



Electricity Generation and Climate Change Policies

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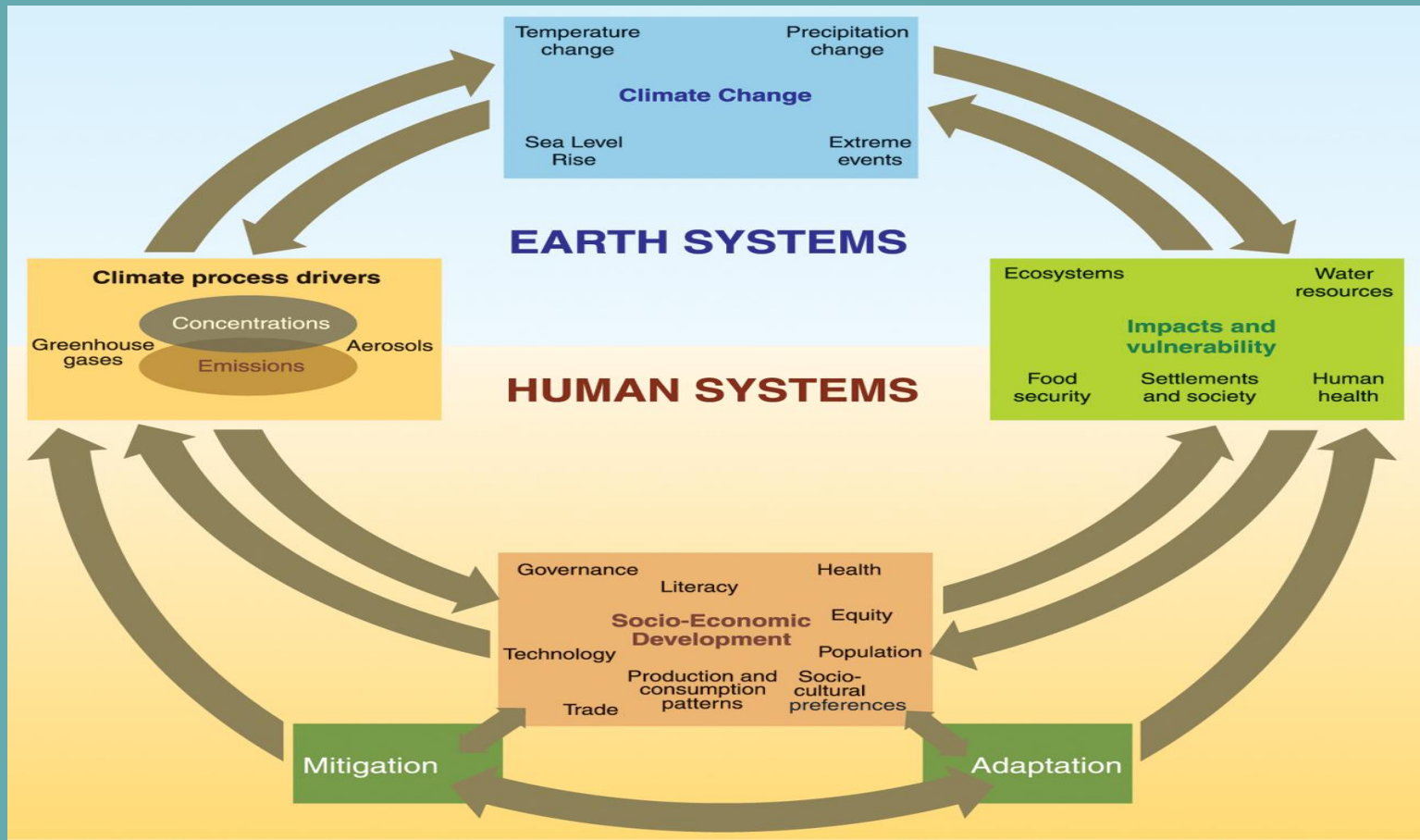
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

The energy and climate change problems

- ***We are in an energy and global economy transient period***
- ***End of Fossil fuels (oil and natural gas) is not too far***
- ***Climate change indications due to global warming threat are accelerating***
- ***Climate change policies should be agreed and urgent measures should be taken***
- ***Green world economy plans should be agreed and states should start immediately their implementation***
- ***Academia, industry and politicians should be tuned for the war against the unconventional enemy threatening human and living species on earth and our civilisation***

Greenhouse gases, global warming and Climate change

Intergovernmental panel on climate change had prepared an excellent documentation on the human influence on earth climate <http://www.ipcc.ch/>

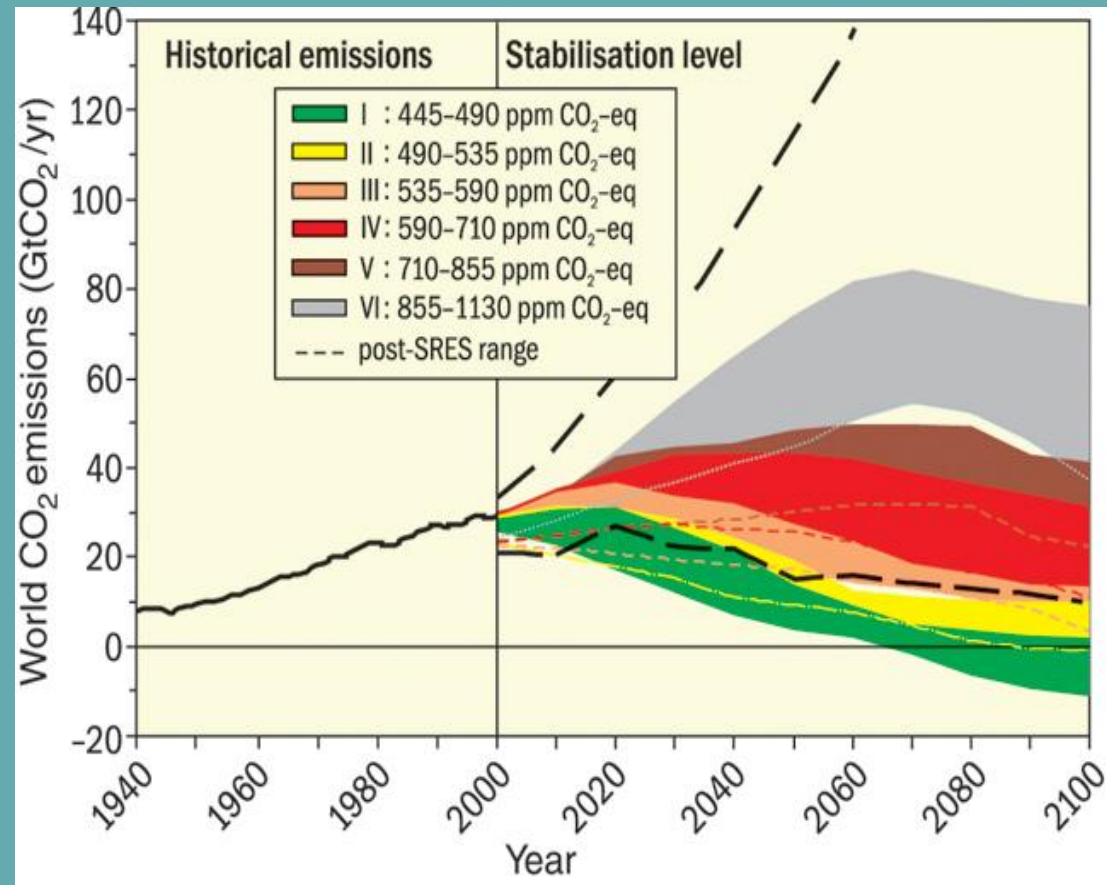


Where the anthropogenic greenhouse gases (CO₂ etc.) are coming from?

- *For year 2010 an estimated quantity of 29,055 Mt of carbon dioxide will be spread to the environment, **by fossil fuels** (weto-h2 report of European Commission) of which:*
 - *36.4 % for electricity generation*
 - *20.8 % for the industry*
 - *18.8 % for transport*
 - *14.2 % for household, service and agriculture and*
 - *9.8 % in international bunkers*

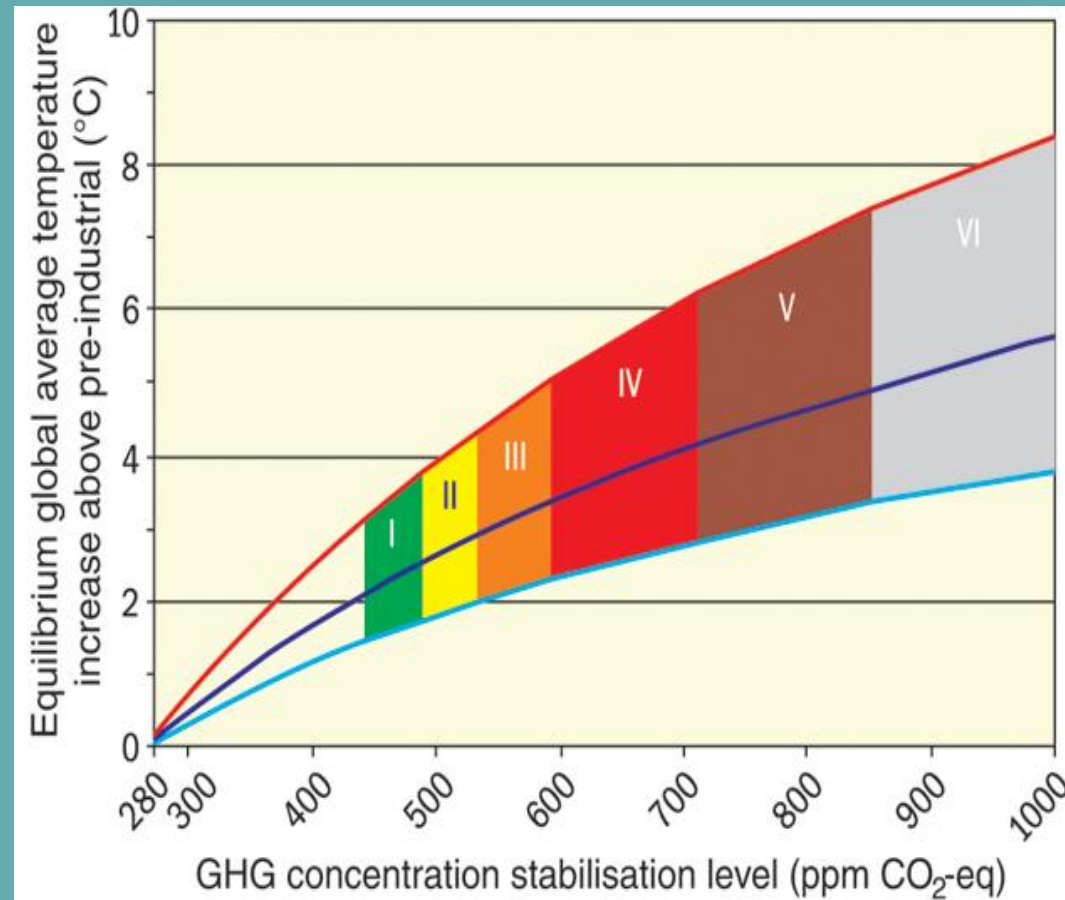
IPCC Scenarios for CO₂ mitigation

- Without the proper measures for CO₂ emissions the climate change will become a real threat
- The China's and India's energy demand make the situation worst
- The best scenario has a high cost, however the cost of the inaction is much higher



The climate change due to global warming by CO2 emissions

- Even with the best scenario the global temperature increase until the end of the century will be (1.8÷3.2 0C)
- Without any measures this increase could be higher than 8 0C
- The increased global temperature **will last for millennia**



Estimated Scenarios for the CO₂ (carbon) emissions

- ***The world 1990 carbon dioxide emissions, by fossil fuels, were 20,161 Mt (and the total equivalent CO₂ emissions 39,400 Mt)***
- ***For USA by (AEO2008 DOE of USA) the fossil fuelled carbon emissions will be increased by 22 % i.e. from 6,034 Mt for year 2010 they will be raised to 7,373 Mt for year 2030***
- ***For Europe the carbon emissions are estimated (weto-h2 report) to remain almost constant for the same period to 4,500 Mt or at the best scenario (carbon constrain scenario) to be decreased to 3,278 Mt***
- ***Globally the average scenario (weto-h2 report) predicts fossil fuelled carbon emissions for 2030 up to 38,750 Mt and the best carbon constrain scenario predicts the emissions to remain constant in ~29,000 Mt.***

However the best scenario is ~50 % higher than the (target) of 1990 carbon emissions

Why the results for global carbon dioxide emissions are so disappointing?

- The main reasons are:
- **Confusion on the choice of the proper electricity generating technologies**
- **Cost problems (IEA predicts a 45 trillion USD cost up to 2050)**
- **Geo-strategic problems**
- **Slow progress of Kyoto protocol policies**
- **A realistic assessment of the electricity generating technologies it is necessary in order to design a successful policy to eliminate the global warming threat**

The inevitable spread of electricity- Developed countries

- ***The use of electricity in developed countries it is increasing and it will continue to increase, due to penetration of electricity in all industrial applications and gradually in car transportation (clean electricity or Hydrogen)***

Main reasons:

- ***End of (cheap) oil and natural gas***
- ***Environmental pollution in the big cities***

The inevitable spread of electricity- Developing countries

- ***The spread of electricity in developing countries will continue due to the increased electricity participation in their industrial applications and introduction of electricity in their households and transport***
- ***Main reasons:***
- ***High rates of development in their industry (China, India)***
- ***Globalization pressure (improvement in standard of living)***
- ***Consideration of pollution problems in big cities***

The inevitable spread of electricity - results

- ***The world's economic development should be transformed in people's improvement in income and life quality***
- ***Only this result could secure long term world prosperity, peace and progress***
- ***Spread of electricity is a positive factor towards this aim***

How electricity can support the elimination of global warming threat

- ***Replacing fossil fuels with clean electricity in industrial, commercial and residential applications can limit carbon emissions in these sectors by 30-60%, or 6-11% of the overall energy carbon emissions***
- ***Efficient consumption in electrical devices and equipment, for household, services and for industry can limit the overall energy carbon emissions by 3-6 %***
- ***Introducing electricity in transportation (60-80%) i.e. replacing fossil fuels with clean electricity or Hydrogen produced by renewable technologies can limit carbon emissions by 6-8%***
- ***Bio-fuels for transportation is a transient and not a generally acceptable solution (in certain cases gasoline for rich instead of food for poor is true)***
- ***The electric transportation it will be the final and permanent solution at least for cars and trains***

How electricity can support the elimination of global warming threat

- ***Thus replacing fossil fuels with clean electricity in Industry, services, transport and residence with a parallel increase in the efficiency of end-use electricity we can limit the overall carbon emissions by 15-25%.***
- ***Replacing all fossil fuelled electricity generating technologies with zero carbon emissions technologies we can eliminate by 35 % the overall carbon emissions due to human energy activities***
- ***Thus introducing electricity in energy activities, as much as possible, and generating electricity with zero carbon emissions technologies, greenhouse gases can be decreased by by 50-60%***
- ***Electricity is not a threat but, under certain presuppositions, the main instrument for the elimination of global warming***

How much electricity (or equivalent Hydrogen) we need for transport ?

- *Taking into consideration that the gasoline cars in average they have efficiencies of 16% (theoretical 28%) the necessary electricity is approximately 16% of the equivalent KWh of the fuels spent in car transportation.*
- *Globally this figure for 2010 it is estimated to 1200 Mtoe or ~14000 TWh, thus the necessary electricity for electric transportation is 2200 TWh*
- *For year 2050 this figure will reach 5000 TWh (10 % of the electricity demand)*

Zero carbon emission electricity generating technologies-REN

- ***The Renewable technologies***
- ***Hydro electric (Large and Small)***
- ***Wind (Onshore and offshore)***
- ***Biomass (waste, farmed)***
- ***Solar Photo Voltaic (PV)***
- ***Geothermal***
- ***Solar Concentrating (parabolic through or Stirling dish and tower)***
- ***Wave and tidal***

Zero carbon emission electricity generating technologies-non REN

- ***Non Renewable technologies***
- ***Coal fired power plants with Carbon Capture and Storage (CCS)***
- ***New advanced nuclear fission power plants***
- ***Nuclear fusion***

The energy machines of the electricity generating technologies

All the electricity generating technologies, except Photo- Voltaic, are using the same basic types of energy machines i.e.:

- ***Turbines*** (steam turbines, gas turbines, water turbines, special fluid turbines, wind turbines and air turbines) and
- ***Electric generators*** (Synchronous or Induction)

An alternative option is the use of fuel cells.

Fuel cells can be used for electricity generation with hydrogen as fuel

- Usually hydrogen is generating by reforming natural gas (followed by CO₂ emissions)
- Clean hydrogen can be generated by renewable electricity technologies through electrolysis

Environmental problems related to electricity generation (1)

- **Emissions of CO₂** and other Green House Gases (like methane, CH₄ etc.), very dangerous for the earth's climate due to the greenhouse effect and Global warming

All fossil fuelled Power Plants

- **Nuclear radioactivity** (due to the operation of nuclear power plants or by accidents in them or in the process of handling of nuclear fuels or the remaining of used nuclear fuels and reactors)

The nuclear fission Power Plants

- **Emission of excess heat to the biosphere**
All fuel consuming Power Plants and Nuclear fusion

Environmental problems related to electricity generation (2)

- ***Pollution to local environment***
- Air pollution near the PPs (***Main example is the Coal fired Power Plant***)
- Escapes of pollution to soil or waters near the Power Plants (***Almost all fuel consuming Power Plants + Solar Concentrating power plants***)
- Thermal energy to nearby waters or sea (***Almost all fuel consuming Power Plants***)
- Noise (***Almost all fuel consuming Power Plants + onshore wind turbines***)
- Aesthetic “pollution” (***very subjective criterion but it is real***)

Environmental problems related to electricity generation (3)

- ***Disturbance to local animal and plant ecosystems***
- Large Hydroelectric Power Plants (***very large effects during construction***)
- Almost all fuel consuming Power Plants (***the usual industrial negative effects***)
- Wind turbines (***accused as rare bird killers***)

Quality of electricity (1)

- The electricity supply it is defined by the daily seasonal and annual demand profiles
- ***In order the electricity consumers to receive quality services, the electricity generation should cover always the electric power demand***
- The electricity generating technologies can be divided in the following categories in sequence of their quality and reliability:
- ***Continuous Base load*** (producing continuous and controlled electric power) **Coal fired, Nuclear (?), Geothermal, Biomass, Renewable Technologies with energy storage systems**
- ***Peaking*** (producing continuous controlled electric power in peak demand hours) **Natural gas, Hydropower (Load following, resource)**

Quality of electricity (2)

- **Intermittent class A** (Producing continuously during some hours per day, due to enhanced energy storage and source periodic reliability) **Concentrating Solar thermal with Thermal Energy System, and Solar PVs with batteries**
- **Intermittent class B** (Producing only if solar irradiation is above a threshold-reliable, without energy storage but periodic and reliable source) **Concentrating Solar thermal and Solar PVs**
- **Intermittent class C** (Producing when air speed or waves are above a limit and below another-unreliable non periodic source) **Wind, Wave**
- **As a general rule we can state that all kinds of electric KWh they are not the same and their generating power plants can not replace each other**

The cost of generated electricity (per KWh)

- ***The misleading KW in cost calculations***
- **Construction cost of electricity generating Power Plants per installed rating KW it is a misleading comparative figure between various technologies. The direct cost per produced KWh it is necessary to be used for comparison**
- ***The misleading consideration of the capacity factor***
- **The capacity factor (i.e. the annually produced KWh by the Power Plant divided by the rating power in KW and 8760 hours of the year) it can also be a misleading figure. In the capacity factor it is not included the quality of the produced electricity**
- ***Comparison costs per KWh can be done only for technologies that they can replace each other i.e. they generate electricity of the same quality***

The external cost

- **The external cost, although it is arbitrarily estimated, as **damage to the health of the people and to the environment**, it is also an important factor for consideration in the cost of KWh calculation**
- **All the CO2 emitting fuel consuming technologies and the nuclear Power Plants and some times renewable (like large hydroelectric Power Plants) have hidden external costs that they should be added to the direct costs**
- **If these external costs are added some renewable technologies (onshore wind) are cost prevailing to fossil fuelled technologies**
- ***The mechanism of Kyoto protocol it aims to make "objective" the external cost at least for the threatening carbon dioxide emissions through trading their rights***
- ***This mechanism it is not taking into consideration other types of pollution and their external cost. For example the external cost of nuclear pollution, of local pollution or heat emissions into the biosphere, it is not included in the Kyoto protocol***

“Clean” Technologies for unlimited and uninterrupted electricity supply

The following technologies can generate huge amounts of free carbon uninterrupted electricity:

- ❑ **Coal fired power plants with Carbon Capture and Storage** (10-20% emissions of ordinary coal fired)
- ❑ **New generation Nuclear Fission** power plants (10-30 % emissions in the preparation of Uranium)
- ❑ **Wind Parks** with energy storage system for uninterrupted electricity supply
- ❑ **Solar Concentrating** power plants with energy storage system for uninterrupted electricity supply
- ❑ **Solar Photo-Voltaic** power plants with energy storage system for uninterrupted electricity supply
- ❑ **Biomass** power plants (waste, farmed)
- ❑ **Nuclear Fusion**
- ❑ **Hydroelectric and Geothermal** are not included due to their limited production capabilities

Massive Energy Storage Technologies

(Uninterrupted operation of Renewable Technologies)

- Flow Batteries (sized up to 10 MW)
- NAS (Sodium Sulfur) batteries (sized up to 10 MW)
- (PHS) Pumped Hydro Storage (sized at 100's of MW)
- (CAES) Compressed Air Energy Storage (sized at 100's of MW)

The major problems of the “clean” electricity technologies

“clean” Technology	Major problems
<i>Carbon Capture and Storage (CCS) Power Plants</i>	<i>-The biggest problem of the CCS technology is to define the appropriate safe places for the geologic storage of CO2, to convince local communities and to achieve public acceptance that the storage is safe.</i>
<i>Nuclear fission power plants</i>	<i>-To define the proper places for the installation of the new power plants - To accommodate the nuclear waste - To avoid nuclear weapon diffusion - Their power plants emit thermal energy to the biosphere and demand water</i>
<i>Wind Parks (inshore or offshore) with energy storage system</i>	<i>Due to the unreliable source the energy storage system should be large and expensive</i>
<i>Solar Concentrating power plants with energy storage systems in deserts</i>	<i>-The solar concentrating mirrors demand a lot of water for cleaning and cooling (water is precious in desert areas) -Relatively high investment cost and direct cost of the produced KWh</i>
<i>Solar Photo-Voltaic power plants with energy storage systems in deserts</i>	<i>Very high investment cost and direct cost of the produced KWh</i>
<i>Biomass power plants</i>	<i>-Demands huge fertile lands (energy for the rich instead of food for the poor) -Spends a lot of energy</i>
<i>Nuclear fusion</i>	<i>-Method in experimental phase with dough full results -Emit thermal energy to the biosphere</i>

Increased cost of KWh produced by the “clean” electricity technologies

“CLEAN” ELECTRICITY TECHNOLOGY	KWh DIRECT PRODUCTION COST % OF EXISTING BASE LOAD AVERAGE KWh DIRECT COST (~ 6 cents)
<i>Carbon Capture and Storage (CCS) Power Plants</i>	135-160 % (8-10 cents)
<i>Nuclear Fission (New Power Plants 3500 EURO/KW)</i>	130-160 % (7.5-10 cents)
<i>Wind Parks (With Energy Storage System)</i>	140-160 % (onshore) (8.5-10 cents) 180-200 % (offshore) (11-12 cents)
<i>Desert Solar Concentrating Parks (With Energy Storage System)</i>	300-350 % (18-21 cents)
<i>Desert Solar Photo-Voltaic Parks (With Energy Storage System)</i>	500-550 % (30-33 cents)
<i>Biomass Power Plants</i>	100-150 % (6-9 cents)
<i>Nuclear Fusion</i>	- Non yet defined but most probably very high (>1000 %) (>30 cents)

A resume of the proposals for electricity in order to limit global warming threat

- ***Support and increase end-use electricity appliances efficiency***
- ***Introduce and develop electric vehicle technology***
- ***Replace when possible coal fired power plants with natural gas power plants. The natural gas Power Plants are producing almost half of the carbon emissions for equal electricity KWh generation (Geo strategic problems some times decelerate these decisions)***
- ***Replace existing nuclear reactors with more advanced light water nuclear reactors***
- ***Introduction of new nuclear PPs only after careful study, public acceptance and considering the nuclear weapon proliferation.***
- ***Test and start the gradual application of Carbon Dioxide Capture and Storage technology for coal fired power plants***
- ***Increase the renewable participation in the electric grid using advanced management technologies for the grid and unification policies of state grids.***
- ***The non hydropower renewable participation technologies (wind, solar, wave) should exceed 15% in the grid***
- ***Use wise non food biomass technology for electricity generation (waste, cellulose biomass)***
- ***Replace in all appropriate industrial procedures the non electric energy devices with clean electricity driven devices***

The Kyoto Protocol adoption

- *The Kyoto protocol rules, should be adopted by all nations immediately*
- ***USA, China and India** should enter to the treaty as soon as possible*
- *This will give a higher boost towards the elimination of global warming threat*
- *A more advanced treaty, that will replace Kyoto treaty, it is necessary to be prepared and agreed as soon as possible by the international community*

Applying all these policies is it possible to eliminate the global warming threat?

- ❑ ***By the official USA and EU projections for the best scenario this is not possible***
- ❑ ***Considering the carbon emissions time variation diagram, even for flat carbon emissions curve, the situation for earth's anthropogenic climate change looks inevitable***
- ❑ ***In order to mitigate or eliminate global warming threat an ideal electricity generating technology is necessary***

The Ideal electricity generating technology (1)

- ***An ideal solution to stop or limit the climate change process below any safe threshold it should be based on a carbon free electricity generating technology that could supply the projected fossil fuelled generated 50% of electricity demand, including electricity for transportation***

The Ideal electricity generating technology (2)

- ***The ideal electricity generating technology should have the following characteristics:***
- ***Continuous high quality electricity generation***
- ***Simple technology that can be applied in all continents***
- ***Low construction cost of its Power Plants and low direct cost of the produced KWh***
- ***Easy and fast deployed technology, based on existing material and using local personnel for construction, operation and maintenance of its Power Plants***
- ***Zero CO2 emissions and any other forms of pollution***
- ***Zero water demand***
- ***Zero thermal energy generation to the biosphere***
- ***Recycling construction material***
- ***Originated from renewable source (better Solar) in order to secure sustainability***

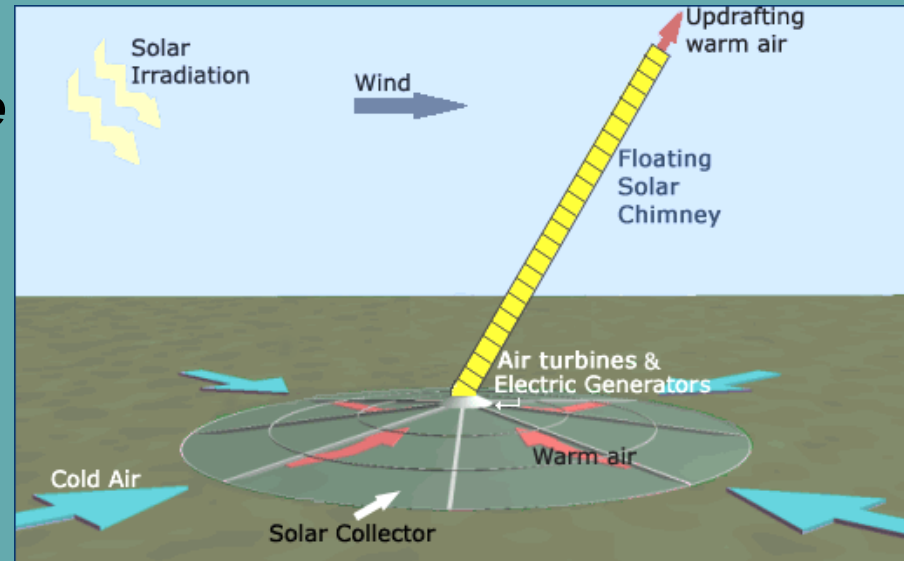
Solar Aero-Electric power plants (SAEPPs) with Floating Solar Chimneys

- Is there an ideal electricity generating technology?
- The reply is almost yes!!
- **The technology of Solar Aero-Electric power plants with floating solar chimneys is very close to the ideal technology**

Indicative picture of a Solar Aero-Electric power plant with Floating Solar Chimney

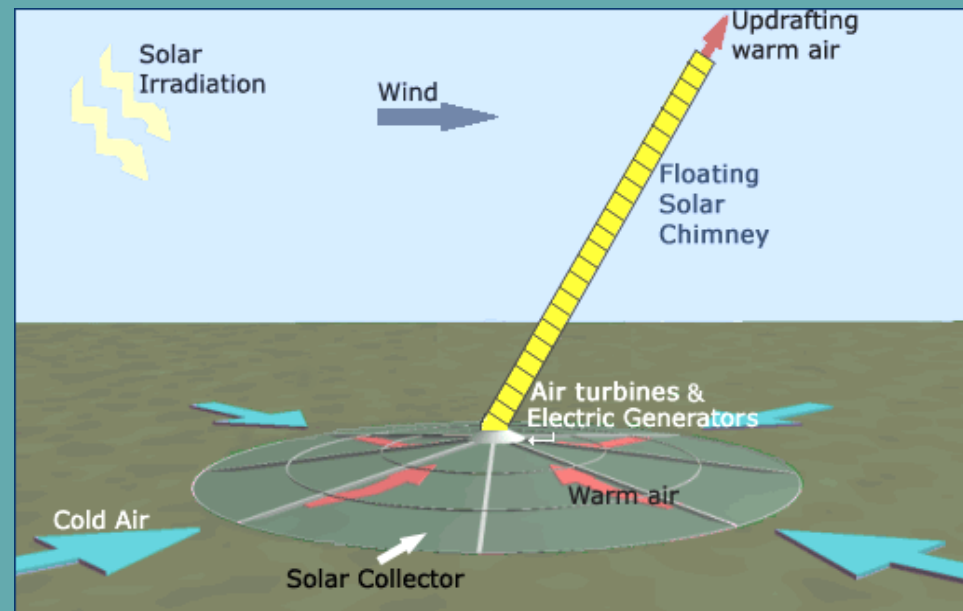
A SAEPP is made of three components:

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



How SAEPPs are operating

- **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**

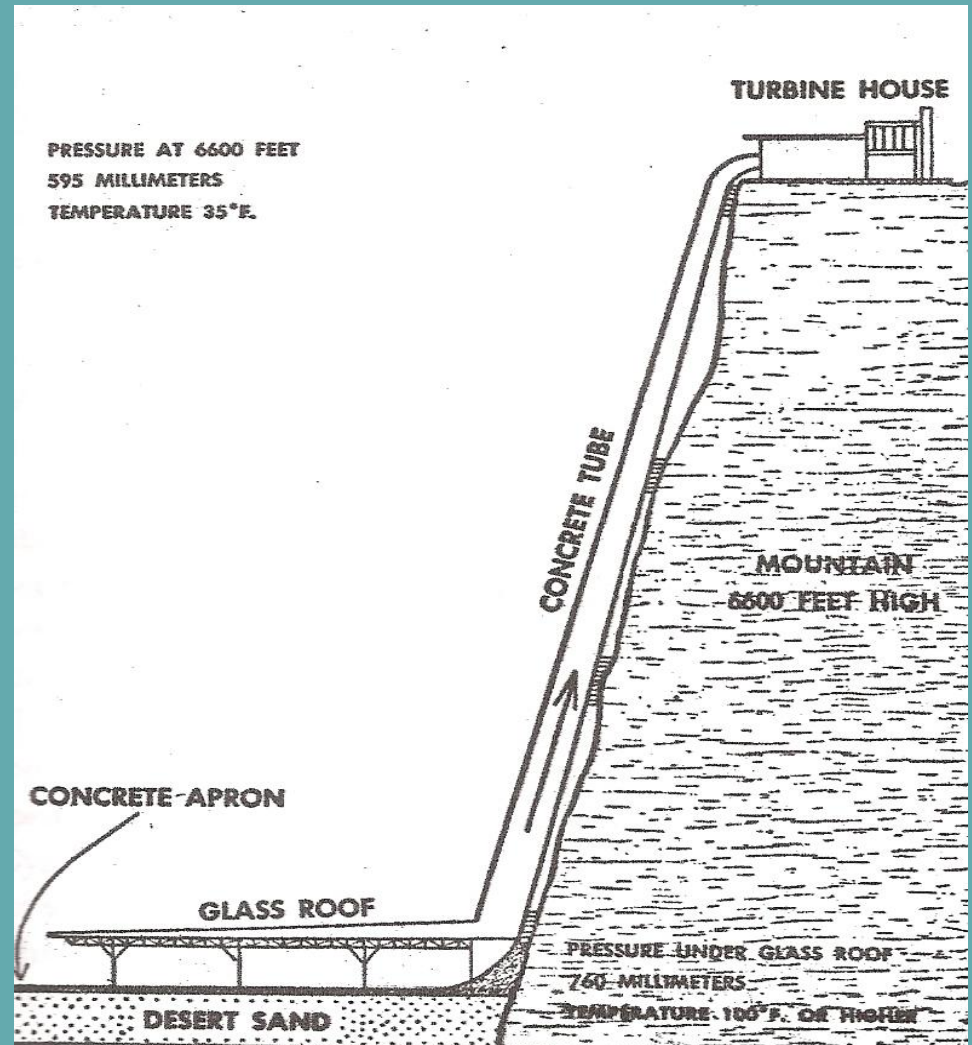


Solar Aero Electric Power Plants' similarity to Hydro Electric Power Plants

- **SAEPPs are similar to “Hydro-Electric” Power Plants**
- **That is why I named them “Solar 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)**

History (1)

- 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



History (2)

- Prof Dubos proposal was soon abandoned as very costly
- Later in 1982 with the financing of German government,
- Prof Engineer J. Schlaigh built a small prototype of a solar Aero-Electric power plant of 50 KW in Manzanares of Spain
- The solar chimney was 196 m high, with internal diameter 10 m
- The greenhouse area was 45.000 sqm
- The prototype was operating successfully for 6 years

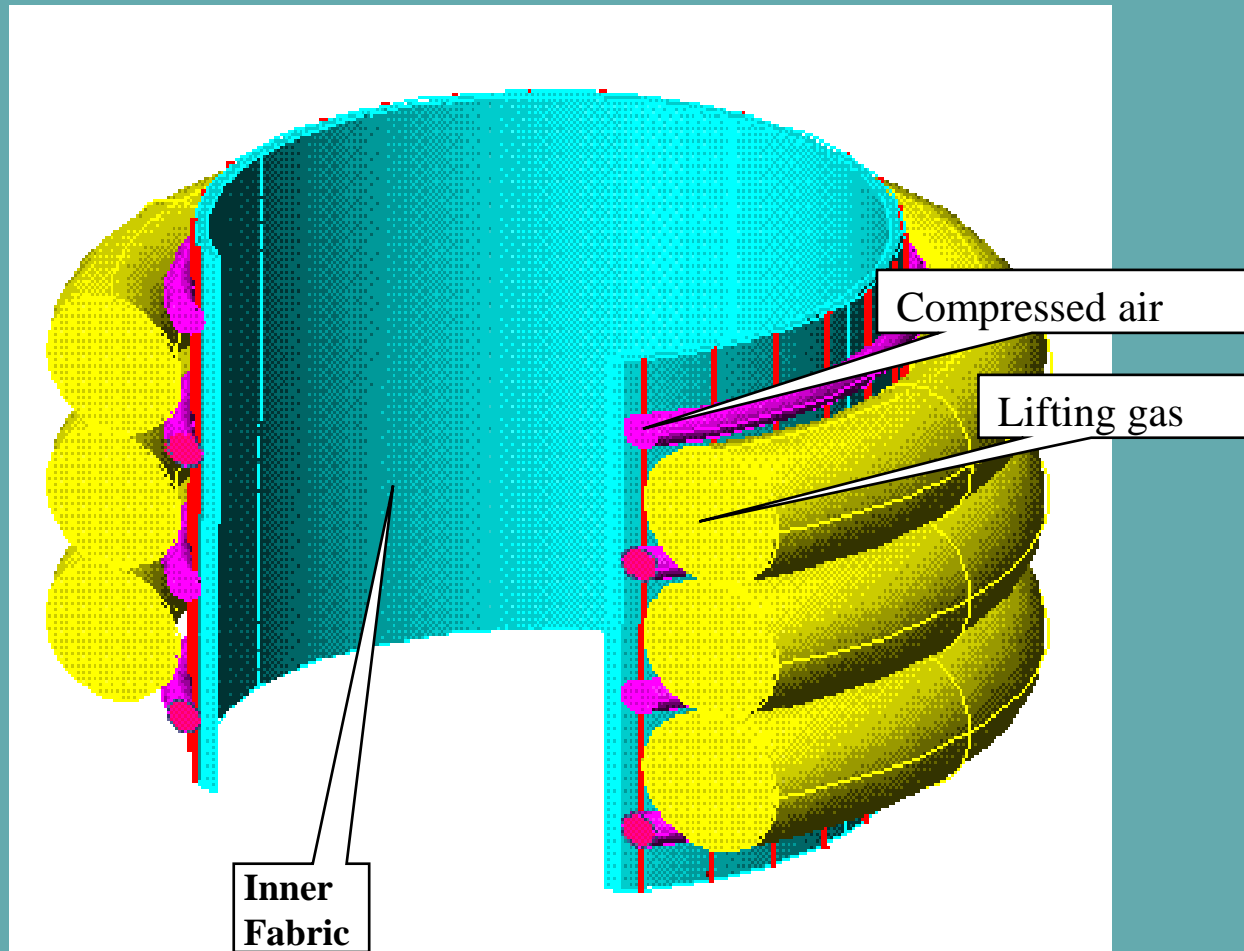


History (3)

- Prof J.Schlaigh proposed to build Solar Aero-Electric power plants with reinforced concrete solar chimneys of heights (500m-1000m)
- In 2002 this simple solar technology was attracted my attention, however I realized that the tall concrete structures (beyond the problems of earthquakes) will be of high cost, that could be a large obstacle towards the large scale application of the solar chimney technology .
- In 2003 I proposed the replacement of the concrete solar chimney with a low cost alternative. A lighter than air fabric structure, free standing and inclining by the external winds.
- Due to its patented construction this Floating (in the air) Solar Chimney can encounter external winds and operating sub pressures, executing its operational duties effectively

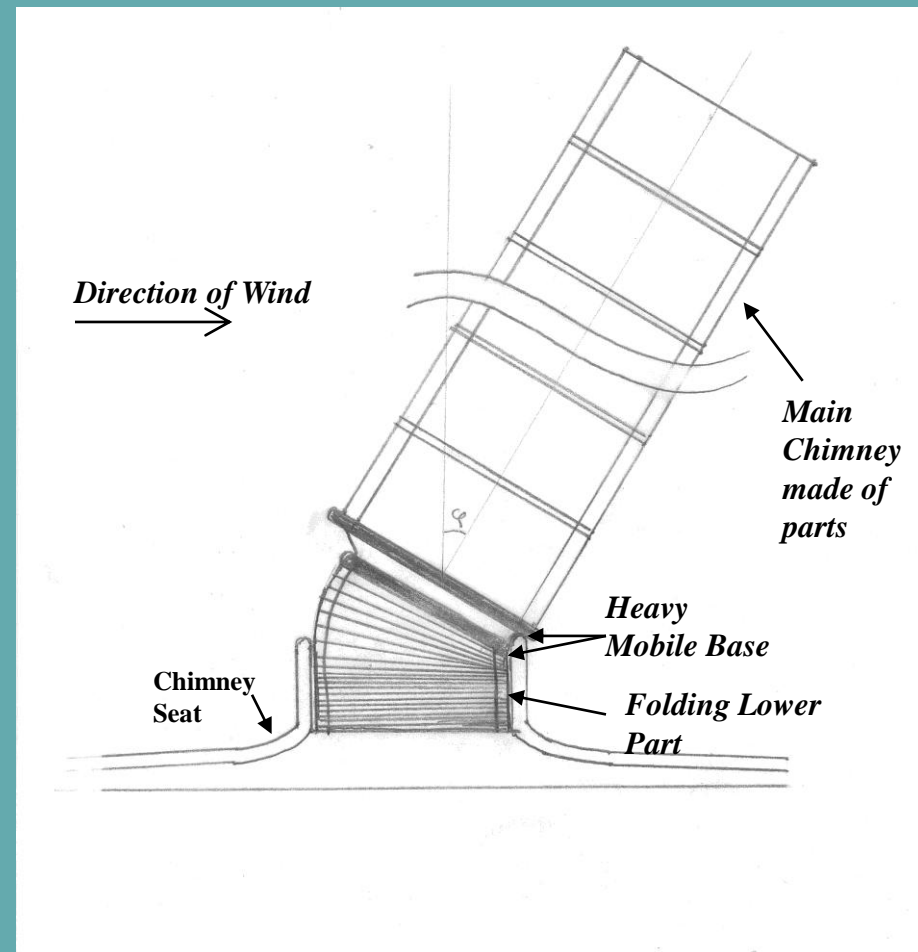
The Floating Solar Chimney

- **The Floating Solar Chimney is made by a set of successive fabric tubular balloons as shown in the figure beside**
- **These tubes are lighter than air due to internal balloons filled with lighter than air gas (He or NH₄)**
- **The tubes are kept over pressed in order to maintain their shape and their necessary rigidity**

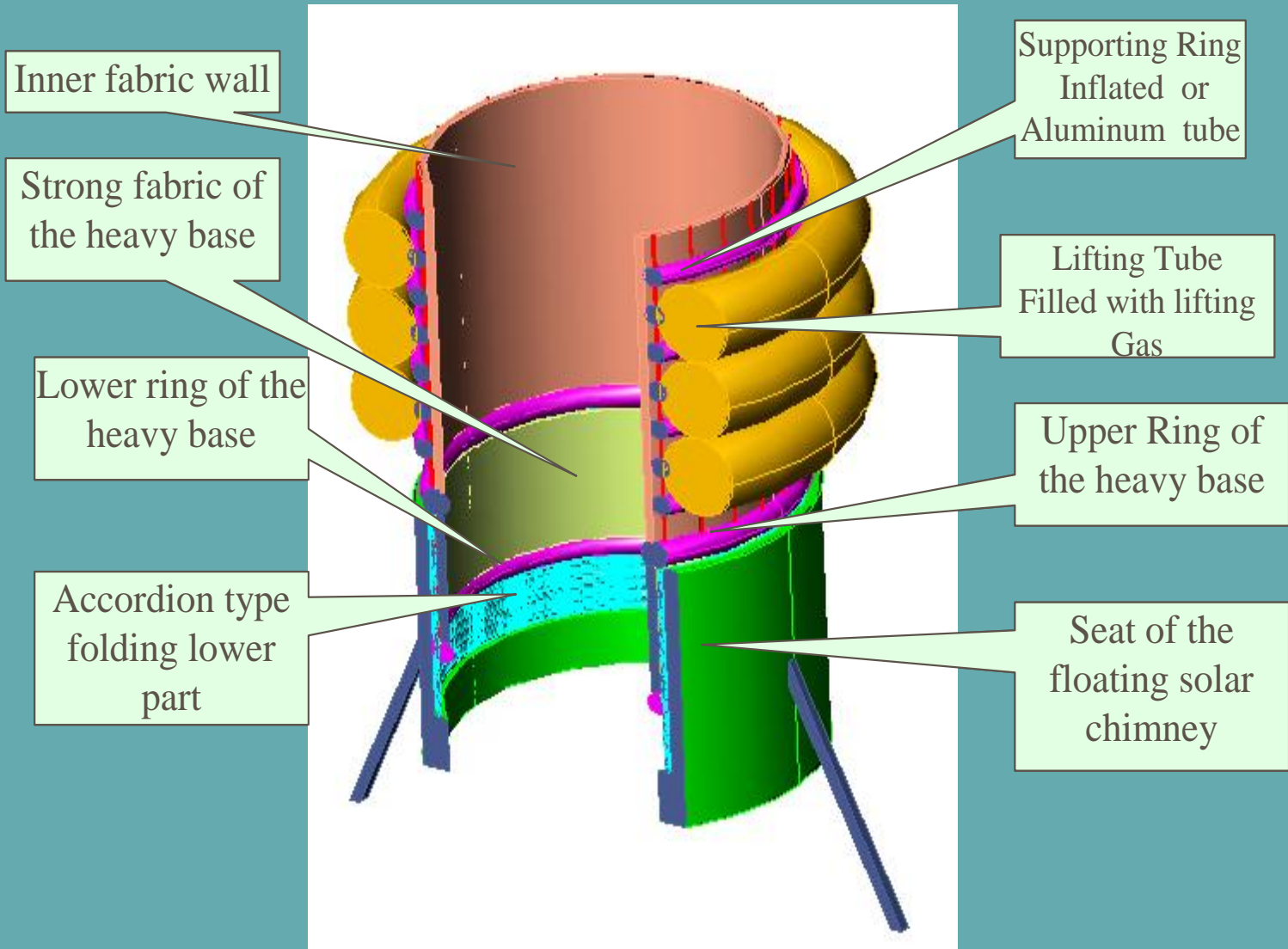


Indicative diagram of the Floating Solar Chimney under external winds

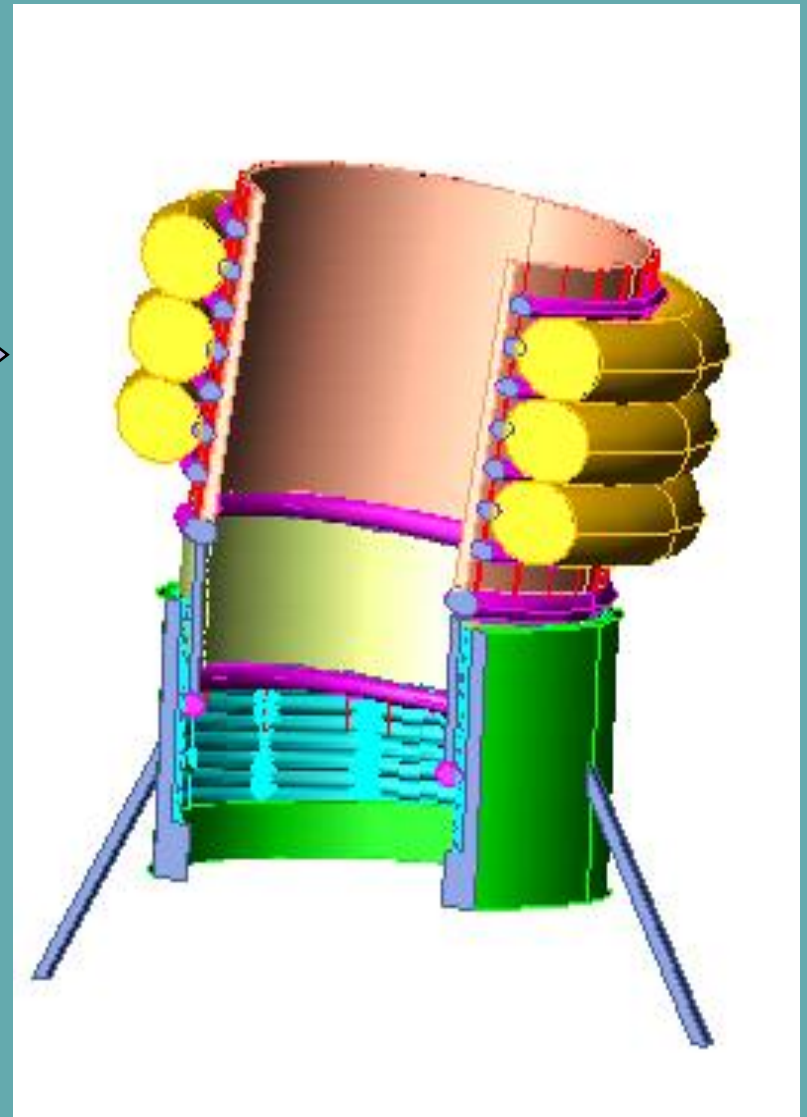
- The main body of the floating solar chimney is a lighter than air, warm air up drafting cylinder made of a set of successive tubular balloons filled with lighter than air gas (He, NH₃).
- This air up drafting cylinder is made of successive parts attached separately to a heavy inclining base with an 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.



The seat, the heavy base and a small part of the Floating Solar Chimney

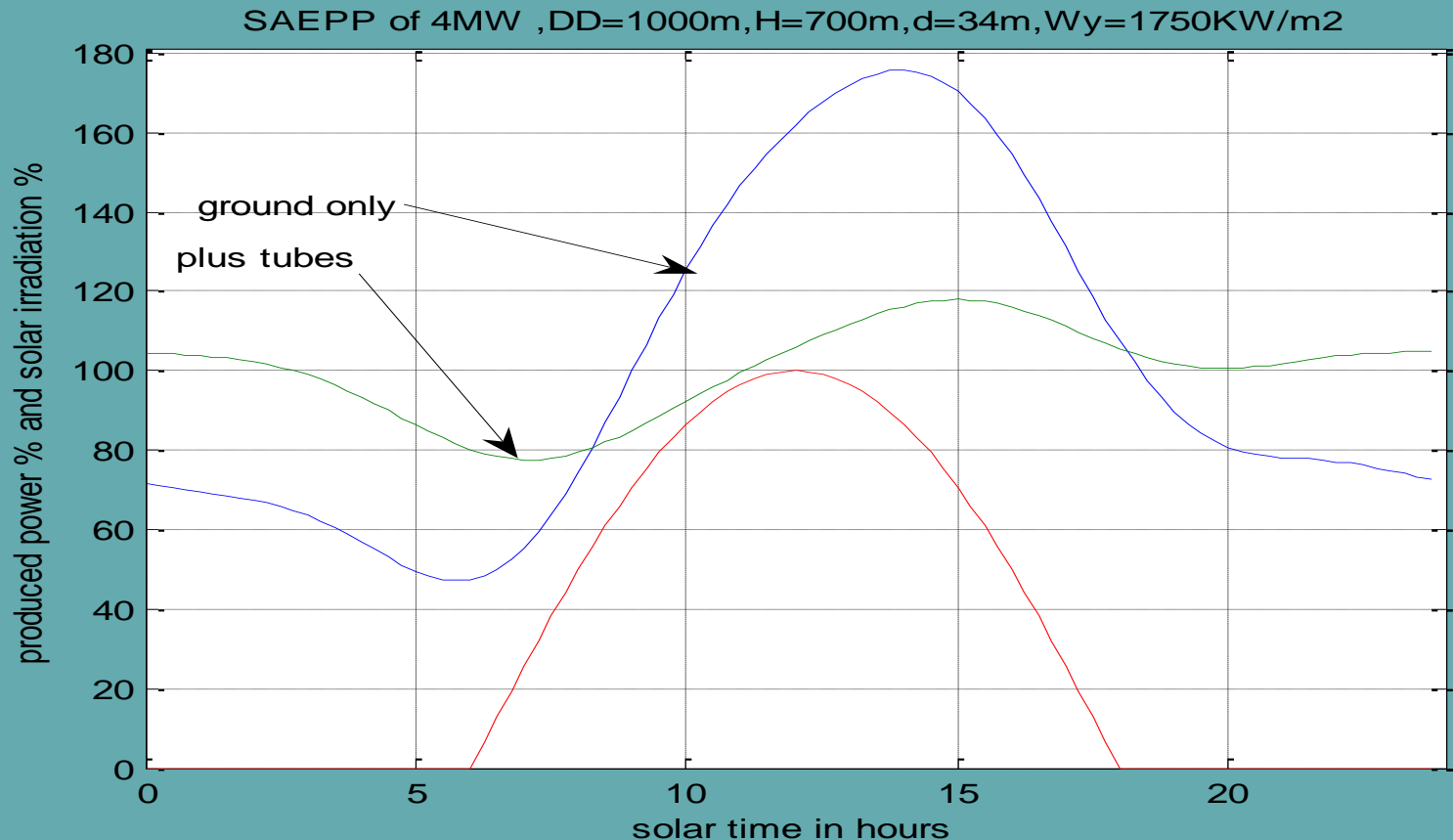


The body with the heavy base of the Floating Solar Chimney is inclining due to external winds



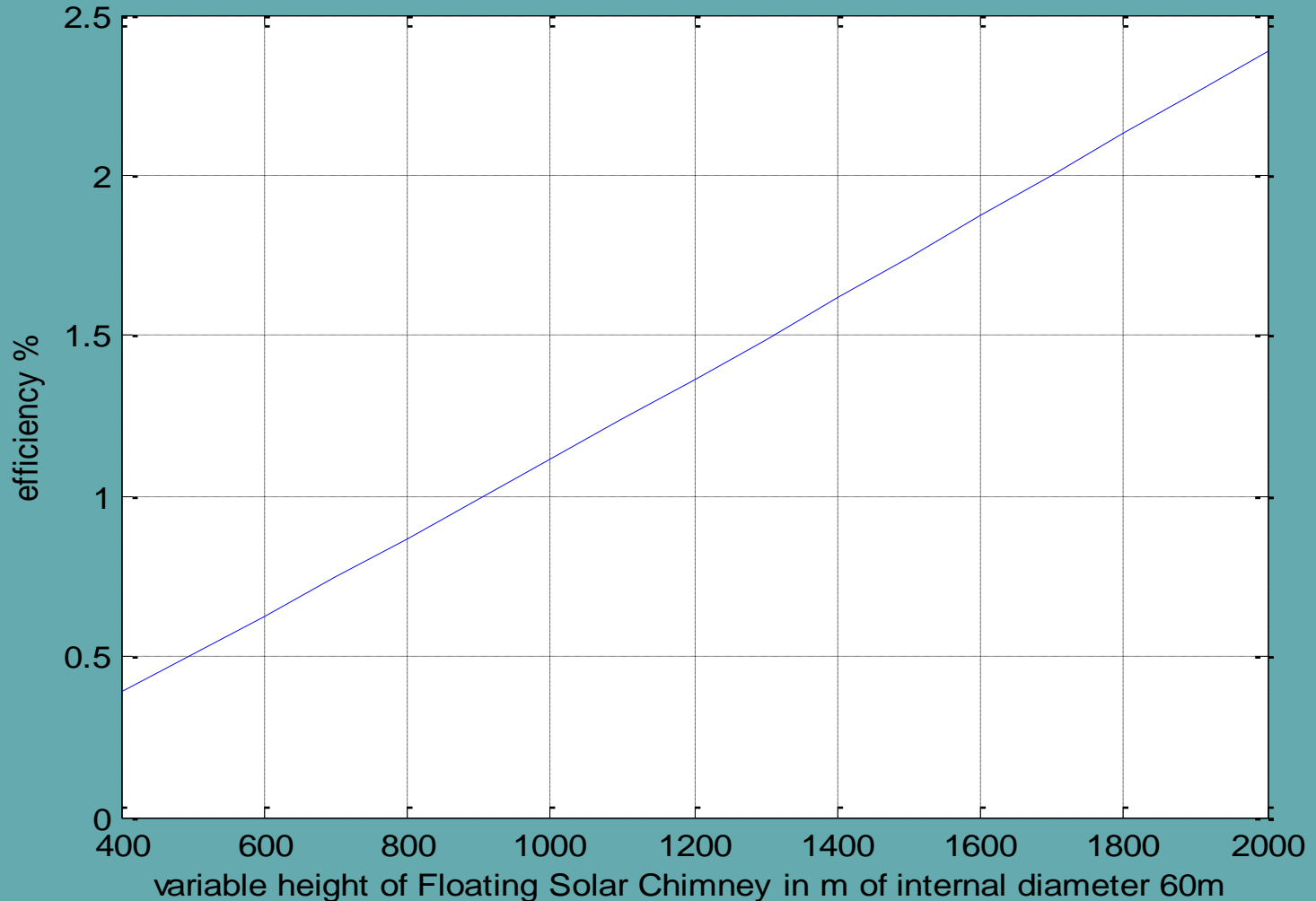
Solar Aero-Electric power plant daily operation due to thermal storage effect

- Ground only (blue)
- Ground plus artificial thermal storage (green)
- Solar irradiance % (red)



Efficiency as function of the solar chimney height

SAEPP of 4sqKm solar collector in a place of annual solar irradiation 1750KW/sqm



The operational behavior of a Solar Aero-Electric power plants with Floating Solar Chimneys of 400m -1000m

- Their efficiencies (for heights 400m-1000m) are approximately 0.45% - 1.25%, night operation is included
- With artificial thermal storage the Solar Aero Electric power plants' capacity factor can be up to 55% (Ground only up to 35%)
- This means that their annual energy production in KWh can be found as a product of their rating power in KW by 4800 h (ground only 3200 h)
- With artificial thermal storage, their average power production is approximately half of their rating power that should be equal to the higher power achieved in summer noon.

The Floating Solar Chimney technology the main characteristics (1)

- ❑ The technology is very simple and can be applied in all continents using local personnel
- ❑ Due to the ground thermal storage (reinforced if necessary with artificial thermal storage) they are generating continuous electricity power profiles of which their daily averages are proportional to the daily solar horizontal irradiation (direct and diffuse). A 24hX365days annual operation is achieved
- ❑ It is a low investment cost electricity generating technology
- ❑ Its power plants can be maintained and operated by local personnel everywhere
- ❑ The construction material of its power plants is already exist and all of them are recyclable
- ❑ The direct production cost of KWh is low (less than 6EURO cents/KWh maybe not for the first demo power plant but definitely for the next)
- ❑ Its power plants can be deployed very quickly
- ❑ The technology it is not diffuse any thermal energy to the biosphere

The Floating Solar Chimney technology the main characteristics (2)

- ❑ The technology it is not producing CO₂ or any other pollution to the local or global environment
- ❑ The technology does not demand any cleaning or cooling water
- ❑ Due to its solar origin the technology is securing sustainability
- ❑ The best lands for the technology application are the desert or semi desert areas where the horizontal annual solar irradiation exceeds 2200 KWh/sqm
- ❑ With a small part (3%) of these desert lands we can cover above 50% of the present and future demand in electricity
- ❑ Hence the technology does not compete for land with agricultural production
- ❑ If more fertile land is going to be used (for example in Cyprus ,Greece, Spain, Italy, etc.) most of the ground below the power plant greenhouses can be used for farming
- ❑ The technology can be used (project under research) for water desalination

Covering the missing 50% of world “clean” base load electricity

- The annual electricity demand is (year 2008) ~20.000 TWh
- A respectable part of the produced ~28 billion tons CO₂ is coming from fossil fueled electricity generating technologies
- The annual electricity demand will be doubled in the next 30 years. In 2040 the estimated electricity demand is ~45.000 TWh
- The electricity generation by “clean” technologies it is not estimated to be more than 50%
- A large scale application of the Floating Solar Chimney technology could generate the missing 50% of electricity demand, cost effectively, eliminating furthermore the global warming threat

The necessary investments in the FSC technology for the 50% electricity generation

- A cost effective choice, in order to minimize CO2 emissions, is to build, for the next 30 years, and for every year, SAEPPs with Floating Solar Chimneys of overall rating power 160 GW, that will produce annually >750 TWh
- The investment cost for this choice will not exceed the amount of 380 billion EURO/year or 11.5 trillion EURO for the next 30 years
- These investments in electricity generation are necessary taking into consideration that the investment cost, in any reasonable mixture of fossil fueled technologies, for the same electricity generation is almost similar
- The IEA is estimating the climate change policies cost in 45 trillion USD !!!
- The necessary land for the 30 years FSC power plants is 1.000.000 sqKm (1000 Km X 1000 Km)
- This land is only 3% of the desert unused land estimated to 36 million sqKm

Major reference sources

- **An excellent presentation of the climate change and the mitigation policies is given in the documents of Intergovernmental Panel on Climate Change (IPCC)**
- **IPCC information through key word IPCC <http://www.ipcc.ch>**
- **EU information through the key words EU energy <http://www.energy.eu>**
- **USA information through the key word DOE USA <http://www.doe.gov>**

That was all !!!!

Thank you for your
attention!!!