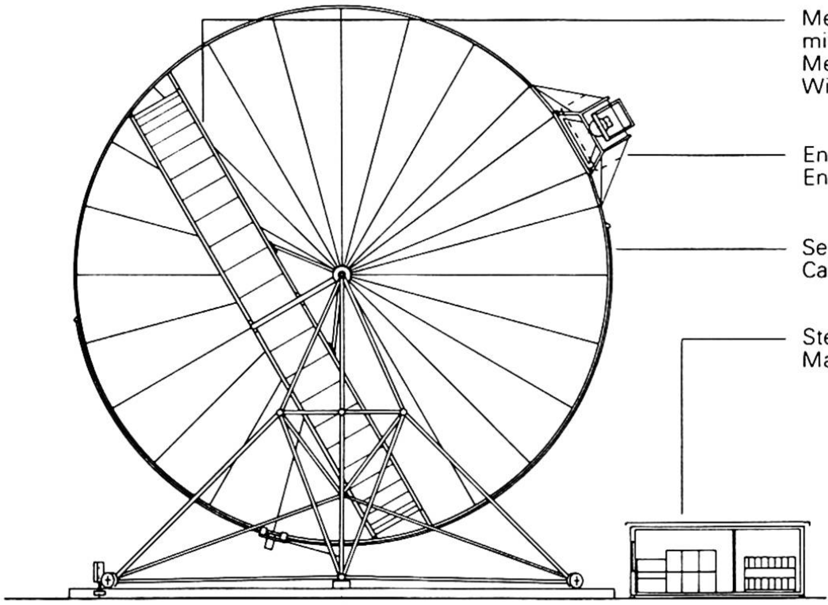
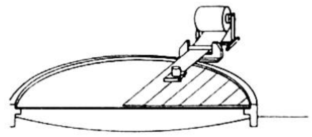


Fig. 6 A 50 kW solar power plant (see also Fig. 1).

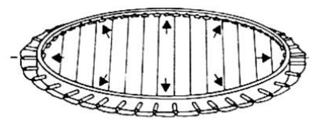
Since each unit is capable of fully independent operation, as many concentrators as desired can be operated in conjunction, according to requirements. They can be operated both in grid connection mode or "stand-alone" mode with storage devices (batteries, pumped storage etc.). The prototypes are to be tested with both operating modes. The technical data of the power plants are given in Table 1. The fabrication of a reflector is given in detail in Figure 7.

Power plants with reflector membranes are capable of an overall efficiency (defined as the ratio of the output usable electricity to the solar irradiation over the reflector surface) of up to 27%. This has never been achieved with other types of solar plants. As the membrane construction method used for the reflector is relatively inexpensive they also make economic electricity generation a real possibility. The output of the energy converter depends on the accuracy of the beam path. The reflector membrane satisfies this requirement, though only a simple technology is needed for its fabrication. With carefully planned technology transfer such power plants could therefore also be fabricated in the low-income countries of the Third World.

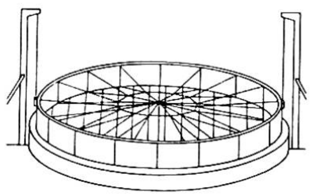
As this paper is written in spring 1984, the first plant is under construction. It will be ready at the time of the congress and both plants will be in operation in the Solar Village near Riyadh in 1985.



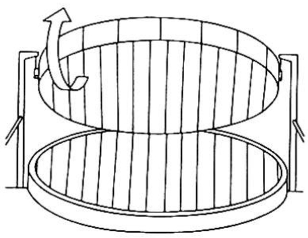
The membranes, which are 17 m in diameter, are made of individual sheet-metal strips welded together in the same plane with a welding device specially developed for thin sheet metal, which insures a gastight seam.



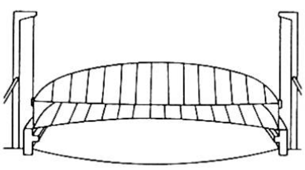
They are fixed to a ring and stretched radially until flat.



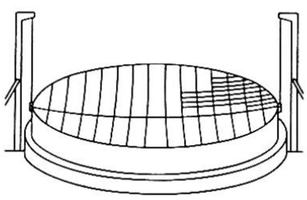
After fixing the rear membrane to the ring the concentrator is turned over.



The front membrane is then deformed to a paraboloid by applying air pressure between the membrane and the ground and subsequently fixed to the ring.



Now the air can be extracted from the concentrator housing thus created: with a partial vacuum between them the membrane surfaces will also withstand high wind loads.



Finally, thin glass mirrors are bonded onto the front membrane.

Fig. 7 The fabrication sequence of a metal membrane reflector

Concentrator diameter	17 m
Concentrator area	227 m^2
Usable mirror area	95 %
Reflectivity (cleaned)	92 %
Concentration factor (average)	600
Focal length	13,6 m
Interception factor of receiver	90 %
Power reflected onto receiver	178,6 kW
Concentrator efficiency	78,7 %
Receiver loss	36 kW
Available thermal power	142,6 kW
Efficiency of Stirling engine	42 %
Generator efficiency	91 %
Power output	54,5 kW_e
System consumption	2 kW_e
Net power input to grid	52,5 kW_e
Efficiency (overall)	23,1 %
Permissible wind velocity while generating	50 km/h
Permissible wind velocity while moving concentrator	80 km/h
Permissible wind velocity in survival position	160 km/h

Table 1

Technical data for a solar power plant with a membrane concave mirror (with open receiver), applicable for 1000 W/m^2 direct solar irradiation.

3. SOLAR CHIMNEYS

When in the seventies the need for very large natural draught cooling towers arose, because of the apparently increasing demand for more and more fossile and nuclear power plants, the first cable net cooling tower was developed and built in Schmehausen, Germany [3]. It demonstrated that vertical tubes, open at their bottom, of almost any size - say 1000 meters high - can be built, either by increasing the Schmehausen type or by stapling on top of each other several of them and guying them by inclined cables. Such large towers are neither necessary nor acceptable in populated areas but they suddenly made an old and very useful idea feasible: the solar chimney (Fig. 8).

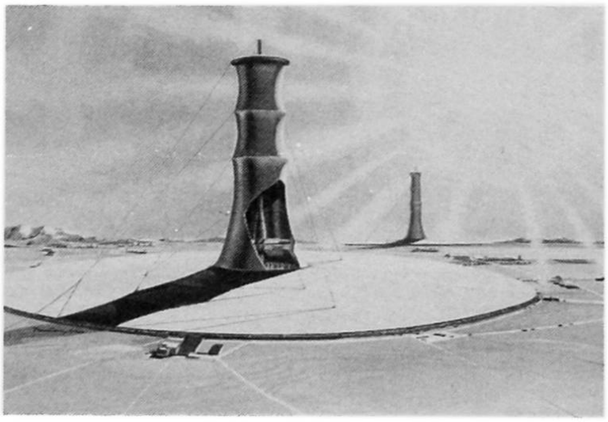


Fig. 8 Drawing of a 100 MW Solar Chimney.

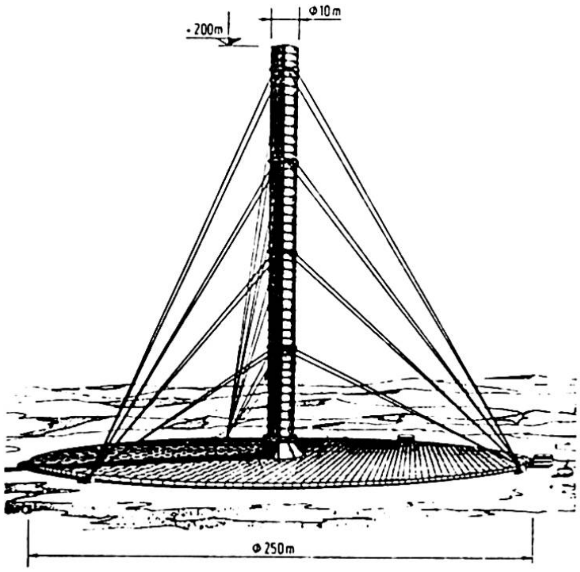


Fig. 9 Main dimensions of the pilot plant in Manzanares, Spain.

Solar chimneys convert solar radiation into electrical energy by combining in a novel way the principles of the greenhouse, the chimney and the wind-turbine generator. The "greenhouse" serves as the solar collector and covers a circular area. It consists of a horizontal canopy roof of translucent plastic or glass, open along its periphery; to increase absorption the ground is simply blackened. At the centre of the canopy roof is the chimney cylinder, around the base of which the roof is closely fitted. The opening of the base of the chimney is underneath the roof so that the air mass under the roof, which is heated up there, is sucked up through the chimney cylinder. The wind turbine, which will be turned by this updraft, is placed in the lower part of the chimney with its axis oriented vertically. The *higher the chimney*, the greater is the efficiency factor.

A 50 kW pilot plant in Manzanares, Spain, which the German Research Ministry (BMFT) sponsored, demonstrated the feasibility and the simple operation of solar chimneys (Fig. 9). It confirmed the theory according to which solar chimneys with hundreds of Megawatt output are possible and promise to be economical, if chimneys in the range of 800 to 1000 meters height are provided. Since IABSE Structures C-26/83 has been dedicated to solar chimneys, the reader may kindly collect further information from there.

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