

Floating Solar Chimney Technology

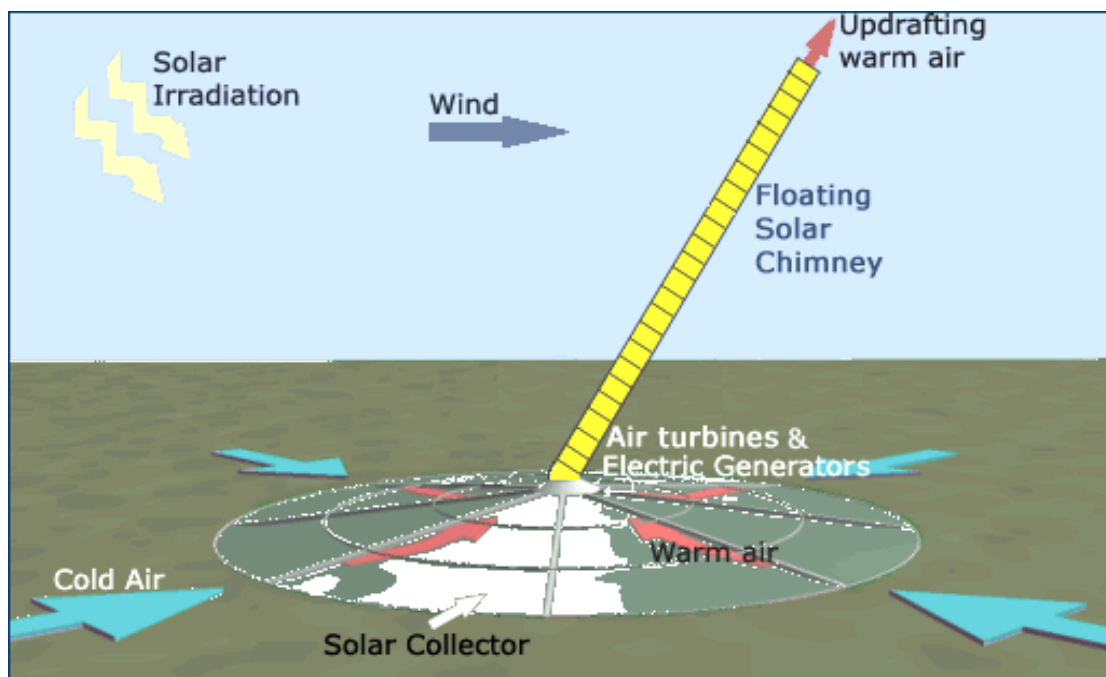
A cost competitive solar technology that can secure world's energy demand and eliminate the global warming threat

Prof. Dr Eng. Christos D. Papageorgiou
PhD of Imperial College

Postal address: Nymfon 1b Kifissia, 14563 Athens Greece

Tel.: +306937377998

www.floatingsolarchimney.gr



Floating Solar Chimney Technology

1. Introduction

Solar chimney electricity generation power plants are referred to as solar updraft towers (http://en.wikipedia.org/wiki/Solar_updraft_tower) and the related solar chimneys are huge reinforced concrete structures.

However due to the high construction cost of the concrete solar chimneys the solar up-draft tower technology is expensive demanding a high initial investment in comparison to its competitive solar technologies. Their solar up-draft towers are huge structures of high initial investment cost that can not be split into small units. That is possible for the relatively also expensive PV solar technology.

Floating solar chimney (FSC) technology, is a low cost alternative of the solar updraft towers (www.floatingsolarchimney.gr). The FSC technology is the advisable one for candidacy for large scale solar electricity generation especially in desert or semi desert areas of our planet and a major technology for the global warming elimination.

The Floating Solar Chimney Power Plant, named by the author as **Solar Aero-Electric Power Plant (SAEP)** due to its similarity to the Hydro-Electric power plant, is a set of three major components:

- **The Solar Collector (greenhouse)**

It is a large greenhouse open at its periphery with a transparent roof supported a few meters above the ground. A low cost alternative (patent pending) is described in chapter 4.

- **The Floating Solar Chimney (FSC).**

It is a tall fabric cylinder placed at the centre of the solar collector through which the warm air of the greenhouse, due to its relative buoyancy to the ambient air, is up-drafting. Floating Solar Chimney is patented by the author in USA and several other countries.

- **The Electric Power Unit.**

It is a set of air turbines geared to appropriate electric generators in the path of up-drafting warm air flow that are forced to rotate generating electricity. The gear boxes are adjusting the rotation speed of the air turbines to the generator rotation speed defined by the grid frequency and their pole pairs.

The energy source, for the rotation of the air turbines and the electricity generation, is the horizontal solar irradiation passing through the transparent roof of the greenhouse and heating the ground beneath it. The ground thermal energy is partly transferred to the air stream, entering the greenhouse and moving towards the FSC bottom entrance.

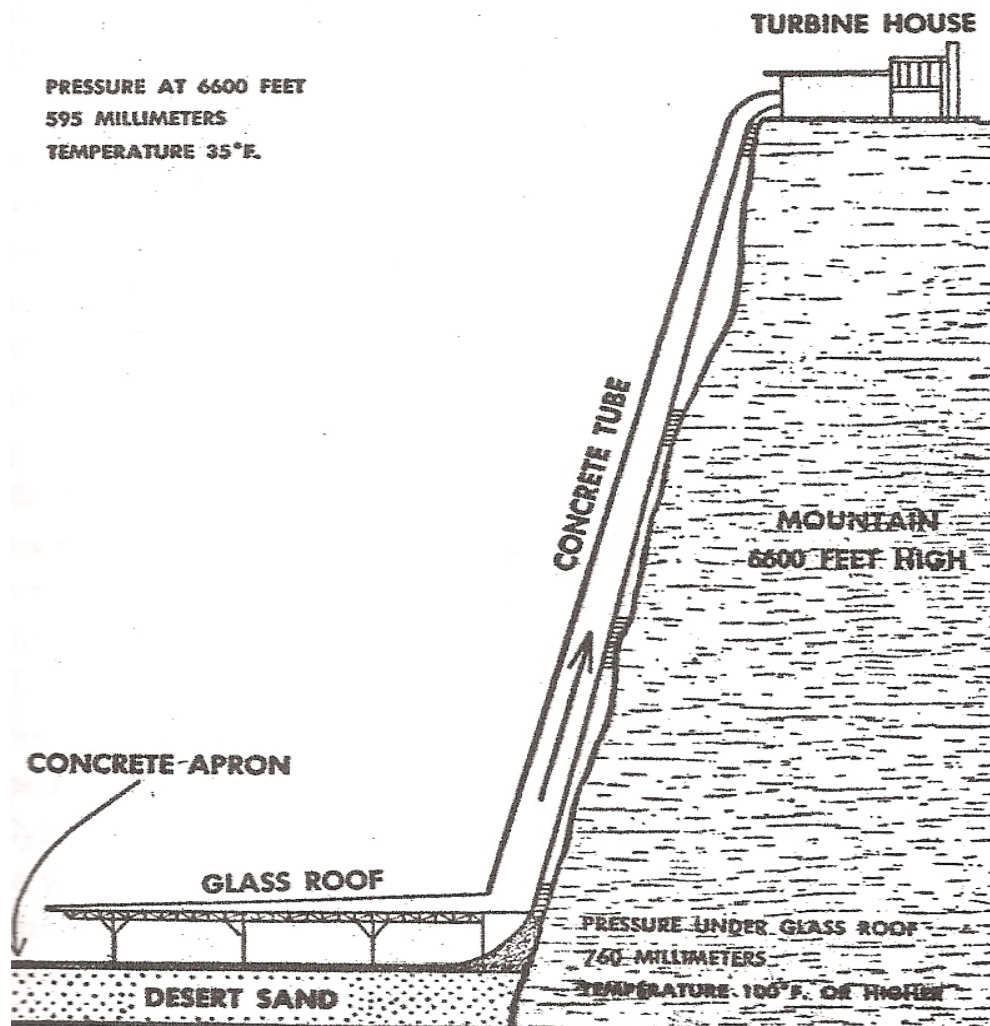
The up-drafting air mass through the FSC, due to its relative buoyancy to the ambient air, is offering a part of its thermodynamic energy to the air turbines rotating the geared electric generators, which generate electricity.

Thus the first two components of the floating solar chimney power plants form a huge thermodynamic device, up-drafting the ground ambient air towards the upper atmosphere layers and the third component is the electricity generating device operating by the up-drafting warm air mass.

Due to ground thermal storage capacity the electricity generation of the SAEPs is continuous and uninterrupted.

2. History

- The Solar Chimney technology for electricity generation was inspired by several engineers in the first decades of 20th century. In 1926 Prof Engineer Bernard Dubos proposed to the French Academy of Sciences the construction of a Solar Aero-Electric Power Plant in North Africa with its solar chimney on the slope of the high height mountain.



**Figure and data from the book: "Engineer's Dream"
By: Willy Ley, Viking Press 1954**

More recently Schaich, Bergerman and Partners, under the direction of Prof. Dr. Ing. Jorg Schlaigh, built an operating model of a SAEP in 1982 in Manzaranes (Spain), which was funded by the German Government. This solar chimney power plant, of rating power 50 KW, was operated successfully for approximately 8 years (see the video)

http://www.youtube.com/watch?v=XCGVTYtJEFk&feature=feedrec_grec_index

- Its solar chimney was made by steel tubes of 10 m diameter and had a height of 195 m. http://www.math.purdue.edu/~lucier/The_Solar_Chimney.pdf . During its operation optimization data was collected. Prof. Jorg Schlaigh in 1996 published a book (titled "The Solar Chimney") presenting the solar chimney technology.



A view of the Manzanares Solar Chimney Power Plant

- The collected operational data were in accordance with the theoretical results
- Prof. Jorg Schlaigh proposed in his book huge reinforced concrete solar chimneys of heights 500m-1000m. These solar chimneys are very expensive constructions. Therefore the investment cost per produced KWh on the solar chimney technology with concrete chimneys is higher than the competitive solar thermal technologies (SCP for example).
- However the solar chimney technology has an important benefit in comparison to the other renewable technologies (Wind, SCP, PV). This is the ability of its Power Plants, equipped with thermal storage facilities of negligible cost, to produce electricity for 24h/day, 365days/year.

3. The Floating Solar Chimney (A low cost fabric structure)

In order to decrease the construction cost of the ***Solar Aero-Electric Power Plants (SAEPs)*** the inventor proposed to replace the concrete solar chimneys with lighter than air inflated fabric structures named ***Floating Solar Chimneys***

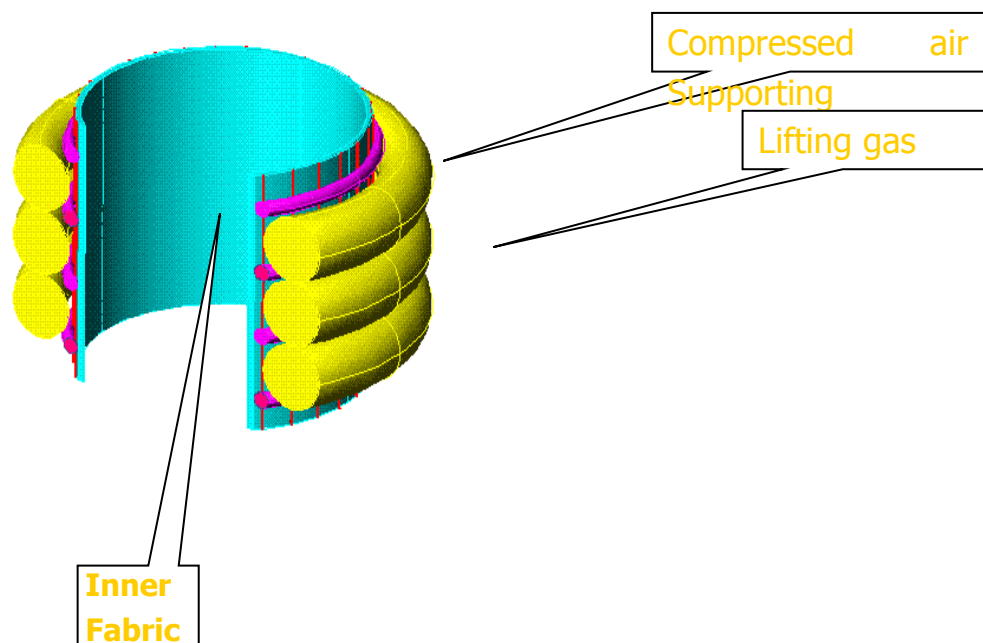
(FSCs). He is granted USA, AUSTRALIA, EU, CHINA, INDIA and SOUTH AFRICA patents for his invention.

In a series of papers the inventor gave the main characteristics of the SAEPs with **Floating Solar Chimneys.**

Low cost **Floating Solar Chimneys** up to 500 m with internal diameters 32 m ÷ 42 m, can be constructed with existing polyester fabric, giving to their respective **Solar Aero-Electric Power Plants,** low investment costs.

By this innovating **Floating Solar Chimney Technology** for FSC heights of maximum 500m, up to 0.6 % of the arriving horizontal solar radiation on the solar collector surface, can be converted to electricity.

An indicative representation of the small part of a **Floating Solar Chimney** main cylindrical air up-drafting body is shown in the lower figure. The inner core can be placed outside the fabric structure in order to protect by solar UV radiation the supporting and lifting balloons.



4. The desert solar collector (A low cost greenhouse)

The solar collectors of updraft concrete solar towers are ordinary circular greenhouses usually with double glazing transparent roofs supported a few meters above the ground. The periphery of the circular greenhouse should be open to the ambient air. The outer height of the greenhouse should be at least 2

meters tall in order to permit the entrance of maintenance personnel inside the greenhouse. The height of the solar collector should be increased as we approach its centre where the FSC is placed. As a general rule the height of the transparent roof should be inversely proportional to the local diameter of the circular solar collector in order to keep relatively constant the moving air speed. The circular greenhouse periphery open surface can be equal or bigger than the FSC cut area. These greenhouses are expensive and demand an expensive and continuous maintenance especially when will be installed in desert areas for cleaning their roofs.

In desert application of the FSC technology the solar collectors will be used exclusively for air warming. Also in desert or semi desert areas the dust on top of the transparent roofs of the conventional greenhouses could be a major problem. The dust can deteriorate the transparency of the upper glazing and furthermore can add unpredictable weight burden on the roof structure. The cleaning of the roof with water or air is a difficult task that can eliminate the desert potential of the FSC technology.

Furthermore in desert or semi-desert areas the construction cost of the conventional solar collector (a conventional greenhouse) could be unpredictably expensive due to the unfavourable working conditions on desert sites.

For all above reasons another patented design (**Patent under pending**) of the solar collectors has been proposed by Prof. C. Papageorgiou.

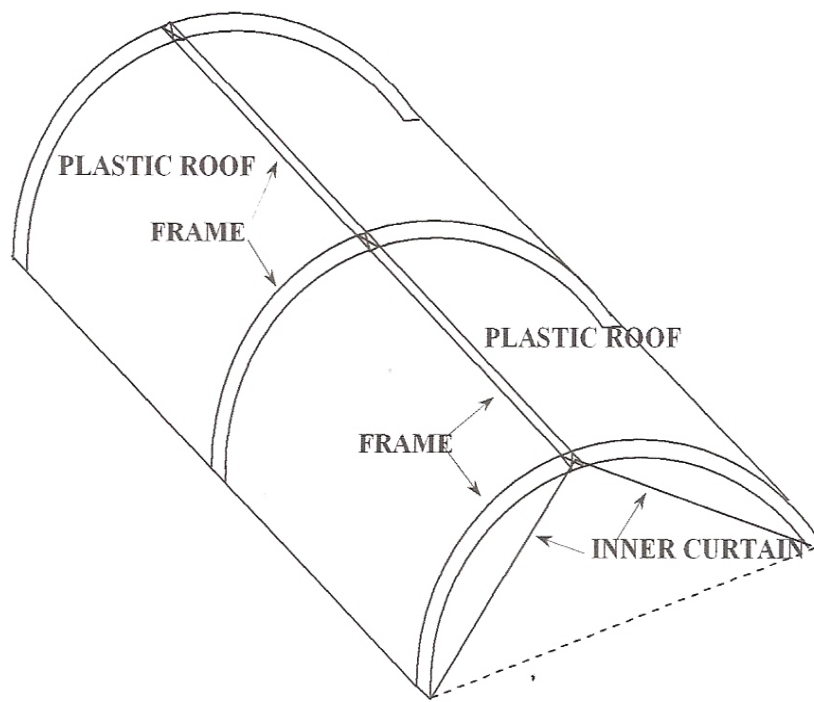
The proposed desert solar collector is a low cost alternative solar collector of the circular or rectangular conventional greenhouse which can minimize the works of its construction and maintenance cost on site.

The solar collector is the unit of the SAEP used just to warm the ground beneath it and the moving air mass in through it. Thus in deserts it is possible not to have the usual form of conventional greenhouses because no farming activity takes place beneath it. The modular solar collector shape is orthogonal, just like the usual shapes of the land fields.

We can also use and follow the ground elevation on site, and put the FSC on the upper part of the land-field therefore the works on site for initial land preparation will be minimized.

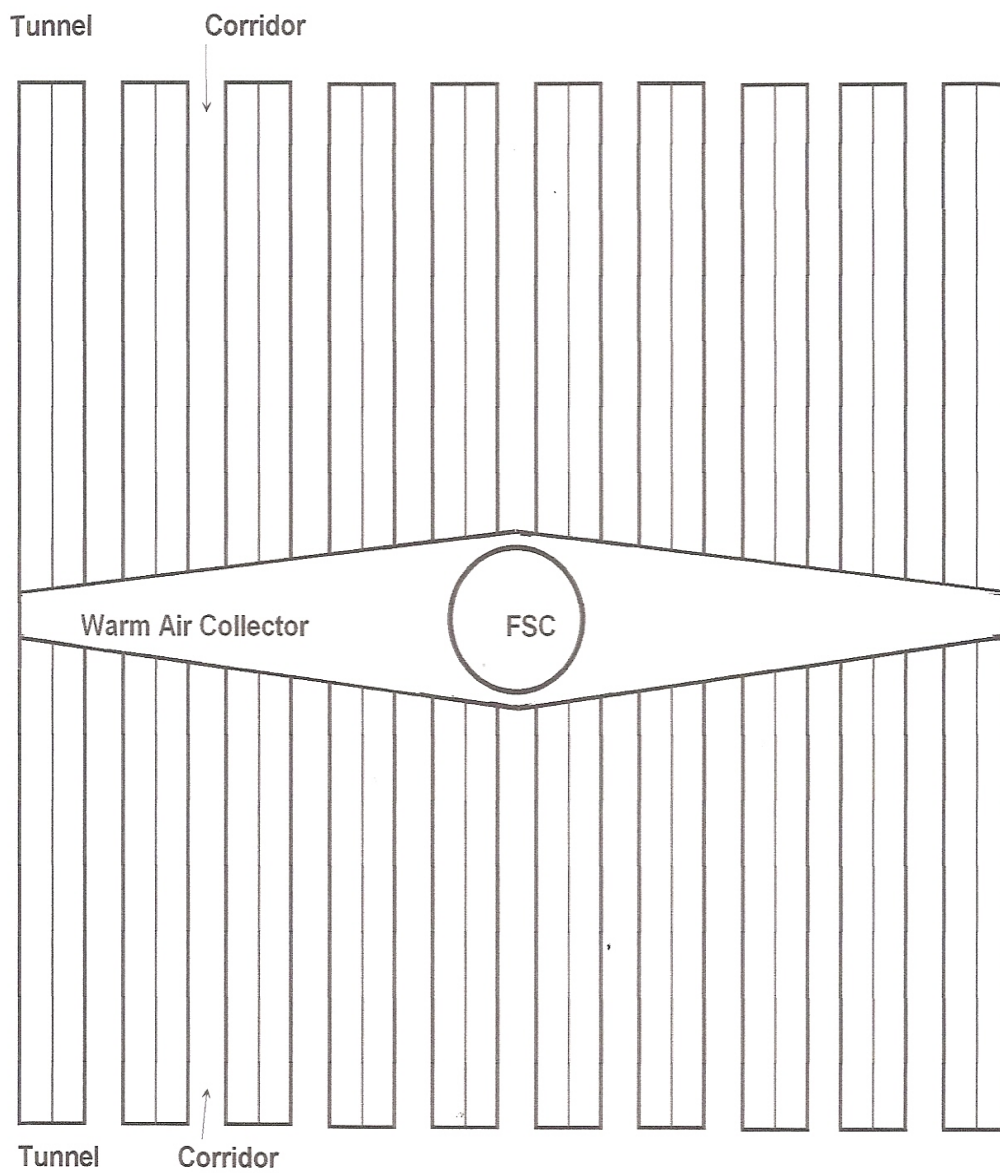
The greenhouse will be constructed as a set of parallel reverse-V transparent tunnels made of crystal clear double glazing as shown in the next figure. The height of the air tunnel should be 180cm in order to facilitate the necessary works inside the tunnel.

All the parallel series of reverse-V tunnels of panels will slowly elevate, following the ground physical inclination and heading their warm air moving mass, towards a closed corridor of appropriate dimensions leading to the entrance of the FSC.

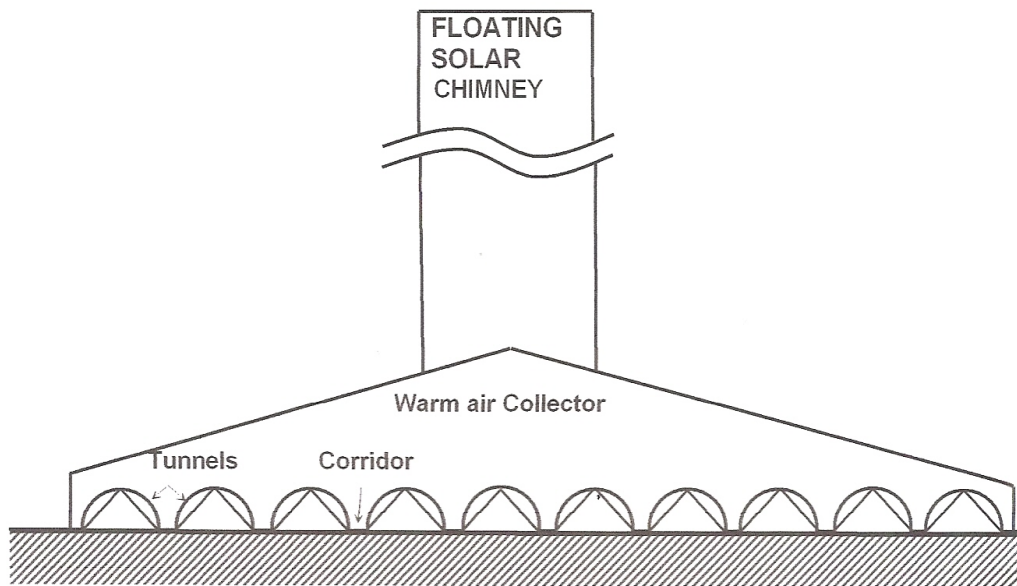


A SMALL PART OF THE TUNNEL

An indicative figure of a greenhouse made of several air tunnels is shown in next figure. Among the parallel air tunnels it is advisable that room should be made for a corridor of 40-50cm of width for maintenance purposes.



DESERT SOLAR COLLECTOR TOP VIEW



DESERT SOLAR COLLECTOR FRONT VIEW

By above description it is evident that the desert solar collector is a low cost alternative of a conventional circular greenhouse for the FSC technology in desert or semi-desert areas that minimize the works on site and lower the construction costs of the solar collector and its SAEP.

Furthermore the dust problem is not in existence because the dust slips down on the inclined triangular glass panels.

The average annual efficiency of the modular solar collector made by a series of triangular warming air tunnels with double glazing transparent roofs is estimated to be even higher than 50%. Thus its annual efficiency will follow the usual diagram of efficiency (or it will be even higher).

The total cut area of all the triangular air tunnels should be approximately equal to the cut area of the FSC for constant air speed. The central air collecting corridor cut should also follow the constant air speed rule for optimum operation and minimum construction cost.

5. Desert application of Floating Solar Chimney technology

The solar energy arriving on the earth's surface is approximately $\sim 1.2 \cdot 10^9$ TWh/year or $\sim 4.2 \cdot 10^6$ Quads/year (1 Quad = 10^{15} BTU).

http://en.wikipedia.org:80/wiki/World_energy_resources_and_consumption

The surface area of the sun-belt deserts is approximately 36 million Km^2 . Each m^2 of these desert areas is receiving an average of 2000 KWh/year of solar irradiation, thus the whole desert area of our planet is receiving not less than $7.2 \cdot 10^7$ TWh/year or $\sim 2.5 \cdot 10^5$ Quads/year ($\sim 6\%$ of the overall solar energy arriving on earth).

The primary (thermal energy) consumption for 2009 is an estimate of 500 Quads while the electricity demand will be less than 28000 TWh or ~ 100 Quads ($\sim 20\%$ of primary consumption). It is estimated that this figure most probably could be doubled within the next 30-40 years partly because that transportation fuels could be replaced by electricity or Hydrogen made by electrolysis of clean electricity.

Let us assume that Floating Solar Chimney technology is used in desert or semi-desert areas. In order to cover a 40-50% of the future electricity demand i.e. 80-100 Quads or $\sim 22,000$ - $28,000$ TWh, we should use a desert area of 1.5-2.0 million Km^2 . This is approximately 10% of the desert or appropriate semi-desert areas of our planet.

Desert or semi-desert areas of high solar irradiation exist in all continents and close to the big carbon emission producers.

Europe can cover its 40-50 % of its present and future electricity demand by FSC technology application in North Africa and Middle East desert and semi desert areas. An area of (300 Km X 300 Km) is sufficient.

Appropriate areas for the Floating Solar Chimney Technology application can be found in South West States of USA (Arizona, California, New Mexico, Nevada etc.) where the high solar irradiation is combined with mild winds. A 6% of the areas of Arizona, New Mexico and Nevada can cover USA 40-50% future electricity demand.

Taklamakan desert areas of East China can be used in order to cover China's 30-40% of its present and future electricity demand.

In India, Australia, South and Central America Middle East and Africa there are more than enough desert or semi- desert areas for a large scale of FSC technology application to cover any demand of clean electricity in these areas.

6. Direct production cost of MWh and investment cost

The following table gives us the average direct production cost of MWh and the necessary investment per produced MWh among the most significant electricity generation technologies (for new investments).

Fuel or Method of Electricity Generation	MWh Direct Production Cost in EURO	Investment in EURO produced per MWh/year	Mode of operation and Capacity factor
Coal fired (not including carbon emission penalties)	55-60	200	Combined cycle base load 85%
Coal fired with CCS (Carbon capture and storage)	80-100	300-400	Combined cycle base load 85%
Natural Gas fired (not including carbon emission penalties)	60-65	150	Combined cycle 85%
Nuclear Fission	65-75	400÷450	Base load 95%
Wind parks onshore	65	500	Intermittent 30%
Wind parks offshore	75	650	Intermittent 30%
Concentrating Solar CSP	180	2000	Continuous with thermal storage 30%
Photo Voltaic PV	280	3000	Intermittent 15-17%
Solar Up-draft Tower (concrete solar chimney)	155	~2000	Continuous ~50%
Floating Solar Chimney	Less than 60	Less than 500	Continuous ~50%
Biomass	60-75	500÷700	Continuous 85%
Geothermal	60-70	500÷800	Continuous 90% (limited resource)
Hydroelectric	60-65	500÷800	Continuous (load following, limited resource)

From the above table it is evident that, for new investments, for renewable electricity generating technologies, the Floating Solar Chimney technology

combines the continuous operation and the smaller capital expenditure per produced MWh/year.

Also because the FSC technology does not demand any fuel its MWh direct production cost is equal to the lower investment, base load fuel consuming technologies (coal, natural gas, etc.), and the most important is that the SAEPs do not emit any greenhouse gases.