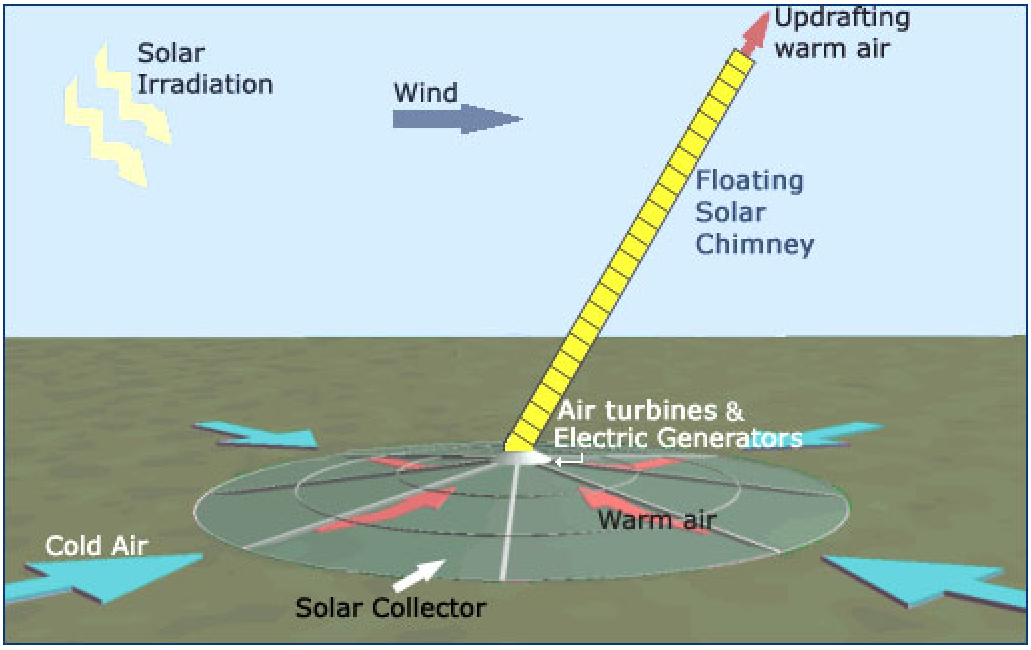
Floating Solar Chimney Technology

A short presentation



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1. History

Solar chimney technology (http://en.wikipedia.org/wiki/Solar_chimney) is an electricity power generating method working with the warm air of a large solar collector up drafting through a tall chimney.

One of the earliest descriptions of a solar chimney power station was written in 1931 by a German author, Hanns Gunther.

More recently Schaich, Bergerman and Partners, (http://www.sbp.de) under the direction of German engineer Prof. Dr. Ing. Jorg Schlaigh, built a working model of a solar chimney power plant in 1982 in Manzanares (Spain), 150 km south of Madrid, which was funded by the German Government. This power plant operated successfully for approximately 8 years. The chimney had a diameter of 10 m and a height of 195 m, and the maximum power output was about 50 KW. During the final 3 years, optimization data was collected on a second-by-second basis.

Prof. J. Schlaigh in 1996 published a book [1] in order to present this technology.

Although J. Schlaigh proposed initial physics to explain the solar chimney technology operation, the theoretical foundation for the operation of solar chimney power plants was done later by Von Backstrom and Cannon [2], [3].

Prof. J. Schlaigh proposed Power Plants with tall solar chimneys made by reinforced concrete up to 1000m. Following his ideas the "enviromission" Ltd of Australia (http://www.enviromission.com.au/) with "Solarmission technologies" of USA, (http://www.solarmissiontechnologies.com/) were going to build in Australia a Solar Chimney Power Plant of 200 MW, (this decision recently was revised to a 50 MW Power Plant). The initial Power Plant of 200 MW shoud have a huge reinforced concrete solar chimney of 1000 m with internal diameter 130m and a circular solar collector with a diameter 7000 m.

This Power Plant has the brand name "Solar Tower". The construction cost of this "Solar Tower" was estimated to be approximately 700 million USD. The plant will produce annually not less than 600 GWh.

A similar renewable power plant of 200 MW, with wind turbines (50 turbines of 4 MW each for example) will produce almost the same GWh/year but will have a cost 200 ÷ 250 million USD.

Taking into consideration the construction difficulties of huge reinforced concrete Solar Towers and the high construction cost of their respective power plants the energy society has not considered yet the reinforced concrete solar chimney technology as a successful competitive option in renewable technologies.

2. The Floating Solar Chimney Technology

In order to increase the efficiency of solar chimney power plants and to decrease their cost, prof. PhD Engineer Christos Papageorgiou, proposed to build higher and less costly solar chimneys, as lighter than air structures, named ***Floating Solar Chimneys****, with his inventions [GR 1004334/27-3-03], [GR 10004837/16-3-04] and [PCT/GR03/00037].*

The inventor in order to support scientifically his ideas, related to the ***Floating Solar Chimney technology****, presented a series of papers to various international conferences see ref. [4,5,6,7,8,9,10,11].*

The inventor has shown that a Floating Solar Chimney Power Plant of 100 MW producing annually not less than 300 million KWh could have a cost of 35÷70 million Euros. This Power Plant will have a Floating Solar Chimney of 2÷ 3 km height and 50÷85 m internal diameter and a solar collector with diameter of 2000 m÷3000 m.

Taking into consideration that the respective wind farm of 100 MW, producing in average annually 250 million KWh, will have a construction cost of 100 million Euros, it is evident that the ***Floating Solar Chimney technology*** *could be a very interesting option for renewable electricity generation.*

The ***Floating Solar Chimney power plants*** *were named* ***Solar Aero-Electric Power Plants (SAEPPs)*** *due to its similarity to Hydro-Electric Power plants. These* ***SAEPPs****, equipped with low cost thermal storage facilities, can operate 24 hours/day for 365 days per year, producing a guaranteed Power profile. Thus the* ***SAEPPs*** *can replace conventional fuel consuming Power Plants.*

In the following pages a short presentation of ***SAEPPs*** *is given as appeared in the site* *www.floatingsolarchimney.gr*

3. Floating Solar Chimney Technology Application

The solar energy arriving on the earth's ground is approximately ~$1.2.10^{12}$ Gwh/year or ~ $4{,}2\bullet 10^{6}$ quads/year (1 quad=10^{15} BTU). The world energy demand for Electricity and Transportation Fuels (by a Hydrogen technology) it is in the range of 100 quads and most probably it will be doubled in 30 years.

This means that if we could convert cost efficiently a negligible fraction of the solar energy we could cover the world's future energy demand in Electricity and Transportation Fuels without any environmental consequences.

For example, in proper sunny places, the solar energy arriving on horizontal surfaces is more than 2000 KWh/year·m^2. This means that using the ***Floating Solar Chimney Technology*** *by which we can convert approximately 3-5% of this energy to Electricity (and with electrolysis to Hydrogen fuels) we can generate Electrical Energy 60÷100 KWh/year·m^2.*

Under this assumption the necessary land to produce fifty percent (50%) of the existing world energy demand in Electricity and Transportation Fuels (~50 quad/year), using the ***Floating Solar Chimney Technology****, is 140.000-200.000 square Km (i.e. less than a square of dimensions 440 Km X 440 Km).*

For USA the necessary Electricity generation to cover its Electricity and (Hydrogen made) fuels is estimated today to 10÷15 quads, with its future demands (year 2030) to reach 20 quads. In order to cover 50% of this future demand using ***Floating Solar Chimney Technology*** *a land of ~ 40.000 square Km is necessary (i.e. a square of 200 Km X 200 Km).*

Appropriate areas for the ***Floating Solar Chimney Technology*** *application can be found in South West States (Arizona, California, New Mexico, Nevada etc.) where the high solar irradiation is combined with mild winds.*

In Europe, South Spain, South Italy, South Greece, South Turkey and Cyprus are best candidate States for ***Floating Solar Chimney Technology****. In China, India, Australia, South and Central America and Africa there are more than enough places for this Technology.*

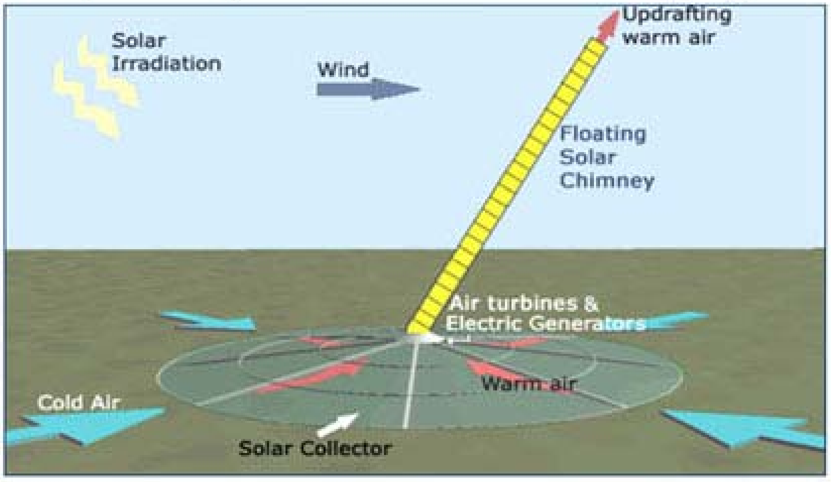
Thus ***Floating Solar Chimney Technology*** *can be applied everywhere, where appropriate climate conditions exist. In certain areas the* ***Floating Solar Chimney Technology*** *can be combined to special greenhouse agriculture bellow the protected area of their Solar Collectors. Thus useful agriculture lands will not be lost by* ***Floating Solar Chimney Technology*** *application but rather promoted.*

Floating Solar Chimney Technology

This is a Solar Technology that can solve the Energy problem protecting the Environment and securing world's Sustainable Development

1.The Solar Aero-Electric Power Plant with Floating Solar Chimneys.

A Solar Aero-Electric Power Plant (SAEPP) is shown in the following figure



2.The Solar Aero-Electric Power Plant (SAEPP) main components

A SAEPP is made of three components:

- A large circular solar collector with a transparent roof supported a few meters above the ground (the Greenhouse).
- A tall, warm air up drafting, Cylinder on the center of this Greenhouse (The Floating Solar Chimney).
- A set of Air Turbines geared to appropriate Electric Generators around the base of the Solar Chimney(The Turbo Generators).

3.How SAEPPs operate

- The Solar energy warms the air inside the solar collector (greenhouse effect).
- The warm air tends to escape through the Solar Chimney to the upper atmosphere.
- This up drafting stream of warm air leaves part of its thermodynamic energy to the Air Turbines geared to Electric Generators, converting this energy to Electrical.

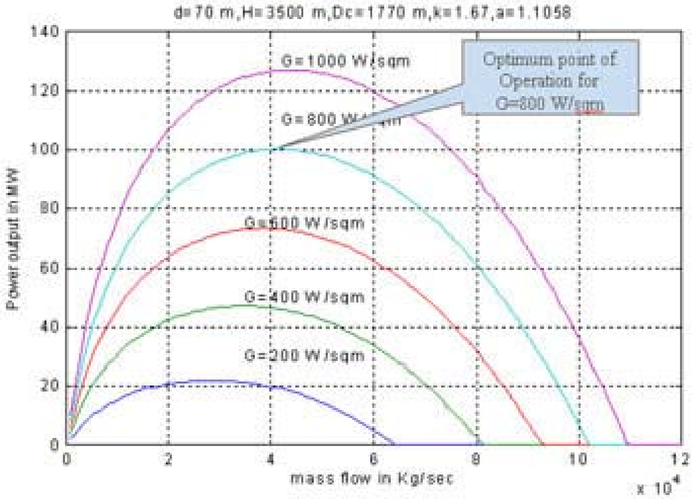
4.Is Solar Aero Electric Power Plants (SAEPPs) similar to Wind farms?

- Although artificial wind is generated inside the solar collector (from its periphery towards its center) SAEPPs are not similar to wind farms.
- The wind Turbines convert the wind kinetic energy to rotational energy.
- The SAEPP's Air Turbines leave the moving warm air kinetic energy unchanged.

5.Solar Aero Electric Power Plants' similarity to Hydro Electric Power Plants

- SAEPPs are similar to Hydro Electric Power Plants (that is why I called them Aero Electric)
- Their Air Turbines convert the up drafting air dynamic energy (due to buoyancy) to rotational energy,as Water Turbines convert the water's dynamic energy (due to gravity) to rotational.
- In both Power Plants their Power Output is proportional to H (Floating Solar Chimney air up drafting height or Dam falling water height)

6.Typical SAEPP's operational curves for constant turbo generator efficiency n_t

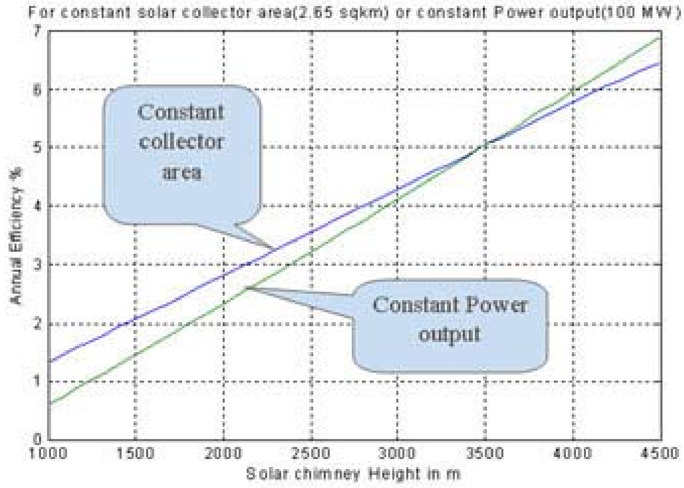


7.The SAEPPs' annual Efficiency η_o

$$\eta_o = \frac{Co \cdot P_{\max}(G_{av})}{G_{av} \cdot A_c}$$

- The annual efficiency η_0 of the SAEPP is equal to its annual electrical energy production divided by the annual solar energy arriving on the solar collector's area. P_{max} is the maximum operating Power of the SAEPP, in the point of optimum operation for the solar irradiance on a horizontal surface G, (that Maximum is almost proportional to G).
- A_c is the Solar collector's area.
- G_{av} is the average operating solar irradiance of the SAEPP i.e. the ratio of the solar irradiation on horizontal surface divided by the hours of operation of the SAEPP.
- C_0 is slightly bigger than one due to thermal storage ability of the ground just around the solar collector of the SAEPP.

8. The effect of FSC's height H on n_o



9. The floating solar chimney

- In order to build efficient and cheap SAEPPs we should have taller and less expensive solar chimneys than the reinforced concrete "solar towers".
- Floating Solar Chimneys (FSCs) are lighter than air structures , invented by the author, that can be as tall as 1.5 to 3 Km, executing efficiently their air up drafting operation.

10.The problems related to lighter than air (Floating) Solar Chimneys.

An effective lighter than air (Floating) Solar Chimney structure must encounter :

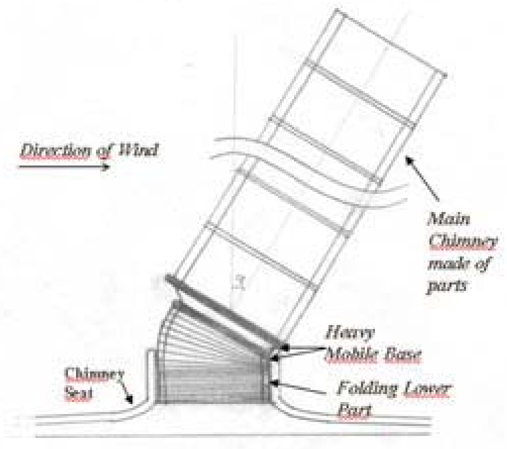
- The operational and wind sub pressure acting on its wall.
- The external winds' overall action.
- The variation of wind velocity with altitude.

11.How the invented FSCs encounter these problems

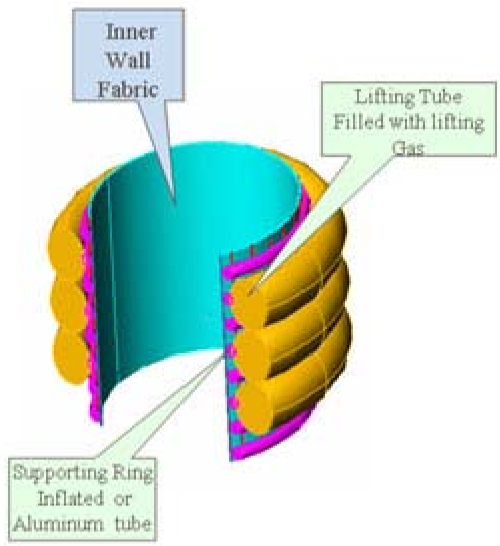
- The wall sub pressure, acting on the main body cylinder of the FSC, is encountered by the action of the supporting rings made of Aluminum or air inflated pressurized tubes.
- The wind huge forces and respective moments are encountered through the structure's ability to tilt, due to the inclining ability of its heavy base and the action of the folding (accordion) part that prevents any air escapes.
- The wind's variation with altitude is encountered through the isolation relief tubes,separating the upper cylinder in successive, dynamically independent, parts that are independently attached by the upper cylinder of the heavy base.

12.The FSC's construction

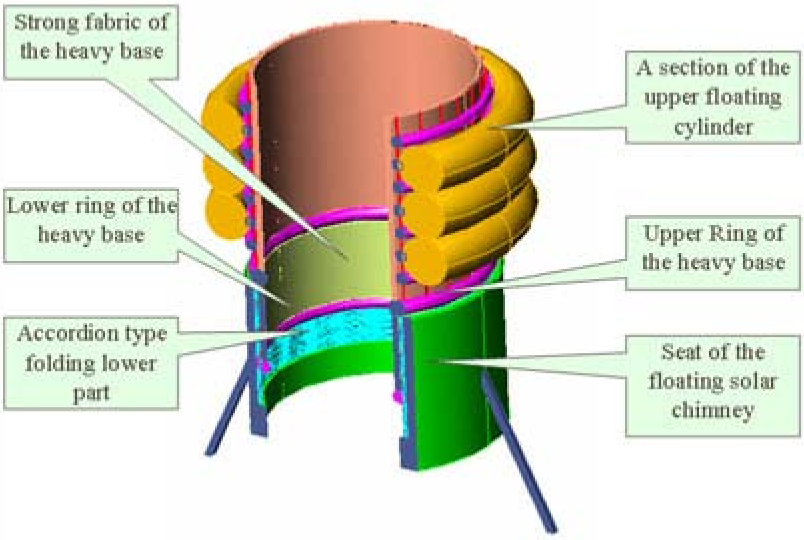
- The main body of the floating solar chimney is a lighter than air, warm air up drafting cylinder made of a set of successive toroidal tubes filled with lighter than air gas (He, NH3).
- This air up drafting cylinder is made of successive parts attached separately to a heavy inclining base with an accordion folding lower end.
- This accordion type folding end is unfolding partly when the structure is bending, securing that the warm air does not escape from its bottom.



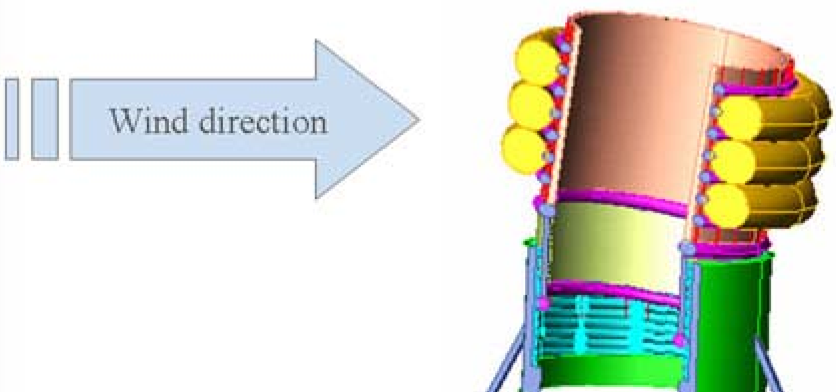
13.A possible FSC's upper part structure (with an inner fabric wall)



14. An indicative 3-D animation of the lower part of a possible structure of the FSC



15. An indicative 3-D animation of the previous FSC under external winds



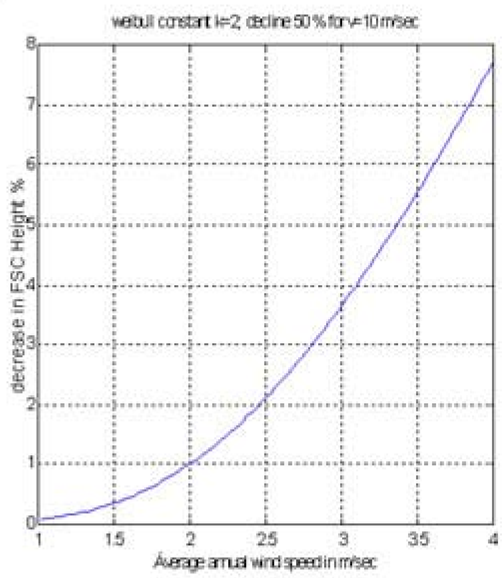
16.Is the FSCs' integrity secured under external strong winds ?

- The existing modern plastic and composite fabrics and fibers, tested already to air ship and inflated structures have given valuable information and know-how for an appropriate construction of the FSCs ,in order to withstand external strong winds and high pressures.
- The related industry,supported by research of specialized academic institutions, can solve any problems that may appear, producing cheap, strong and enduring FSC's structures.

17.The wind effect on the operational height of the FSCs

Due to the titling property of the FSC, its operational height is decreasing under external winds . The average annual FSC's height operational decrease depends on the average annual wind speed and the net lifting force of the FSC's lighter than air cylinder.

For example, for an average wind speed of 3 m/sec and a net lift force assuring a 50% bending for a wind speed of 10 m/sec, the average height decrease is 3.7%.



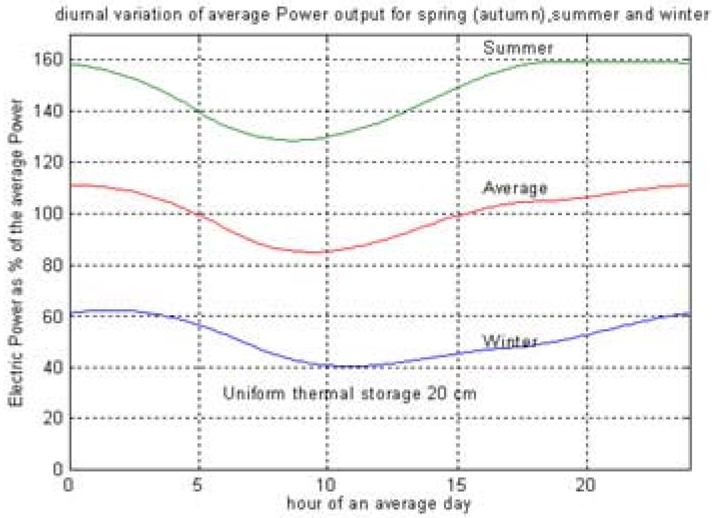
18.The SAEPPs with FSCs of 3000 m

- SAEPPs with FSCs of 3 Km height have annual efficiencies 3 % to 4.2% (depending on the air speed inside the solar chimney,i.e. on its internal diameter) .
- SAEPP's rated power is defined as the maximum Power for the annual average solar irradiance on horizontal surface for the insolation hours in the place of its installation G_{AV}.
- SAEPPs with rated power Pmax(G_{AV}) will produce annually at least 3000 KWh per rated KW, for proper sunny places of installation, operating 24 hours/day with artificial thermal storage.

19.The thermal storage effect on SAEPPs

- The daily operation curve of a SAEPP depends on daylight solar irradiance and on the solar collector's ground or artificial thermal storage.
- If we leave bags or closed tubes filled with water on the ground of the solar collector (covering part of it) the daily operation of the SAEPP becomes smoother .
- This means that the SAEPP is producing electric power 24 hours per day with power varying between P_{Max} to P_{min} the difference between P_{Max} and P_{min} depends on the thermal storage water quantity .
- The maximum operating power (on the summer period) can be arranged by the quantity of thermal storage water.

20.The thermal storage effect on SAEPP



21.Solar Aero Electric Power Plants Material-The Solar Collector

- The roof of the cyclical solar collector of a SAEPP is made by glass or clear plastic (or any appropriate inexpensive alternative) .
- The supports for the glass roof are made by steel or hard plastic in concrete foundation.The supports for clear plastic roof could be made by a more inexpensive procedure.

22.Solar Aero Electric Power Plants Material-The Floating Solar Chimney

The main material for the FSCs of the SAEPPs are:

- Strong and enduring artificial fabric, reinforced with composite fibers for tubes and inner wall.
- The fabric of lifting tubes should be impermeable to lifting gas and UV protected as the usual fabric of air ships or balloons.
- The connecting fibers or ropes of the structure are of very strong composite yarn (Aramid).
- The lifting gas could be He or NH_3. The later has a smaller cost and can be found easily.

23.Solar Aero Electric Power Plants Equipment-Turbines & Generators

The main equipment are:

- Axial shrouded Air Turbines
- The respective one stage Gear boxes
- and Electric Generators ,with their Power electronics

These combined power production units ,are placed with horizontal axis around the base of the floating solar chimney.

Their overall rating Power due to artificial thermal storage can be 60÷100 % of the rating power of their SAEPP (i.e. equal to their maximum Electric power production on summer).

24. Availability for local construction of SAEPPs.

- By the previous presentation it is evident that all the necessary material and equipment for SAEPPs can be found easily in the market.
- Taking into consideration the construction experience and Know how of the related companies in similar works ,the construction of the SAEPPs can executed locally in every place of the world.
- The FSC's tubes can be ordered and constructed by specialized industrial units and transported locally, where the final FSC's construction will be take place .

25.Favorite places of installation for Solar Aero Electric Power Plants

The best places of installation for the SAEPPs with FSCs should have:

- High annual solar irradiation on horizontal surface (>1600 KWh/sqm,best >2000 KWh/sqm)
- Low average annual winds (<3 m/sec)
- Limited strong winds (<20 m/sec)
- No heavy snow, hail storms, sand storms or dust storms
- Seismic activity is not important
- In every continent there are excellent places for a broad Floating Solar Chimney Technology application covering its population energy demand.
- It is possible to combine Electricity production with specific agriculture production in the Greenhouse and rain or distilled water collection using the SAEPP's solar collectors glass roofs or FSCs.

26. Cost and related information of SAEPPs with FSCs of 1500 m to 3000 m

- The following tables show the minimum cost and other information for SAEPPs with FSCs of 1500m to 3000m with glass or clear plastic roofs in places with annual irradiation 2300 KWh/sqm
- The solar collector area for the clear plastic roof is larger of the glass roof SAEPP for the same Power output, however the construction cost of them is almost half due to the cheaper roof's material and construction cost.
- for places with lower irradiations the solar collector areas should be larger increasing the cost per rated KW of the respective SAEEPs.
- For the construction of the first (demo) unit should be wise to assume an increased cost at least 50%.

27.SAEPPs with clear plastic roof, H=3000 m

SAEPP's Rating Power in MW	50	100	200
FSC's internal diameter in m	35	50	70
Solar collector's area in sqKm	2	3.7	7.2
FSC's construction cost in million €	11	15.8	22
Solar collector's construction cost in million €	4	7.4	14.4
Turbo Generators' construction cost in million €	4.5	9	18
SAEPP's construction cost in million €	21	33	55
Annual Energy Production in millions KWh	150	300	600

28. SAEPPs with glass roof, H=3000 m

SAEPP's Rating Power in MW	50	100	200
FSC's internal diameter in m	50	70	100
Solar collector's area in sqKm	1.6	3	6
FSC's construction cost in million €	15.8	22	31.6
Solar collector's construction cost in million €	13.6	25.5	51
Turbo Generators' construction cost in million €	4.5	9	18
SAEPP's construction cost in million €	35	58	103
Annual Energy Production in million KWh	150	300	600

29.SAEPPs of 100 MW with clear plastic roofs and variable FSC's height H.

FSC's height in m	3000	2500	1500	1000
FSC's internal diameter in m	50	55	60	70
Solar Collector's area in sqKm	3.7	4.4	5.7	7.9
FSC's construction cost in million €	15.8	14.5	12.9	11.5
Solar collector's construction cost in million €	7.4	8.8	11.4	15.8
SAEPP's construction cost in million €	33	34	35	37

30.SAEPPs of 100 MW with glass roofs and variable FSC's height H.

FSC's height in m	3000	2500	1500	1000
FSC's internal diameter in m	70	80	90	100
Solar Collector's area in sqKm	3	3.6	4.6	6.4
FSC's construction cost in million €	22	21.2	18.4	16.5
Solar collector's construction cost in million €	25.5	30.6	39.1	54.4
SAEPP's construction cost in million €	58	62	68	80

31. Comparison of SAEPPs with FSCs to conventional Power Stations

WETO World Energy Technology & climate policy Outlook 2030 data				
Power Station	Investment Cost in €/kW		Fuel Cost	Maintenance Cost
	Year 2000	Year 2010		
Gas Combined Cycle	745	587	Above Average	Average
Coal Supercritical	1970	1303	Average	Above Average
Coal Gasification	2631	1805	Average	Above Average
Nuclear	3632	3574	Above Average	Above Average
Biomass	2368	2198	Above Average	Above Average
Wind	996	911	Zero	Low
Photo Voltaics	6457	4378	Zero	Low
Floating Solar Chimney	350-580 (y 2005)	300-500	Zero	Very Low

32. Comparison of SAEPPs with FSCs to conventional Power Stations

- Taking into consideration the relatively low investment cost of SAEPPs
- Combined with their very low operation and maintenance cost
- Their produced KWh could eventually cost as low as 50% of the KWh price produced by any fuel consuming Power Plant.

33.Hydrogen production by SAEPPs

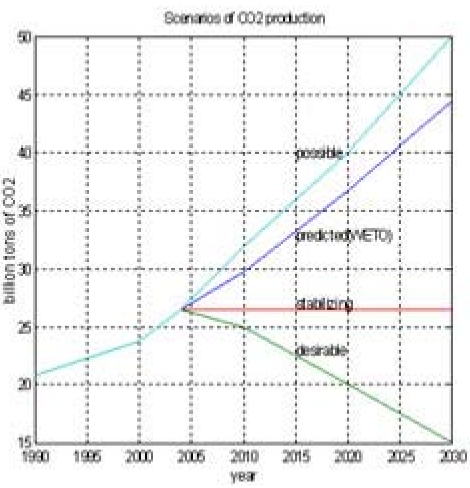
- SAEPPs combined with appropriate electrolysis units can produce hydrogen and oxygen.
- SAEPPs in this case can be electronically controlled in order to produce maximun Power for every G.
- Due to cheap KWh price of SAEPPs Hydrogen price could become eventually less than 1.5 USD/Kg.
- Hydrogen can be used with fuel cell technology as an alternative fuel.
- Hydrogen and Oxygen produced simultaneously by electrolysis can be used in the promising high efficiency H_xO_y motors.

34.The Energy problem

- Energy demand will be doubled in the next 30 years.
- Most probable scenario " the future oil production can not cover the oil demand".
- Increase in oil prices.
- Insecurity for oil supplies.
- International tension.

35.The Environment problem.

- the global warming effect due to fossil fuels is a real threat .
- Following the current trend ,CO_2 emissions will be doubled in next 30 to 40 years
- The development of China and India makes the situation even worst



36. Investments for Floating Solar Chimney technology

- The annual primary energy world demand (year 2004) was ~1.2*10^8 GWh, emitting ~26 billion tones of CO_2.The figures could be doubled in the next 30 to 40 years.
- The annual energy demand for electricity and fuels (Hydrogen generated by electricity) is not more than 20% of this quantity i.e. 24*10^6 GWh.
- A reasonable choice could be, for the next 30 years, to build every year SAEPPs with Floating Solar Chimneys with an overall Power of 330 GW producing ~ 10^6 GWh/year.
- The annual investment for this choice is 100÷150 billion €/year (that is approximately 25 ÷ 35 % of the forecasted energy investments (estimated to 400 billion € /year).
- The necessary land annually, for these SAEPPs installation worldwide will not exceed 20.000 sq Km .
- The 30 years overall land, for the SAEPPs of rating Power of 10000 GW (generating 30*10^6 GWh of electric energy per year), will not exceed worldwide the area of ~600.000 sq Km.

37. Conclusion 1

- *The presented Floating Solar Chimney Technology is not an illusion is a serious innovative electric energy generating method.*
- *The Technology is a many years research project by many independent institutions supported by experimental results.*
- *Although the Technology's Power Plant looks like a perpetual machine, is operating using the solar irradiation energy collected by the greenhouse effect .*
- *The Technology's Power Plants can be constructed using existing material and equipment.*

38. Conclusion 2

- *The Floating Solar Chimney technology supported by the existing renewable technologies can cover the world's energy demand (in electricity and any future transportation fuels based on Hydrogen).*
- *The technology can eliminate the CO_2 emissions below any safe threshold for our planet .*
- *The technology can be the basic "Power vehicle" towards the hydrogen era.*
- *The technology is very competitive to any other fuel consuming energy technology.*
- *The technology is very reliable (as the sunrise !).*
- *Thus Floating Solar Chimney technology can assure world's sustainable development.*

4. References

The References with their respective specific topics are:

[1] Schlaigh J. 1995, "The Solar Chimney : Electricity from the sun" Axel Menges Edition, Stuttgart.

Topic: Solar Chimneys

[2] Cannon A. , Von Backstrom T 2000, "Solar Chimney Cycle Analysis with System loss and solar Collector Performance", Journal of Solar Energy Engineering, August Vol 122/pp.133-137.
Topic: Thermodynamic Cycle Analysis of the Solar Chimney Power Plants

[3] Von Backstrom T, Cannon A. 2000, "Compressible Flow Through Solar Power Plant Chimneys". August vol 122/ pp.138-145.
Topic: Study of Solar Chimneys with Variable Diameter

[4] Papageorgiou C. 2004 "Solar Turbine Power Stations with Floating Solar Chimneys". IASTED Proceedings of Power and Energy Systems, EuroPES 2004, Conference, Rhodes Greece July 2004 pp, 151-158
Topic: Theoretical Performance Analysis of Floating Solar Chimney Power Stations.

[5] Papageorgiou C. 2004, "External Wind Effects on Floating Solar Chimney" IASTED Proceedings of Power and Energy Systems, EuroPES 2004, Conference, Rhodes Greece ,July 2004 2004 pp.159-163
Topic: External Wind Effects on the Floating Solar Chimneys.

[6] Papageorgiou C. 2004, "Optimum Design for Solar Power Stations with Floating Solar Chimneys'', proceedings of ISES Asia Pacific Solar Energy Conference, Kwangju Korea, October 2004 pp.763-772.
Topic: Design, Calculations and Cost of Floating Solar Chimneys and their respective Power Plants .

[7] Papageorgiou C. 2004, "Efficiency of solar air turbine power stations with floating solar chimneys'' IASTED Proceedings of Power and Energy Systems Conference Tampa Florida USA, November 2004, pp. 127-134.
Topic: Efficiency and Annual Performance of Floating Solar Chimney Power Stations

[8] Papageorgiou C. 2005 "Turbines and Generators for Floating Solar Chimney Power Stations". IASTED Proceedings of Power and Energy Systems, EuroPES 2005 conference. Benalmadena Spain June 2005,pp.73-80.
Topic: Operation of Floating Solar Chimney Power Stations taking into consideration its Air Turbines and Electric Generators Performances.

[9] Papageorgiou C. 2005 "Hydrogen Production by Solar Aero Electric Power Plants with Floating Solar Chimneys» International Hydrogen Energy Congress Conference 2005,Istanbul Turkey, July 2005
Topic: Evaluation of Hydrogen Production units composed of Solar Aero Electric Power Plants with Floating Solar Chimneys and appropriate Electrolysis Units.

[10] Papageorgiou C. 2005 "Floating Solar Chimney: The Link towards a Solar Future" ISES 2005 Solar World Congress Conference, Orlando Florida USA, August 2005.
Topic: Cost of Solar Aero Electric Power Plants with Floating Solar Chimneys of variable Height and their comparison to Conventional Power Plants.

[11] Papageorgiou C. 2006 "Floating Solar Chimney Power Stations with Thermal Storage". IASTED proceedings of Power and Energy Systems, EuroPES 2006. Rhodes Greece July 2006(to be presented).
Topic: Thermal storage of SAEPPs for their 24 hours/day operation.

5. Bibliography

There are plenty of books related to the various aspects or parts of the Floating Solar Chimney technology. The following books, chosen by the "inventor", could be valuable for a deeper scientific understanding of the Floating Solar Chimney technology.

- Schlaigh J. "The Solar Chimney : Electricity from the sun" Axel Menges Edition, Stuttgart 1995.
  Topic: Solar Chimneys

- Holman J.P. 2002 "Heat Transfer" Mc Graw Hill international edition .
  Topic: Heat Transfer

- Jones J.B. Dugan R.E. "Engineering Thermodynamics", Prentice – Hall International Inc. 1996
  Topic: Thermodynamics & Thermodynamic cycles

- Beckman Duffie. J.A "Solar Engineering of thermal processes", John Wiley & Sons. 1991
  Topic: Solar Energy Technology

- Incropera F.P. and De Witt D.P. "Fundamentals of Heat and Mass transfer", John Wiley & Sons 1996.
  Topic: Heat Transfer in Solar Collectors

- White F. "Fluid Mechanics" 4th Edition McGraw-Hill N.York 1999.
  Topic: Air Mechanics as a fluid

- McCormik W. Barnes. "Aerodynamics Aeronautics and Flight Mechanics", John Wiley and Sons Inc 1995
  Topic: Air Dynamics

- Mumy L. Saiby "Fundamentals of Atmospheric physics", Academic Press 1996.
  Topic: Winds & Atmospheric Physics

- Heinson R.J. and Kabel R.L. "Sources and Control of Air Pollution", Prentice Hall 1999.
  Topic: Environmental Behaviour & Polution

- Cohen, H. Rogers G.F.C. and saravanamutoo H.I.H. "Gas Turbine Theory", Wesley Longman Ltd England 1996.
  Topic: Air Turbine Theory

- Wright T. "Fluid Machinery Performance Analysis and Design", CRC Press 1999.
  Topic: Air Turbine Classification and Dimensioning

- Beukers A., Hinte E van. 1998 “ Lightness: The inevitable renaissance of minimum energy structures” Amsterdam: 010 Publishers.
  Topic: Light and Inflated Structure Technology

- Koussios S. 2004 “Filament Winding a United Approach” DUP Science Delft Univercity.
  Topic: Inflated Structures

- Veldman S.L.2005 “ Design and Analysis Methodologies for Inflated Beams” DUP Science Delft Univercity.
  Topic: Inflated Structures

- Siegfried H., “Grid Integration of Wind Energy Conversion Systems’’, John Willey and Sons 1998.
  Topic: Electric Generators Geared to Air Turbines

- Peters S.T. (editor) “Handbook of Composites”, Chapman and Hall 1998.
  Topic: Composite Materials Properties

- WETO Energy 2003. “World Energy, technology and climate policy outlook 2030” — European Commission – Directorate General for Research (EUR 20366).
  Topic: Investment cost for Electric Energy Technologies & World Energy Demand

The Internet is also full of information for related topics, that can be retrieved using appropriate word – keys. For example:

- □ *Solar chimney, Solar Tower*
- □ *Floating Solar Chimney*
- □ *Renewable*
- □ *Airships, balloons, inflated structures etc.*

CURRICULUM VITAE

Prof. Christos D. Papageorgiou

STUDIES

1961-1966 Dipl. Mech-Elec Engineer , National Technical University of Athens (NTUA).
1976-1979 Ph.D Imperial College, London University (Scholar of Greek National Scholarship foundation).

ACADEMIC CARRIER

1979- Assoc. Prof. In NTUA(Electromechanical systems of Thrust & Power)
1986-1989 Senate Member of NTUA.
1987-1988 Member of Executive Committee of Chania Technical University.

PROFESSIONAL CAREER

Main Governmental Positions

1981-1983 Deputy CEO of National Hellenic Railways.
1983-1985 CEO of OLYMPIC AIRWAYS.
1986-1987 CEO of PYRKAL (Main defense Industry in Greece)
1988-1989 CEO of National Hellenic Railways.
1994-1995 Chairman of "PAEGA" SA (subsidiary of "National Bank of Greece").
1996-1997 Chairman of National Hellenic Railways.

Main Private Sector Positions

1987-1988 Advisor to the President in "PETZETAKIS" Group of companies
1990-1996 Member of board in "VERNICOS YACHTS" S.A.
2000-2003 C.E.O. of "VERAVIA" Aviation Company

ACADEMIC INTERESTS

- *Floating Solar Chimney Power Stations (Inventor of Floating Solar Chimney)*
- *Renewable Power Systems.*
- *Electromagnetic Applications for Power and Propulsion Systems.*
- *Electromagnetic Theory and Quantum Mechanics.*

HOBBIES

- *Mathematics, Philosophy and History.*

FAMILY STATUS

Married since 1967 with Mrs. Lisa Krikelaidou.
Two Daughters.