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# What Future for Energy and Climate?

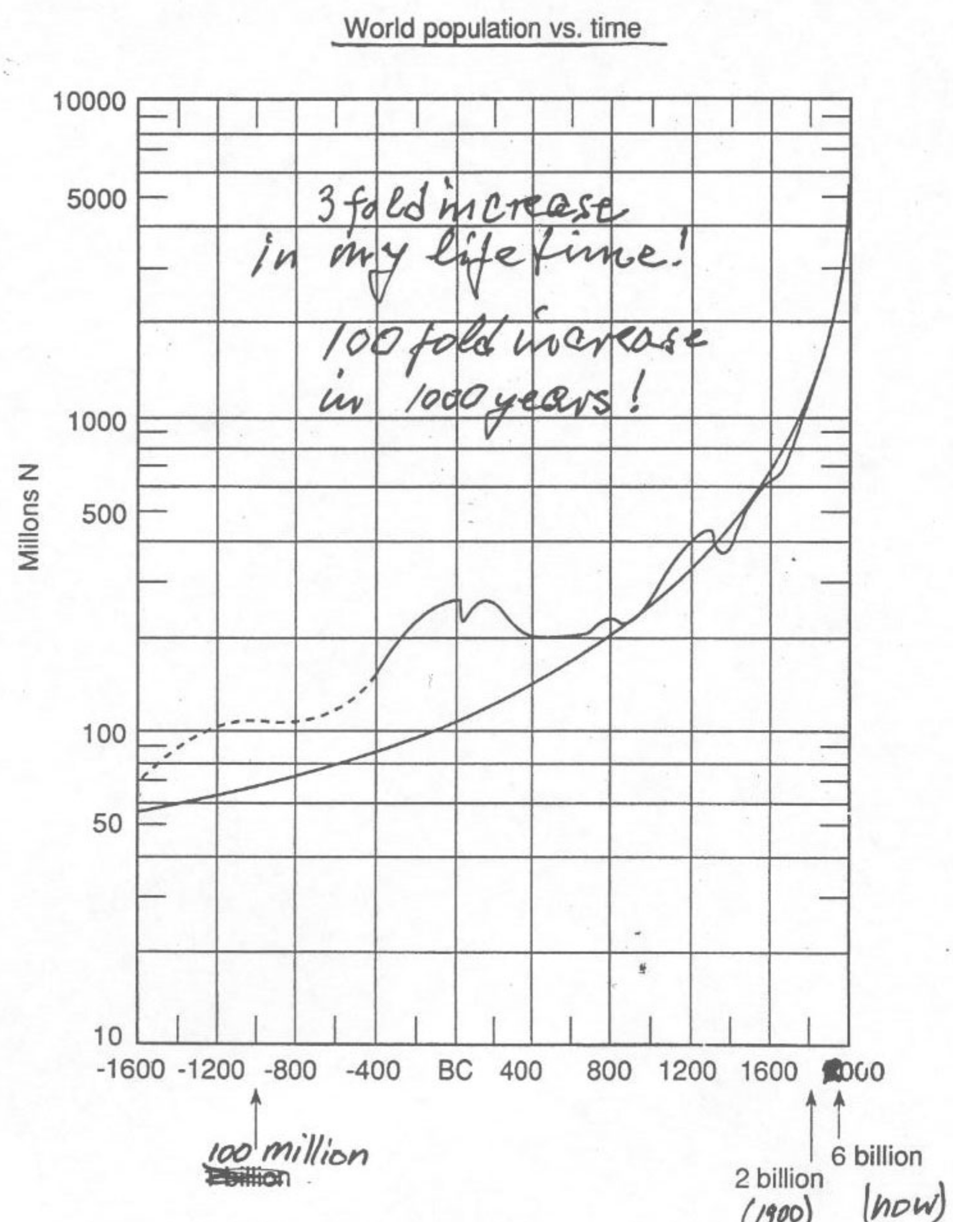
## Possible Mitigation of Disaster:

## Thermal Solar Electric Power

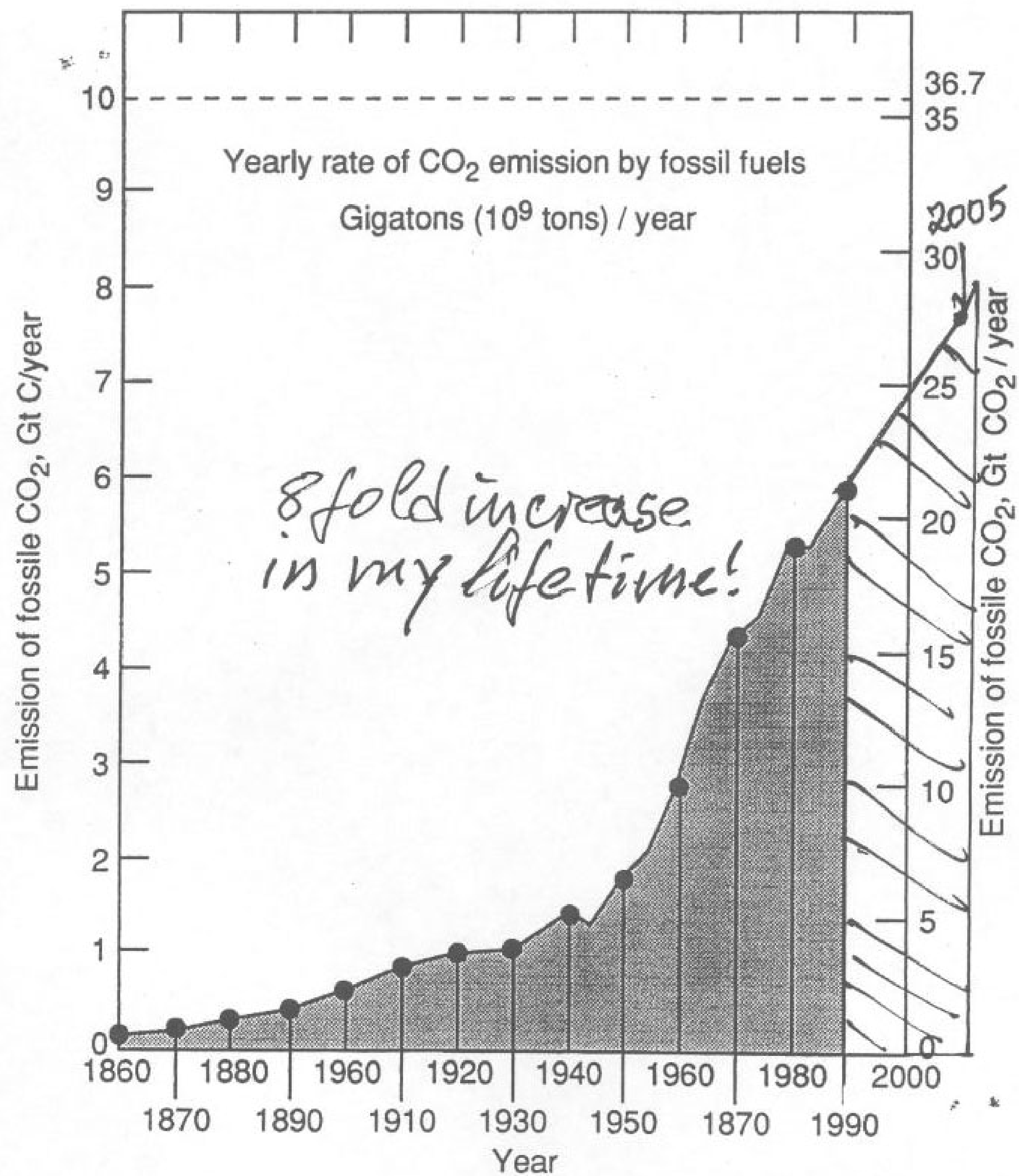
Abstract:

*If we want to leave some fossil fuels to our children, and limit the serious threats to our society posed by global warming, it is high time to pursue the use of renewable energy much more vigorously than is the case at present. Assuming present consumption and present yearly increase in consumption, the presently known, readily accessible fossil fuel resources will be exhausted in 60 years. Given that there is no known technology to store electrical energy, by far the best possibility for energy production without fossil fuel use is thermal solar in the worlds deserts, with overnight thermal storage. This should be the clear focus for energy without fossil fuels.*

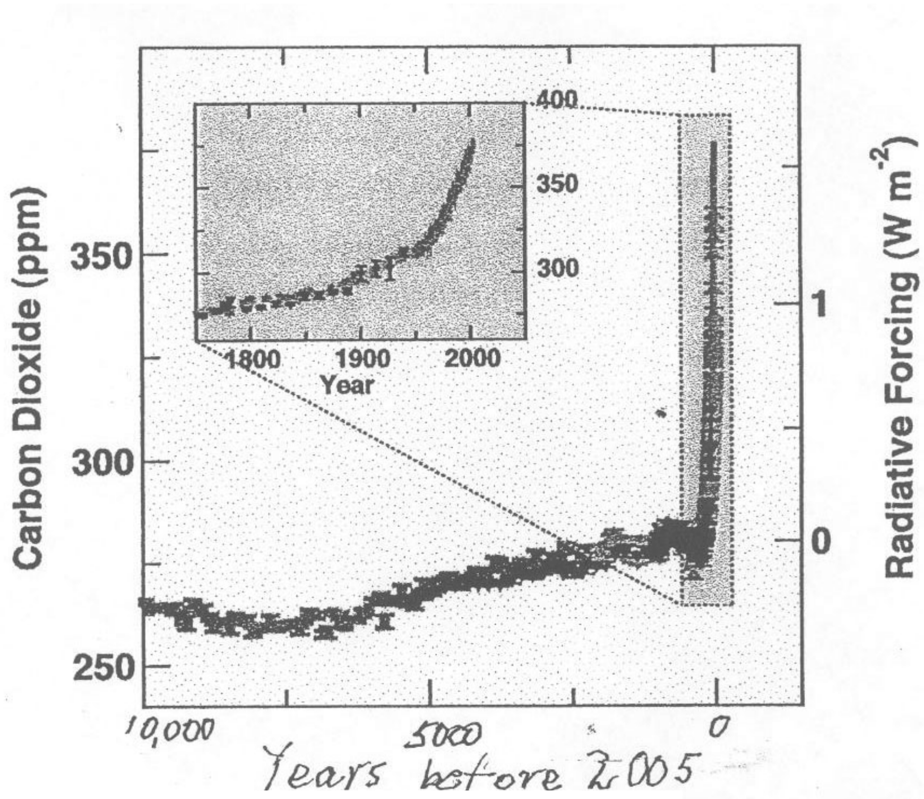
In my lifetime, the **population** of the planet has **grown 3 fold**, from 2 billion to 6.6 billion.

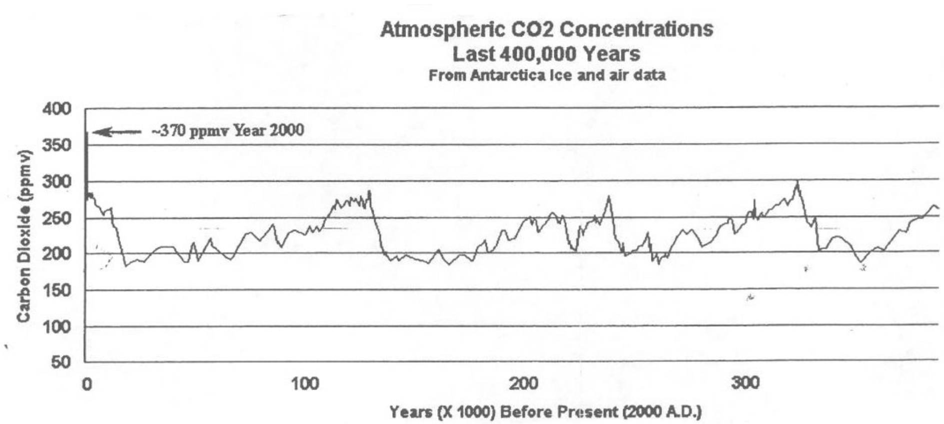


In my lifetime, global **energy** use and **GHG** production have **increased 8 fold**.



Since the beginning of the industrial age, atmospheric $CO_2$ has **risen** from **280 ppm** to **380 ppm.**

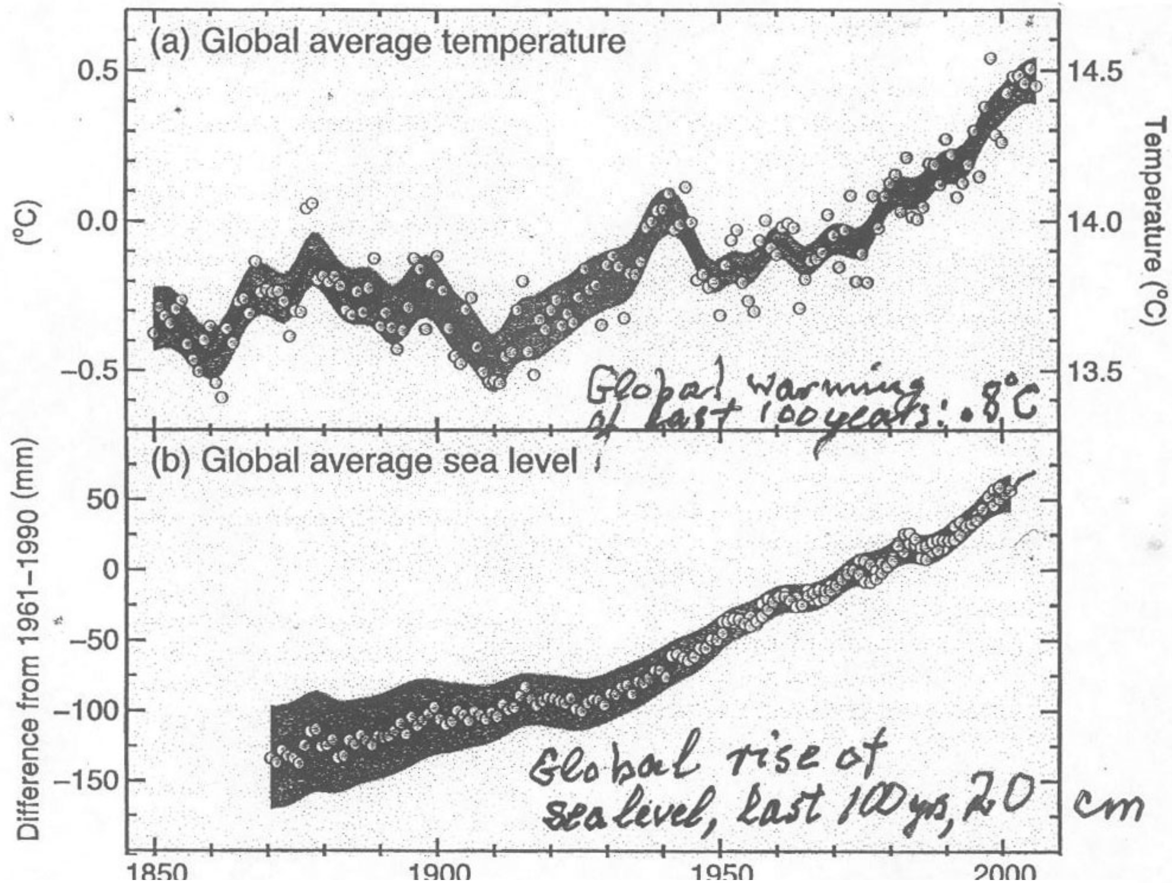



$CO_2$ concentrations during 400,000 years of ice ages, from ice cores. Note the larger variation during the last 100 years!

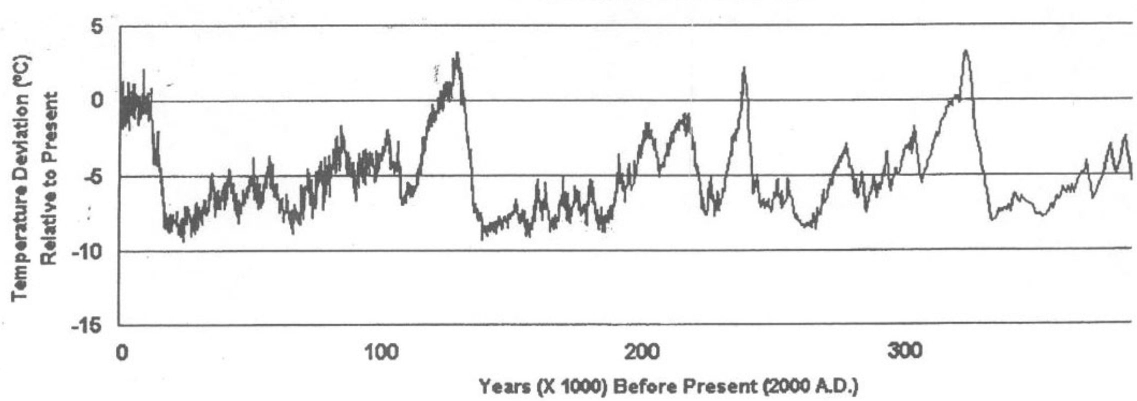
The temperature has risen ~ .8$^0$C.

The sea level Has risen 20 cm




For comparison, temperature fall during ice ages was ~10$^0$C

**Temperature of Lower Atmosphere**
**Last 400,000 Years**
From Antarctica ice and air data



# Growth of energy consumption in 30 years, by regions.

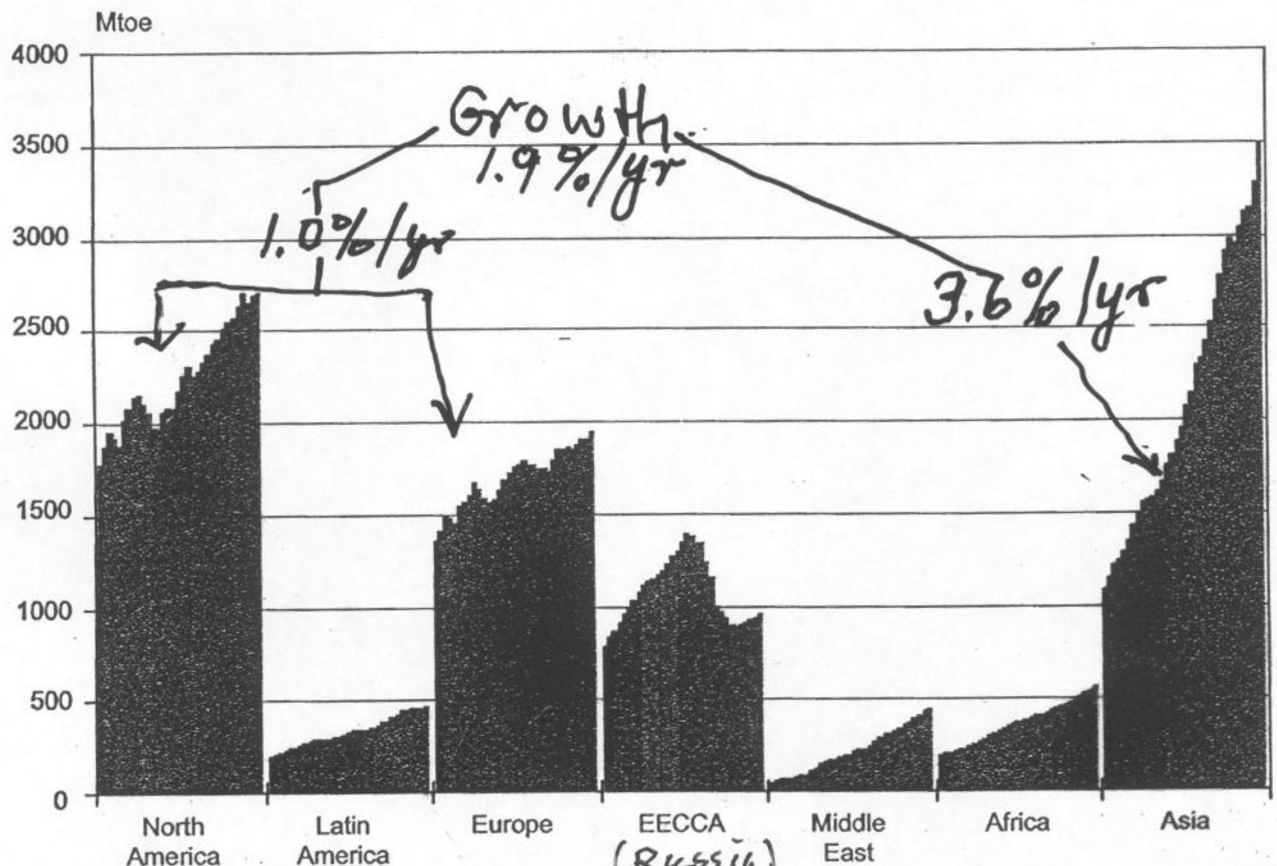



***Figure TS.12:** Annual primary energy consumption, including traditional biomass, 1971 to 2003.*
*[Figure 4.2].* IPCC (2007)
*Note: EECCA = countries of Eastern Europe, the Caucasus and Central Asia. 1000 Mtoe = 42 EJ.*

| | | | |
|---|---|---|---|
| **Energy use by sector:** | Electricity | | 37% |
| | Transport, | road | 15% |
| | | air | 4% |
| | | sea | 1.5% |
| | Industry | | 23% |
| | Buildings | | 20% |

| | | |
|---|---|---|
| **Present energy sources:** | oil | 34% |
| | natural gas | 21% |
| | coal | 25% |

**(all fossil fuels, combined, 80%)**

| | | |
|---|---|---|
| | renewable, combustible | 11% |
| | nuclear | 7% |
| | hydro | 2.3% |
| | wind | 0.5% |

# How Long will Fossil Fuels last?

Assume present population growth of 1%/a, per capita energy use growth of 2.5%/a:

| | known low cost reserves (EJ =$10^{18}$joules) | lifetime |
|---|---|---|
| oil | 7,500 | 30 years |
| natural gas | 7,500 | 35 years |
| coal | 27,000 | 60 years, |

(assuming coal is used to replace exhausted gas and oil)

After these 60 years,

the atmospheric $CO_2$ level would be ~700 ppm,

the temperature rise perhaps $6^0$C,

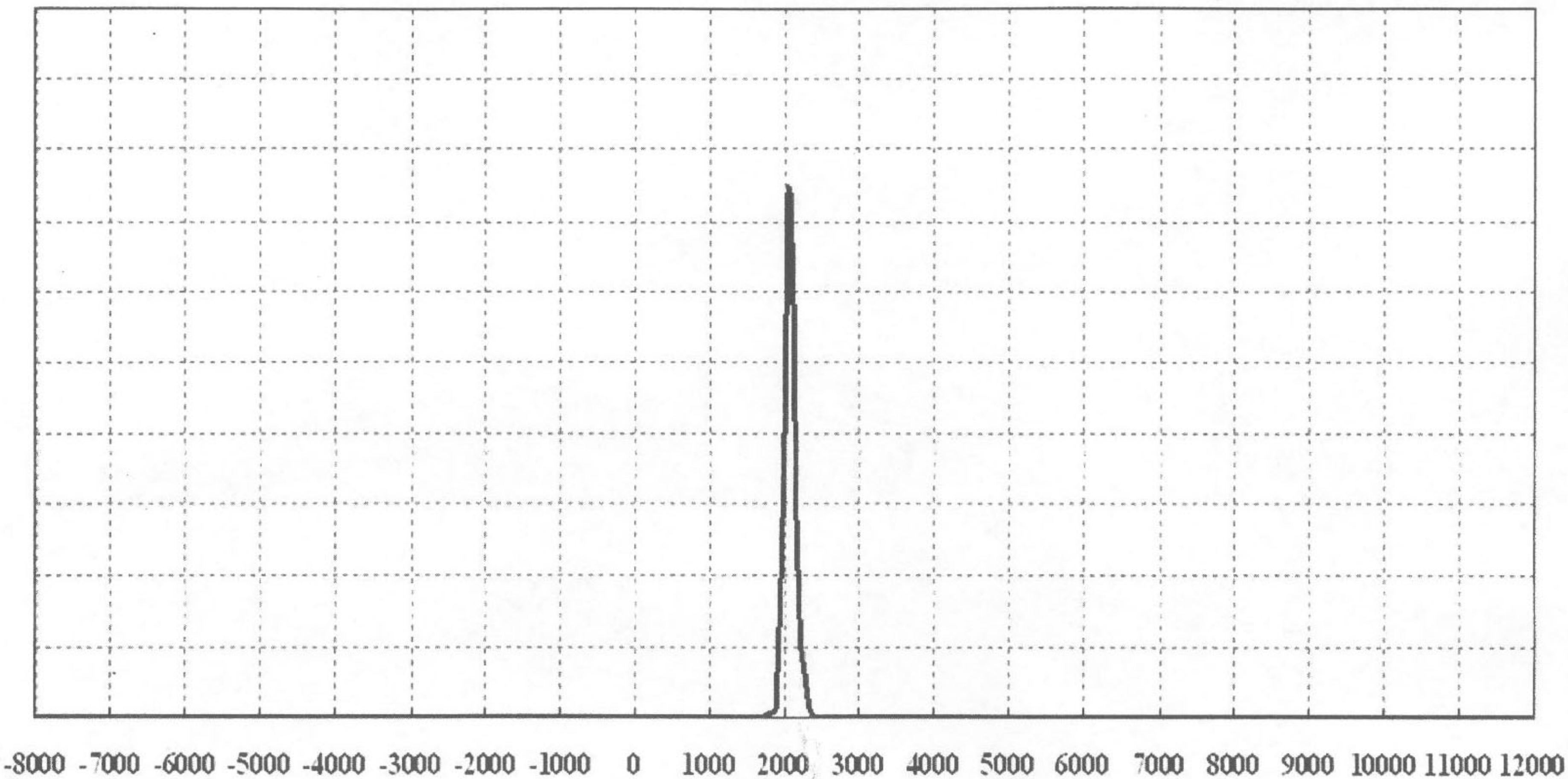
the sea level rise perhaps 5 m.

The main disaster regions would be in Africa and Asia.

What would be the consequent migrations? Bloody conflicts?

# Fossil Fuel Use

A brief moment in our planet's history.




Year

courtesy, Chris Llewelyn Smith

**Can catastrophe be avoided?**

Yes, but this requires a global response, much more concerted than is the case now.

It is already late! Steps to take:

- Reduce birthrate → decrease population.
- Reduce consumption in developed world. *We can be just as happy consuming a lot less*.
- Increase energy efficiency (buildings, etc.)
- Replace fossil fuel use with sustainable energy. This is most difficult in the transportation sector, I am skeptical of the use of biofuels because of tensions on food supply.

# Without fossil fuels, what will be the source of energy?

| | | | |
|---|---|---|---|
| Combustibles | now | 11% | All three are fine, but only limited increase is possible. |
| Hydro | “ | 3% | |
| Geothermal | “ | <.5% | |
| Nuclear | “ | 7% | Better than fossil, but certain problems. |
| Wind | “ | .5% | Economic, but wind blows < .4 of time. |
| Photovoltaic | “ | <.1% | Expensive, and no sun at night. |

Wind and photovoltaic produce electricity directly, but no economically viable method for storing electricity is known.

| | | | |
|---|---|---|---|
| Thermal solar with overnight thermal storage | “ | .1% | In the desert, the sun shines 95% of days. A few % of world’s deserts can supply the global demands. |

**<u>Thermal solar, with overnight thermal storage</u>, is the outstanding source of energy of the future. Remaining problem: What to do on the 5% of the days the sun does not shine in the desert?**

# Economic and political challenges.

Global equity for energy use, rich ↔ poor countries.

Mitigation requires reduced consumption, our market economy pushes increasing consumption. UK Stern Report: "…the greatest and most wide ranging failure of markets ever seen". "Benefits of strong, early action outweigh costs."

Carbon tax: $ 100/ton $CO_2$ , corresponding to ~ 2% of global income, would have big effect on electricity production, and building construction, less on transportation.

Difficulty of rapid change: power plants last 30 years, buildings 100 years.

Need for regulation: e.g. in building constructions.

Need for monitoring.

**Biggest challenge: world wide political will and collaboration.**

# Thermal Solar Electric Power from Deserts, with Overnight Storage.

Requirements:

1) Large fields of concentrators: parabolic troughs, heliostats or fresnel mirrors, with reflecting surface ~7 $km^2$/Gw, total desert area about 20 $km^2$/Gw.  A few percent of the world's desert can supply the total energy need.
2) Thermal fluid "vector" working at a high temperature, to collect the energy and transfer it to the thermal storage or to the steam turbine.  Current fluid vectors are oil, $T_{max} \sim 400^0C$, or a molten mixture of salts, with $300^0C < T < 500^0C$.  A prominent proposal for future plants is direct steam.
3) Thermal storage reservoirs sufficient to last through the night. Present storage material is the same molten salt, 30 Ktons for a 50 Mw plant.
4) A conventional steam power turbine.
5) DC transmission lines for the thousands of kilometers, from the deserts to the rest of the world.

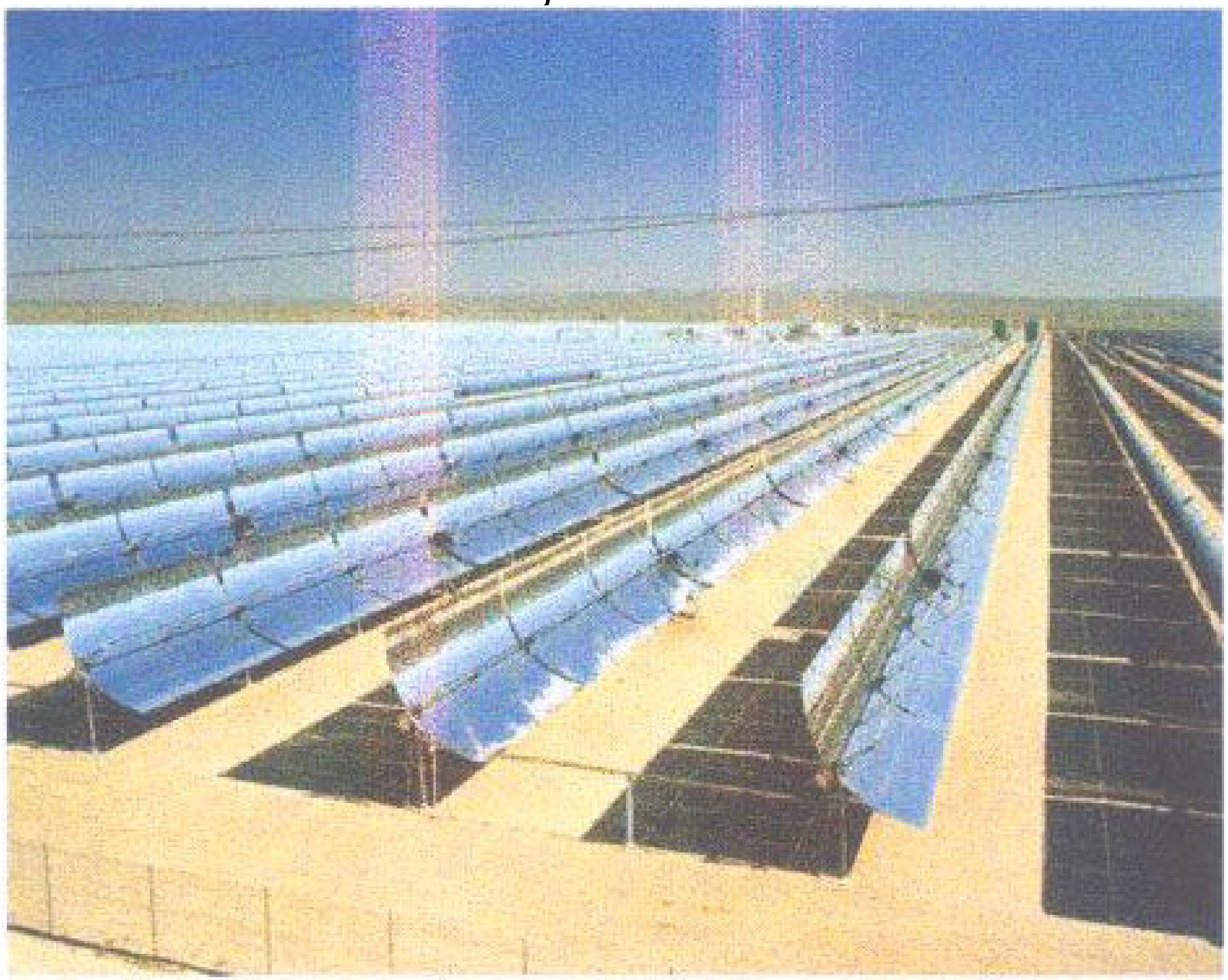
## Current Research and Development Projects

1) In the USA: Parabolic troughs in the California Mojava desert, and in Nevada.
2) Spain: Andasol, Parabolic troughs, with storage, near Sevilla.
3) Spain: Solar Tres, Solar Tower, with storage, near Sevilla.
4) Spain: Abengoa, Parabolic troughs, near Sevilla.
5) Italy: Archimede, Parabolic troughs with molten salt thermal vector, Sicily.

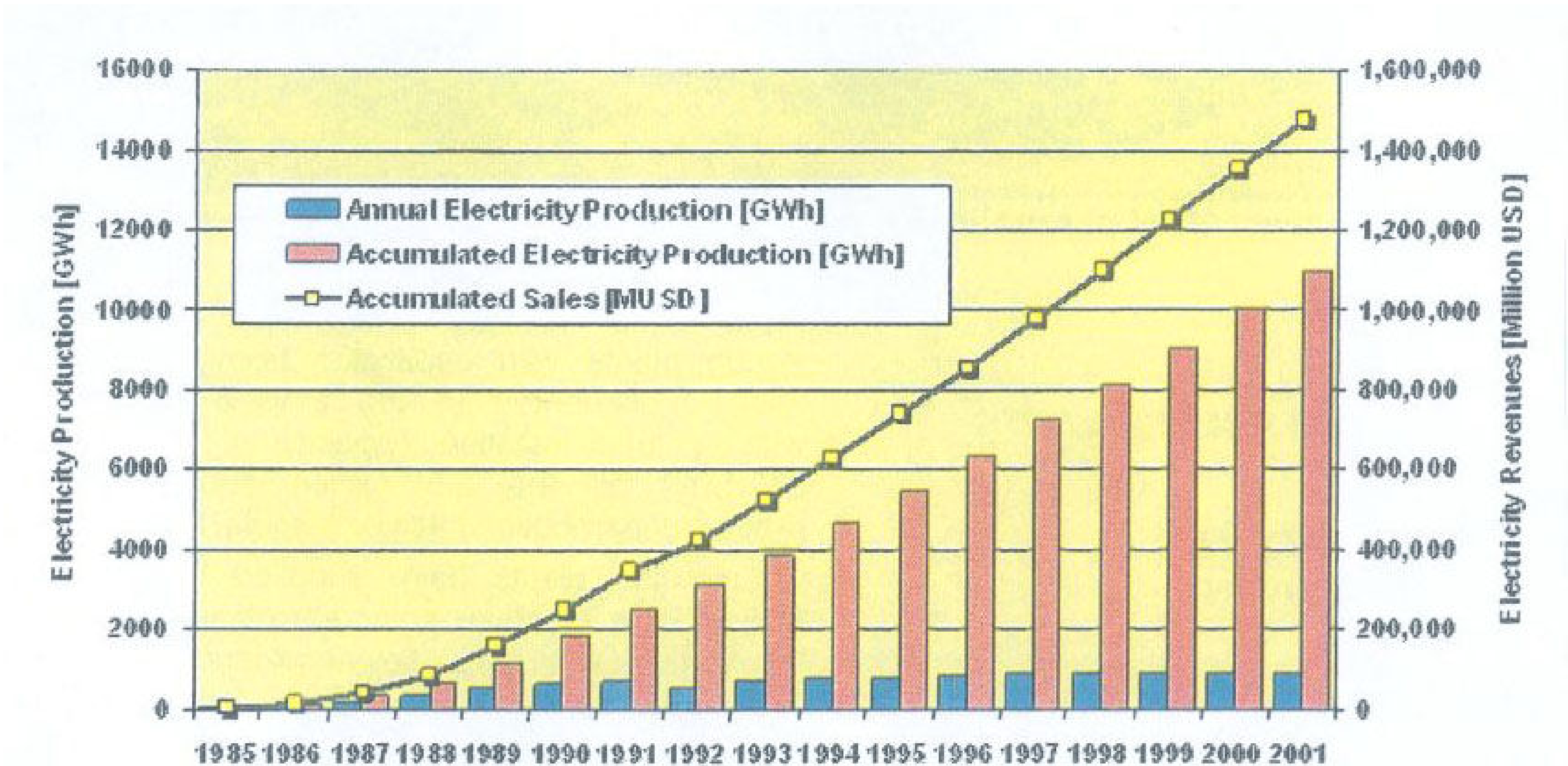
There is a substantial conviction within the community that direct steam would be a better (more economical) thermal vector, but the consequent technological questions have not been very seriously pursued.

## Parabolic plants in the Mojava desert.

8 plants, total power: 450 Mw, reflector surface: 2.3 $km^2$, thermal vector: oil at $390^0C$. First plant in operation in 1985, last one in 1991.



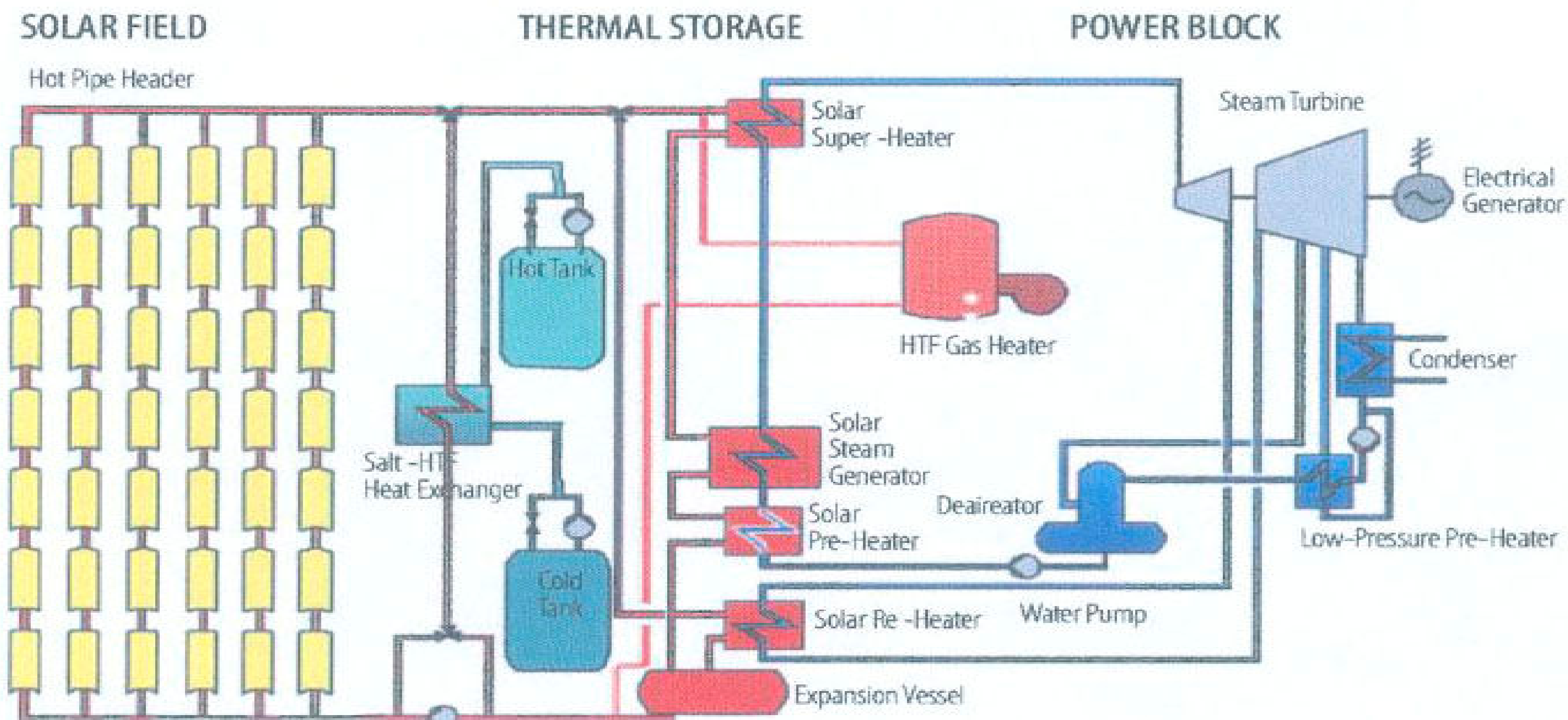
One of the challenges is maintenance of optical quality despite desert storms. This has been demonstrated during 20 years of operation.



**Andasol**, parabolic troughs with thermal storage,

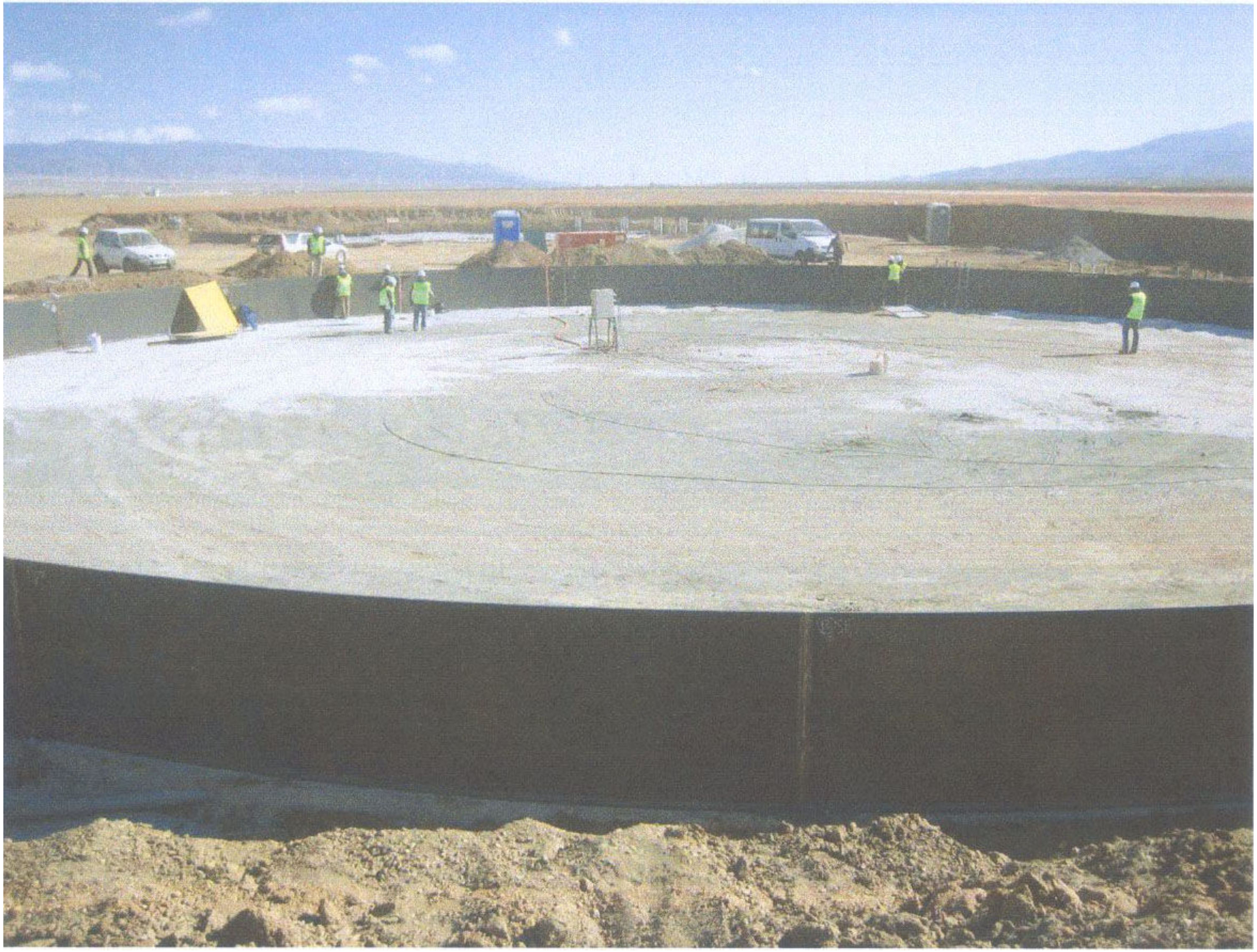
50 Mw plants, cost € 260M each, 3 under construction, Andasol1 in operation since Dec.'08.

Spain subventions project by paying € .20/kwh, ~ 3 times present public price.

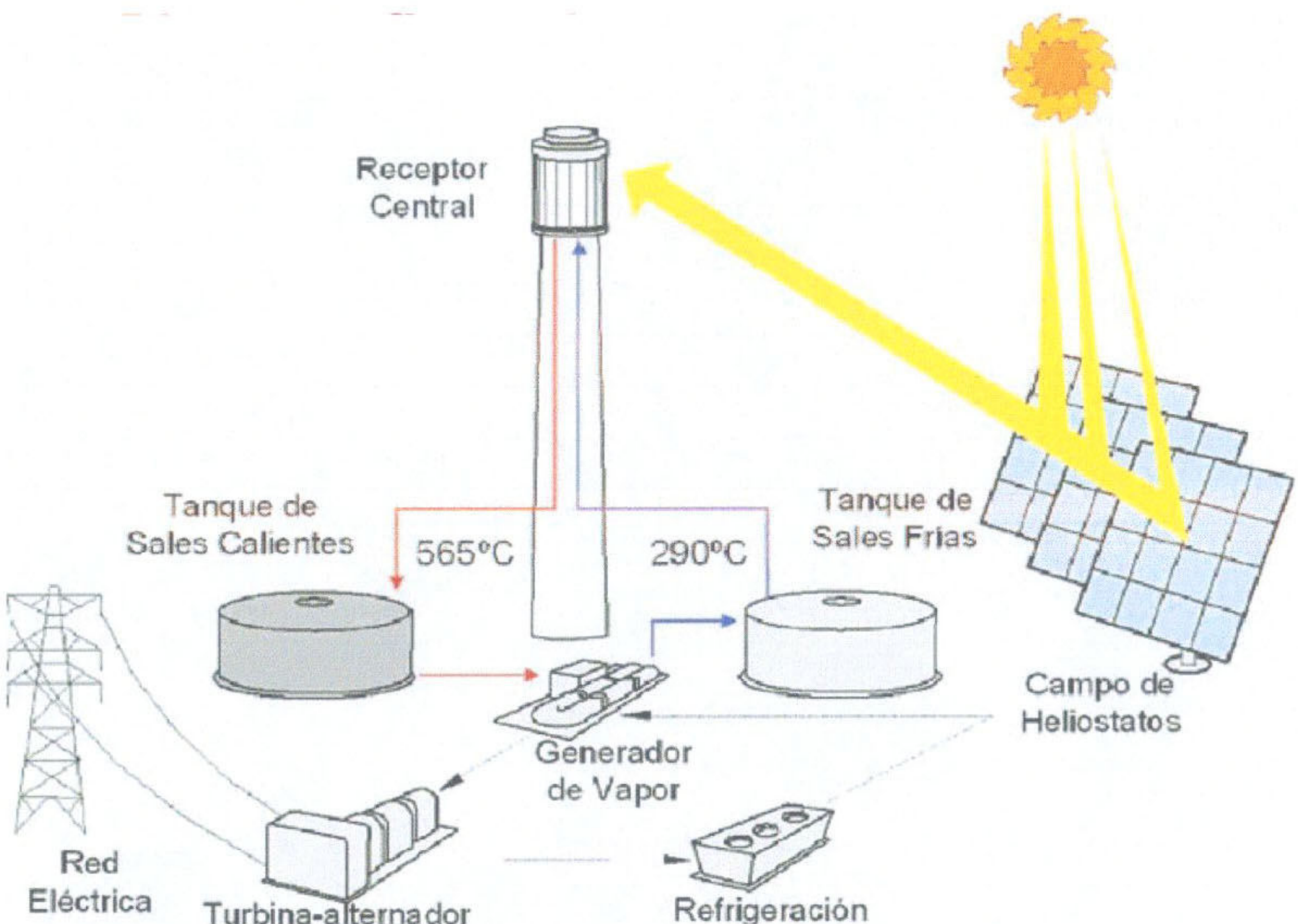


# Andasol

# Andasol.  Molten Salt thermal storage.

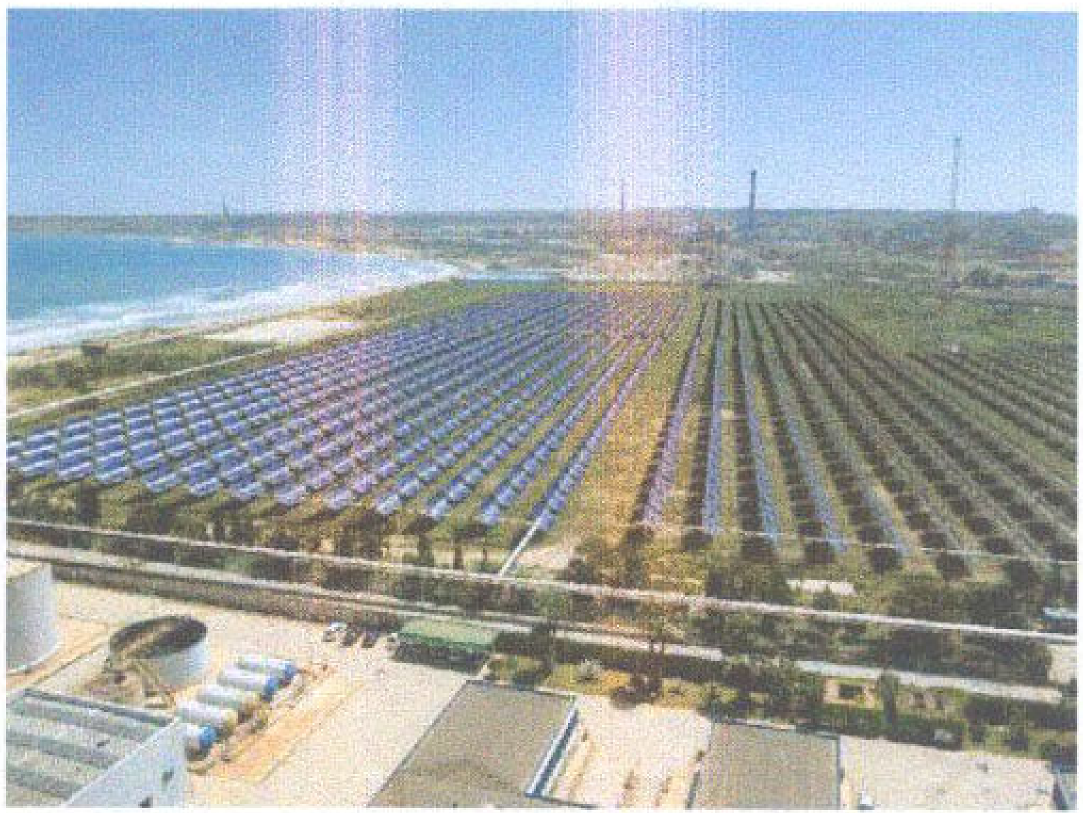


**Solar Tres**. 17 Mw Solar tower with molten salt vector, $300^0C < T < 560^0C$, overnight storage. Tower height 120m, 2600 heliostats 115m$^2$ each. Cost: € 200M.



**Archimede**. Test of Parabolic trough technology with molten salt thermal vector, $300^{0}$C < T < $560^{0}$C. Some loops have been tested. 1 Mw project planned.

Progetto "Archimede": ricostruzione fotografica



# New, larger projects in California:

The California Energy Commission has approved three new, larger projects:

1. 533 Mw of solar towers, by Bright Source Energy.
2. 500 Mw using Fresnel, flat field concentrators, by Ausra. Both projects with Pacific Gas and Electric.

   Both projects consists of one 100 Mw and two 200 Mw plants, to be ready in 2011, 2012 and 2013.
3. eSolar 245 Mw of solar tower, direct steam “Pre-Fab” plants, by agreement with Southern California Edison.

All projects propose to use Steam, as thermal vector.

All projects are very optimistic about achieving costs close to present costs using gas fired plants.

None of the projects incorporate overnight storage, because they are integrated into networks supplied by fossil fuels.

I have been unsuccessful in obtaining concrete info on these projects.

# The next step for Europe?

A pilot project, generating power in North African deserts, with overnight storage and with long distance network to several European countries.

Minimum power requirement, to justify the transmission network, perhaps 3-5 GW. Cost, perhaps ~ 30 billion Euro, largely recovered in 25 years of running.

Would require collaboration of several European and North African countries, perhaps Spain, Italy, Germany, France, Egypt and Tunisia.

Cost of electricity, for 25 years of operation, should be less than 0.1 Euro/kWh, comparable to present fossil fuel costs.

# Conclusion

- Not all renewable energies are equal, some are more equal than others.
- Thermal Solar, from the deserts, with overnight storage, is the outstanding candidate.
- Its technical development should be driven much more intensively.
- Some European countries, in collaboration with North African countries, should undertake a pilot project, transmitting thermal solar energy, with overnight thermal storage, from Africa to Europe.