Solar Energy:

Status Report 2006 and its Potential

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1. Foreword

Abundant cheap and clean energy is a prerequisite for decent human living conditions and a healthy economy. The soaring gas- and oil prize during the recent years is of considerable concern to society and economy. The prizes have increased more than five fold since 1998; i.e. an average annual increase of 23% over the past 8 years. There are 3 reasons to this:

- The oil companies did not discover new large oil fields during the last decades and therefore did not invest in new oil fields and refineries.
- Some of the big oil suppliers are politically unstable countries.
- South East Asia (China, India, S. Korea e.g.) with more than 1/3 of the world population is in a state of enormous economic growth with an increasing energy demand.

All these factors are responsible for the dramatic increase of energy costs, but on the other hand also for the unusual demand and growth of alternative energy development and production. The wealthy industrialized nations are becoming increasingly aware of this situation and also of the climatic consequences of their excessive fossil fuel burning; resulting in faster than expected global warming and increased catastrophic weather pattern. These facts are also realized by less wealthy nations, often becoming the most affected victims of climatic disasters, though their energy consumption is 1-2 orders of magnitude lower than industrialized nations. In fact the wealthy ¼ of the world population is responsible for 88% of the world energy consumption, and therefore for the consequences of it. A few nations are fully aware of this situation and have developed a constructive legislation to promote alternative energies. Germany and Japan are the world leaders in promoting the development of alternative energies (a.e.) Germany's "Einspeisegesetz" (EEG), [could be translated as "feed into grid-law"], put into effect first in 1991 for wind energy and later expanded to other a.e.'s like solarthermal, geothermal, photovoltaic, biomass etc., demonstrated its success and has now been adopted by over 40 nations worldwide.

The purpose of this talk is 3-fold:

- To present a status report of solar energy along with some informative examples, with costs, yield and efficiencies.
- To explore the potential of all types of alternative energies up to the point of complete self sufficiency, i.e. the possibility to become independent of energy imports (gas, oil, coal, uranium). It is important to note that such an independence strategy is part of peace politics to avoid conflicts about resources.
- To point out the economic and social benefits in developing alternative energies for industrial nations as well as worldwide and its ramification to other serious problems like freshwater supply, hunger, medical care, pollution, illiteracy which are troubling the nation's relationships and the whole planet.

This talk will not cover however scientific and technical details and therefore is expected to be understandable to non experts.

2. Introduction

Solar energy has many different aspects with possibilities to harvest heat, electricity and fuel by collectors, solar cells, solar thermal power stations, biomass, upwind generators, etc. All the possibilities are listed in fig 1 – fig 2. The world energy consumption in 2005 was evaluated to 135’000 billion kWh, with an average annual increase of 2.25%, (fig 4). Some characteristic data pertinent to this energy consumption are shown in fig 3. Fig 4 shows the spectrum of our energy consumption, predominantly based on nonrenewable sources like gas, oil, coal, nuclear power (U^{235}): 88.5%, all dominated by oil (36.3%). Among the renewables, hydroelectric energy dominates with 6%. The spectrum of the other “new” renewables indicates the leading role of biomass (except wood) and solar thermal energy, all still below 1%. Fig 5 shows the development of the world’s energy consumption, correlating to the CO_2 increase and to the population growth. The population growth takes place in the 3rd world countries, whereas the consumption and CO_2 increase is caused by industrialized nations with a stable population. Fig 6 exhibits the spectrum of Germany’s energy consumption of 4’100 bln kWh, which amounts to 3% for 1.27% of the world population, typical for the industrialized nations except U.S.A. and Canada, consuming about 25% for 4.72% of the world population, and close to an order of magnitude higher than Mexico and even two orders of magnitude higher than 3rd world countries like Bangladesh (see fig 8). The nonrenewable part of Germany’s energy supply amounts to 95.8%. Among the renewables, biomass is the leader with a total of 2.8% of the energy supply, followed by wind, exceeding even hydropower. Germany has set the ambitious goal to boost the support for renewables in order to achieve about 25% by 2020, reducing the nearly 100% dependence on imports of gas and oil.

In the foreseeable future, called the post fossil fuel era, when the “cheap” gas and oil wells will have dried up, we are faced to a choice between 2 solutions: solar energy with all their varieties listed in fig 1 + 2, and/or nuclear energy (fig 7). It is a simple matter to rule out the pure nuclear option:

- The U^{235} resources (=0.71% of the U reserves) would last at best for about 70 years for the presently operating 440 nuclear fission reactors in the world. Thus U^{235} fission reactors can be a short term partial solution only.
- Even if there were unlimited U^{235} resources , the substitution of all energy sources by nuclear energy would imply <u>at current energy consumption levels</u>, the construction of about 20’000 new nucler reactors of Gigawatt size. The necessary capital investment needed would exceed 10^{14} U.S.$, a capital that simply is not available. Furthermore we would create new depencies. The infrastructure to operate such a huge number of nuclear reactors and to dispose of their radioactive waste cannot be solved in a responsible way.
- A long term nuclear solution would imply the development of a fast breeder, on the basis of e.g. U^{238} or Th^{232}. 2 attempts of Japan & France at enormous costs in the multibillion $ region have failed. Furthermore the breeding of plutonium with a lethal dosis of 6µg/P, the uncontrollability of nuclear weapons proliferation and the transport of thousands of tons of plutonium on our streets and trains makes this

solution unthinkable in a world plagued by terrorism.

- There is one last possibility: nuclear fusion. Given the enormous costs in the double digit billion $ range and the hundreds of billions spent during the last 60 years without any machine of positive yield, this solution is highly unlikely. Cold fusion is considered as a new option, but lack of reproducibility and understanding of processes in the D_2O-Pd electrolysis is not a likely solution in the near future.

We must act now. There is no time left with decades of speculation with uncontrollable expenses. We have alternative energies at hand with controllable, economic and experienced conditions at no environmental risks, which can satisfy our energy need many times over, as shown on fig 8 + 9.

3. Solar Thermal Energy

Following the energy crisis in winter 1973/74, solar thermal energy systems started to become commercially available. In some countries, e.g. Israel or Cyprus, the commercial production of warm water was already a well developed technology. To understand the development of solar thermal collectors some basic knowledge in physics is necessary, presented in fig 10. Solar radiation has 2 components; the focussable direct part and the diffuse part. These 2 parts vary considerably with latitude, season and weather conditions. The annually averaged direct part can be as high as 87% in desert areas and as low as 15-20% in polar regions. For Berlin and Lisbon we find values of 43% and 65% respectively for the annual direct part (fig 10). To harvest solar thermal energy, the diffuse part is of little use. In contrast, solar cells can also use the diffuse part and can generate electricity between 30 and 50% even on cloudy days, whereas thermal collectors, in particular flat collectors will harvest little energy.
Two types of thermal collectors are available on the market: The cheaper flat collectors with typical efficiencies of 40-60% and the vacuum tube collectors with efficiencies between 65-75%. The construction of the latter is more sofisticated and therefore more expensive. The former cost about 100-200 U.S.$/$m^2$, whereas the latter can go as high as 500-700 U.S.$/$m^2$ in Germany. The collector is made from a so called selective absorber, a material that absorbs strongly within the solar spectrum. Turning hot, it begins to emit thermal radiation. However unlike a Planck black body, it exhibits very low emission in the temperature range 300-700K. Many materials have been developed with such properties. In fig 11 the spectral behaviour of TINOX (=TiN_xO_y) is presented, along with the physical appearance of the 2 collector types. The general layout of a thermal collector system is shown in fig 12. Because of excess heat harvest in summertime in areas with cold seasons and little sunshine (northern USA, Germany, France, Italy etc.) it is important to decouple the collector circuit from the water tank via a heat exchanger because in wintertime it must be protected by an antifreeze liquid.
Furthermore sufficient storage volume should be provided. As a rule of thumb 70-100l/m^2 of collector area is needed. There are systems on the market for just generating warm water for household use and extended systems

additionally used for home heating. The salient features of such systems are summarized in fig 13. In Central Europe it is easy to figure out that we can cover our need for warm water and home heating up to about 70%. The missing 30% in wintertime could be bridged by biomass (wood pellets). Therefore we could be completely independent on fossil fuels. Even under conservative consideration, such a system is paying off within 10 years, under current oil prizes even faster; including all costs of hardware, maintenance and installation. The promotion of low temperature (~50-60°C) thermal collectors for warm water use and home heating, along with improved insulation of buildings, is one of the highest priorities. In Barcelona e.g., legislation was passed that new buildings will not be allowed by city authorities without adequate use of solar energy.

In countries with very hot seasons, solar heat can be used for solar cooling by adding a cooling circuit (e.g. by evaporating a low temperature boiling liquid).

Another possibility is the use of solar electricity (photovoltaic energy) to power conventional air-conditioners or fans. The quality of a solar cooling unit is given by a number COP (coefficient of performance). A good system has a value of 3÷3.5 i.e. 1 kWh removes 3÷3.5 kWh of heat. This number is a function of the hot and cold temperature, however. In areas with cold and hot seasons, hybrid systems, i.e. solar air-conditioners, should be used. Their advantage is that the higher the insolation the better they work, regardless of the system. The advantage of grid-independent solar air-conditioners is their independence on the frequent breakdowns of the grid systems and that expensive additional grid restructuring can be avoided. Fig 14 shows a schematic solar cooling system and benefits of energy savings for various cities. Fig 15 presents an overview of solar thermal energy collection compared with other forms of alternative energies. Next to biomass, solar thermal energy is # 2 worldwide, in Germany however, due to its specific climatic condition it is # 4; the average thermal collector area per person in Germany is $0.073m^2$, compared to $0.74m^2$ in Israel. Percentagewise the solar thermal energy harvest in Germany amounts to only 0.071%; slightly above the world's average of 0.050% of the total energy consumption. The potential of harvesting various kinds of alternative energies is given in fig 17.

Applications of solar energy have a long tradition. Archimedes set the wooden fleet of the Roman general Claudius Marcellus in 212 B.C. on fire, when he tried to conquer Syracuse (Sicily), by posting an army of several dozen men on the pier, directing the reflected sunlight on the wooden boats by mirrors (presumably from a Cu-Sn alloy). Lavoisier built a solar heat machine in 1746 using a parabolic mirror and Augustin Mouchot built a solar heat generator in Paris in 1861 at the world's fair, based on 2 large glass lenses. Solar furnaces were built in France by the french pioneer Felix Trombe in the Pyrenees in 1951 and 1970 (Odeillo, Font Romeu), reaching temperatures exceeding 4'000°C with a concentration ratio as high as 20'000 suns, nearly half the maximum value C_{max}=46'211, due to the slight divergence of solar beams of 0.54°. Fig 18-22 show some applications of solar heat, generating electrical power.

Fig 18: the first commercial solar thermal electric power station, built by Luz, a multinational company at Kramers junction in the Mojave desert in California, at the intersection of highways 58/395. They were built in units of 50 MW.

This type of solar system is called DCS (Distributed Collector System) or solar farm, in contrast to a solar tower system or CRS (Central Receiver System). The solar radiation is concentrated by troughsize (~8m long) parabolic mirrors made from special glass (white glass, expensive), silver covered on the back and protected by white enamel. In their focal line the mirrors carry a selective absorber coated tube with a chlorinated oil which is heated up to 380°C. For reasons of convection losses, the oil carrying tube is surrounded by a vacuum tube from Pyrexglass. The hot oil is generating high pressure hot steam in a heat exchanger, driving a turbine to generate electricity. In 1991 Luz went out of business. But a new generation of this type of solar thermal electric power station is under construction, now in Spain, 50km east of Granada, with 510'000m^2 of mirrors. It is expected to generate 50MW and 0.18 TWh annually, at a garanteed prize of 0.21€cents/kWh. The concentration of 80 has geometrical reasons. For linear (monoaxial) tracking systems, the maximum concentration ratio is $\sqrt{C_{max}}=215$. The system has a thermal storage tank of 25'000 t of salt at 380°C, which can bypass an absence of sunshine up to 6 hours. A series of such solar farms are being planned in Spain, Northafrican States and China. (Prod.: Solar Millenium A.G., Germany). The efficiency is about 14-15%.

Fig 19: top: solar tower system in Almeria, Spain. Bottom: solar farm system, similar to fig 18, called DISS (Direct Solar Steam System). The concentrated heat is generating a mixture of steam and water (2 fluid system), which was a difficult problem, solved by a German research group in Stuttgart.

Fig 20: a different approach is a parabolic concentrator with a dish-stirling motor in its focus. Each of these mirrors generates an output of 10 KW with an efficiency of about 15%. A biaxial tracking is neccessary in this case. Useful for small scale application.

Fig 21: outline of an upwind generator with a tower of 1'000m height. It is also planned in Spain in Manzanares.

Fig 22: fig 22 is a thermochemical solar power station, developed by PSI (Paul Scherrer Institute in Villigen, Switzerland). It can generate hydrogen or electricity via a Zn/air battery using Zn, H_2O and Carbon as working substances. The first type of such a solar chemical reactor is under construction in Israel. It is of a solar tower type, because of the high temperatures needed, not achievable by solar farms. Commercially, solar farms are easier & cheaper to operate and are expected to lead the market in this field.

4. Solar electricity

The first solar cell was built by Chapin, Fuller & Pearson in 1954 at Bell Laboratories. It had an efficiency of 5.4%. The first applications were found in the satellite communication technique and space research. Until the energy crisis in winter 1973/74 a few other semiconductors had been explored: GaAs, CdTe and Cu_2S/CdS. The energy crisis led to considerable activities, in particular through the success of S. Wagner (now at Princeton University) with compound semiconductor heterojunctions like $CuInSe_2/CdS$ and InP/CdS achieving up to 15% efficiency for the latter. The maximum efficiency is a function of the forbidden gap Eg in the electron energy spectrum of a semiconductor, investigated by Loferski, Queisser and Shockley. It is shown in fig 23. The maximum efficiency at room temperature of about 27% is achieved with a gap of 1.5eV under 1 sun irradiation. This maximum value is also dependent on temperature and concentration. Concentration increases the efficiency, but heats up a cell if it is not cooled adequately. High temperatures are unfavourable, due to an exponential increase of the reverse saturation current of the diode. Higher gaps reduce the temperature dependence.

For silicon solar cells the loss is considerable: 0.48%/°C. For amorphous silicon (a-Si) and GaAs cells this value is reduced to about half of this value. It is the open circuit voltage which is mainly responsible for this temperature dependence. Though silicon is not the most favourable material for photovoltaic energy generation, it nevertheless dominates the market as shown in fig 24. The remaining 1.8% are few compound semiconductors: GaAs for concentrator cells and satellites, CdTe and $CuIn_{1-x}Ga_xSe_{2-y}S_y$ (=CIGSSe). The only commercially available solar cells are listed below:

Material	Structure	η_{lab} (%)	$\eta_{commercial}$ (%)
C-Si	p/n	24.7 *single crystal* 21.5 *multicrystal*	17-20 14-16
a-Si	p-i-n triple junct.	14.6	8-9
GaAs	p/n, $GaAs/Ga_{1-x}Al_xAs$	25.1	22-23
CdTe	p/n, CdTe/CdS	16.8	8-10.5
$CuIn_{1-x}Ga_xSe_{2-y}S_y$	p-i-n hetero junct.	19.5	14-15

Only 3 materials have exceeded the 20% efficiency limit:
Si (24.7%), GaAs (25.1%) and InP (21.9%).

High efficiencies can be reached by concentration (and cooling), see figs 23+26, and tandem cells, as shown in figs 25+26. 37% is the highest photovoltaic conversion achieved so far, with a double tandem cell under concentration. Among alternative energies, photovoltaic power is one of the more expensive one, though is becoming increasingly economic, compared to diesel aggregates. We have observed a cost degression of close to 20% per doubling of production capacity, except for the past few years, because of silicon shortage on the market (not because of lack of resources). We expect the cost of W_p to drop again by 2009 with new companies emerging to boost the production of solar grade silicon. The costs of a silicon panel can be broken up into various parts as shown in fig 27. Several studies have shown that in principle thin film solar cells should lead to a considerable drop of the photovoltaic kWh (or W_p) cost. So far this drop did not occur for CdTe and only marginally for a-Si, due to their lower efficiency. Recently new companies have emerged to manufacture $Cu(InGa)(SeS)_2$ and $CuInS_2$. It will be interesting to test the predictions in this case. It must be emphasized, however, that the In resources are limited. Problems will arise at production levels in the GW range. Similar problems will arise with Te in CdTe. With silicon only we will be able to generate a sizable part of the world's energy consumption.

Fig 28 presents some fundamental data for photovoltaic energy harvest in Germany representing central Europe, and a southern country like Mexico, considerably more suitable for photovoltaic electricity generation. The amortization period for a photovoltaic generator is 22 years in Germany, roughly twice the period for a thermal collector system. By the end of 2006 we expect about 7GW of installed P.V. power worldwide, generating about 10^{10} kWh annually, or only 0.0074% of the world's energy consumption. Fig 29 shows the area needed to cover the world's energy need by photovoltaic power. In principle we could easily cover the world's energy need by solar energy only (P.V. + Solarthermal) many times over, as shown in fig 9. Solar electricity is a most valuable flexible energy, which can be used for almost any application in a remote rural area, see fig 30. 2.3 bln people do not have electricity for their daily needs. Finally it is important to point out that the energy pay back time for a photovoltaic generator is at least a factor 6 to 20 shorter than their guaranteed life time of 25-30 years by the manufacterer.

cell type	*energy pay back time (y)*
mono - Si (17%)	5.5 ± 1
poly – Si (15%)	4 ± 1
a – Si (8%)	1.5 ± 0.5
$Cu(InGa)(SSe)_2$ (14%)	1.3 ± 0.4
CdTe (11%)	1.2 ± 0.3
Wind (1MW system)	0.6 ± 0.2 (50% duty cycle)

Applications of P.V. power systems have become widespread also in industrialized countries on roofs of industrial-, public- and private buildings; in rural areas for waterpumps, irrigation, emergency power supplies etc. In 3rd world countries it is an ideal power supply system where no grid connection is available. It could substantially improve the quality of life. The consumption of fossil fuels could be substantially reduced by integrating photovoltaic power into daily life. The enclosed examples could indicate some ideas: e.g. the substitution of fossil fuel powered vehicles by solar cars, solar motorcycles and solar bikes. Fig 31 shows a solar bike in action, developed by the Swiss engineer Andrea Vezzini (Fachhochschule Biel, Switzerland). It demonstrated its acid test in an cross country biking race across Australia with an average speed of 66 km/h and a maximum speed of up to 90km/h. Powering solar vehicles could be done by wearing solar cloths, as shown in fig 32, a quite futuristic look for biking fans. For solar bikes additional power as little as 50-100 Watts can bring a considerable boost to muscle power. Fig 33 shows a model of a photovoltaically driven train, built by the federal Italian train company, and a model of a manned solar airplane, designed by Bertrand Piccard (Lausanne, Switzerland) and a German engineer, André Borschberg. They are planning to fly non-stop around the globe with solar power only. Piccard is well known as the first balloonist who succeeded together with Brian Jones to fly non-stop around the globe. Though this sounds and looks rather futuristic, solar airplanes may some day become commercial with high efficiency (25-30%) thin film tandem solar cells, with an energy output of up to 250 W/kg as compared to 5-10W/kg for Si-panels.

5. Biomass

Biomass can mean many things as shown in fig 34. Confusion sometimes occurs whether wood is included in statistics of biomass products. Wood has been a traditional form of energy supply which is thousands of years old. By biomass we understand mostly new ways to generate energy from organic waste other than wood; including manure, sewage etc. The products of organic waste (including wood) can be many traditional forms of energy as shown in fig 34, where also methods of production are indicated. By biomass we mean predominantly the cultivation of agricultural products like corn, sugarcane, palm oil, rapeseed etc. for their use as biogas, liquid fuels, heat or electricity. But traditional waste from household or farming previously dumped into pits, the sea or burned are now considered valuable for energy recovery. This traditional organic waste could supply as much as 2% of our annual energy consumption instead of being disposed of. Examples could be straw, dry residues from olive oil production, from wineries, from cotton production, from sugarcane or sugarbeets etc. A new aspect arising from biomass cultivation like corn, sugarbeets, potatoes, wheat is its competition with the food industry for people and animals. In our free market system we have to worry about food shortage and/or increasing food prizes if benefits of biomass production turn out to be higher than of food production. Another serious threat is the accelerated loss of tropical forest areas for the production of biomass (sugarcane, palmoil e.g.). As usual, the poorest part of the population will fall victim to this development. It will be unavoidable that responsible governments will have to pass legislation in this field, enforcing priorities:

1) Food for people & animals
2) Biomass for energy production

With these considerations in mind, we turn our attention again to the more scientific aspects. With the cultivation of biomass, 3 important questions arise shown in fig 35. Fig 36 shows that biomass could easily supply the world's energy need by photosynthesis only. It is a quantitative proof of the diagram

in fig 9. An important difference to solar energy and wind energy however is the lower areal efficiency (=energy harvest per km^2) of biomass.
The reason is the low efficiency of photosynthesis. The advantage of biomass on the other hand is that it needs very little maintenance from seed to harvest (except for fertilizing, but this reduces considerably the net energy gain; such products should be avoided). The species suitable for biomass cultivation are dependent on climatic condition and must be optimized in each country. Fig 37 shows the biomass potential in Germany, which could contribute as much as 21% of the present energy consumption, giving some numerical justification for numbers used in fig 17. Finally to evaluate the values of the different biomass species we need to know their efficiencies in terms of conventional products like nat. gas, gasoline, coal, kWh (heat & electricity). These numbers are summarized in fig 38.
One of the main purposes of biomass cultivation is the production of l-fuel as a substitute for gasoline and (petroleum) diesel for vehicles like cars, trucks and maybe later for airplanes. The driving forces are their soaring costs and instabilities of supply. Fig 39 lists crop yield per area and energy yield (= net energy gain, where available) for various plants. Bioethanol is mostly produced from sugar or starch producing plants, by means of fermentation, a process well known from untreated fruit juices, shown on the bottom right. The massproduction plans of bioethanol from certain plants has led to a considerable controversy. Several experts (e.g. Prof. Pimentel, Cornell University) have figured out a negative energy gain, in particular if heavy fertilizing, herbicides or pesticides are involved, which is very energy consuming. This controversy has not been settled yet. It remains undisputed for sugarcane, one reason being that the dry endproduct of the whole plant can be used completely as solid heating fuel for the ethanol distillation process. Brazil, the biggest most successful producer of biofuels (mostly ethanol) has achieved stable fuel prizes. Biofuels supply 3% of the world's market ($=1.2 \times 10^{12}$ l/y) with annual growth rates of 50-70% (see also fig16). In fig 40 a list of oil producing plants is given with their crop yield and energy gain. Biodiesel is produced from oil producing plants by esterification with methanol or ethanol. It is argued that biodiesel is advantageous for diesel engines as compared with petroleum diesel. In Germany rapeseed is the nearly 100% supplier for biodiesel with 1.7 bln liters produced in 2005, with over 2000 gasstations supplying it. Germany has also become the world's biggest supplier of bioenergy producing plants, in particular biogas for fermentation of all kinds of bio waste (manure, sewage, agriculture and household waste). Biogas contains about 50-65% of methane (CH_4) but also lots of undesirable compounds like H_2O, N_2, H_2S, PH_3, CO, NH_3 which must be eliminated. The purified biogas is enriched to about 96-97% pure methane and can be fed into natural gas pipelines for heating or electricity production. Fig 41 shows a typical system of León in Spain, processing 200'000t of waste/y, as a new energy resource instead of dumping it into pit holes. 47% of the 200'000t can be used as biomass, 32% are paper cardboard and plastic, the remaining parts being glass, metal, composites. With a guaranteed energy prize of 16€cts/kWh, such a system has an amortization time of less than 10 years.
Finally, we should point out to a challenging R+D problem in the field of biomass: the conversion of cellulose into liquid fuel (ethanol). A solution via

charcoal and the Fischer-Tropsch process is known, but expensive. A cheaper, simpler way is desirable. The U.S. DOE is planning to spend 250 million U.S.$ to solve this problem (N.Y. Times, Aug. 4, 2006).

6. Other forms of primary solar energy

There is a variety of new solutions under consideration as alternative energy sources:

- Upwind power stations, generating electricity (See fig 21, chapter 3)
- Tidal hydroelectric power plants. The first one was built in St. Malo (1960-1966), at the estuary of the Rance river with a power of 240 MW and an energy harvest of 0.5×10^9 kWh/y. A large difference between low & high tide is needed in an estuary. The world's potential of tidal electric power is evaluated to 170 GW with an energy harvest of 360 TWh/y, i.e. 0.26% of the world's energy consumption 2006.
- Ocean thermal energy conversion (OTEC). Vast energy resources are stored in the ocean. Such systems have explored the possibilities to use the temperature difference between warm surface waters (25°C) and cold deep water (4°C). Generators have been built with up to 50 kW power in the warm South Pacific Ocean. The small temperature difference however is limiting the effective efficiency to 5-6% (Carnot's law).
- Floating electricity generating turbines in rivers. This is an interesting idea which could considerably improve the exploitation of hydroelectric power, even for small rivers, without the construction of dams.
- Ocean current electric power stations. The strait of Gibraltar could be an excellent example to realize this idea, but any place where strong permanent ocean currents occur, might be suitable. Figs 42+43 show examples of ocean current turbines and turbines combined with wind mills, built on top of the support pillars of turbines.
- Geothermal energy: it has 2 components: deep geothermal energy with a steady heat current of 0.063 W/m^2 at the surface, flowing from the hot center to the surface, and solar heat, stored in the surface part (surface geothermal heat). The average temperature increase is about 3°C/100m, but can be much higher in hot spot (volcanic) areas. Geothermal heat is used in general by electrically driven heat pumps from a depth between 2 and 100m. In volcanic areas, however, geothermal heat generates high pressure steam, driving turbines to produce electricity. Iceland, e.g. is covering 75% of its energy needs by geothermal power.

7. Energy conservation

Energy conservation can also be considered as an energy source. It's benefits are:

- It is the cheapest "energy source"
- It saves money
- It enhances the percentage of renewables
- It helps the environment and improves the quality of life

There are a variety of possibilities to conserve energy:

- By recycling: fig 44
- In households: fig 45
- In traffic: fig 45
- In industry: investigating less energy consuming processes, eliminating airconditioning on weekends and bridged holidays, development of energy conserving models.

8. The freshwater problem

As pointed out in chapters 1+2, a cheap, clean, stable energy supply is only one out of many current problems plaguing our world's society, before all, the majority of the poorest 70%. Another one is the increasing problem of adequate drinking water and freshwater supply (fig 46). The production of freshwater costs energy. Therefore the freshwater problem is also part of the energy problem. The increasing population is expanding their habitat more and more into areas like tropical forests which must be conserved as our "green lungs" and also into desertlike areas. . Many desert areas could potentially be turned into "Gardens of Eden".

This could be achieved, meeting two conditions:
1) Sufficient energy
2) Sufficient freshwater

Part of the freshwater problem is man made: ground water levels have been excessively drained in part also by the changing climate, in other areas lakes, rivers and the soil have been poisoned by dumping poisonous waste into them and near groundwater areas. In the gulf region, where oil is cheaper than water, freshwater is produced in enormous quantities. In Dubai e.g. the freshwater consumption per capita is the highest in the world: 1'000 l/p, day, for a population of around 700'000 people, i.e. 700'000 m^3/d. Freshwater there, is produced from desalination plants operating with fossil fuels (oil). In other areas however, oil has become too expensive and power must come from solar energy: P.V. or solar thermal energy. The freshwater production is highest during summer when it is hot and dry and the need for freshwater consumption is highest. Presently (2006) about 16'400 desalination plants produce daily $35x10^6m^3$ of freshwater. 2% of the households worldwide depend on them. However desalination accounts for only about 0.21% of the annual freshwater consumption of 6'100 km^3/y, as shown in fig 47. It shows also the extremes of freshwater consumption and the productivity of the

world's largest desalination plant in Ashkalon, Israel (RO=reverse osmosis). Several methods for desalination are known, as shown in fig 48. Thermal methods are simple, but cost more energy and money than membrane methods. Reverse osmosis (RO) has become the most common method where costs of energy and money matters. The principle of reverse osmosis is shown in fig 49. The osmotic pressure of seawater (3,5% salt) is 25 bars (against freshwater). The pressure needed to squeeze the water through a semipermeable membrane (pervious to the solvent, water, but not to the salt) from the saltwater to the freshwater side must exceed the osmotic pressure considerably. Usually it is around 50 bars. The advantages are roomtemperature operation, low energy consumption and low costs. A 1 MW P.V. station would produce about 500'000 m^3 of freshwater annually (in southern countries). With costs of 0.5cts/l such a plant would be paid off in less than 5 years. In fig 50 a hypothetical calculation is presented about costs to supply the 1.6 bln people with adequate water supply (100 l/d per person): It would increase the freshwater consumption by 0.95% and the energy consumption by 0.17%. If operated by P.V., the P.V. power needed would amount to 234 bln kWh/y, or 117 GW, or about 17 times the totally installed P.V. power of the world by the end of 2006. This would cost about 650 bln $, or, 2% of the world's war budget this year.
If we would finance the freshwater need over the next two decades we would have to cut the annual war budget by 0.38% only.

The insight gained from our numerous considerations and calculations calls for a conclusion:

- There is no energy shortage. Alternative energies are abundant to supply the world's energy need.

- No nuclear fission power is needed with all its safety-, security- and radioactive waste problems. It will never become a sustainable option.

- The spectrum of alternative energies is expected to be different for each country, depending on their population structure and climatic conditions. It must be carefully evaluated.

- We have to correct our thinking that energy will be supplied by large centralized power stations only (e.g. nuclear power plants, etc.). They will continue to exist (e.g. windmill parks, hydroelectric power plants, solar thermal power plants, biomass systems making use of large amounts of organic waste etc.), but besides those, a large portion (~ 50%) of our energy needs will be generated individually and decentralized. Proper legislation is necessary that it pays off to save and/or produce alternative clean energy.

- The transition to a post fossil fuel era is a political decision which must be taken now and the public must be informed and included in this process.

- The academic community should take on a more responsible position to help society for a smooth transition to the postfossil fuel era.

- The nation's independence from vital imports of energy, freshwater etc. helps to avoid conflicts and can therefore be considered as an instrument of peace keeping.

Acknowledgement

I am very much indebted to many colleagues for their help in preparing this review: Dr. Paul Egli, Montreal for his information about water management, Drs. Peter Fath, Kristian Peter, Radovan Kopecek, Directors of ISC-Konstanz for their discussion of chapters 3 and 4 and graphic design, Dipl. Phys. Roman Petres, also Director of ISC and Dipl. Phys. Axel Herguth for their help in computer design, and Angela Schellinger, my longtime secretary for carefully and patiently typing this review.

Ernst Bucher
Kreuzlingen, August 2006-08-14

9. Figures

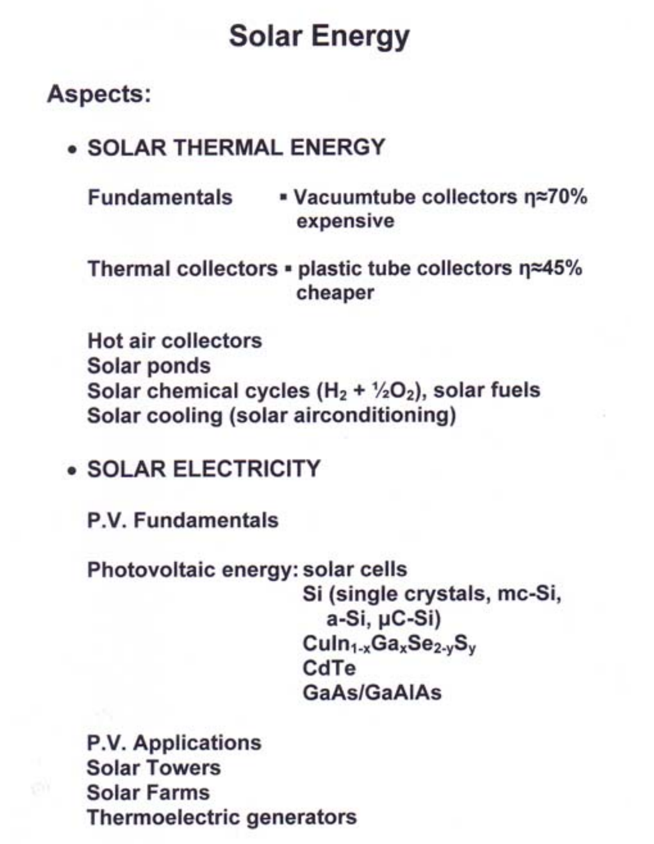


Fig. 1: *Aspects of solar energy 1*

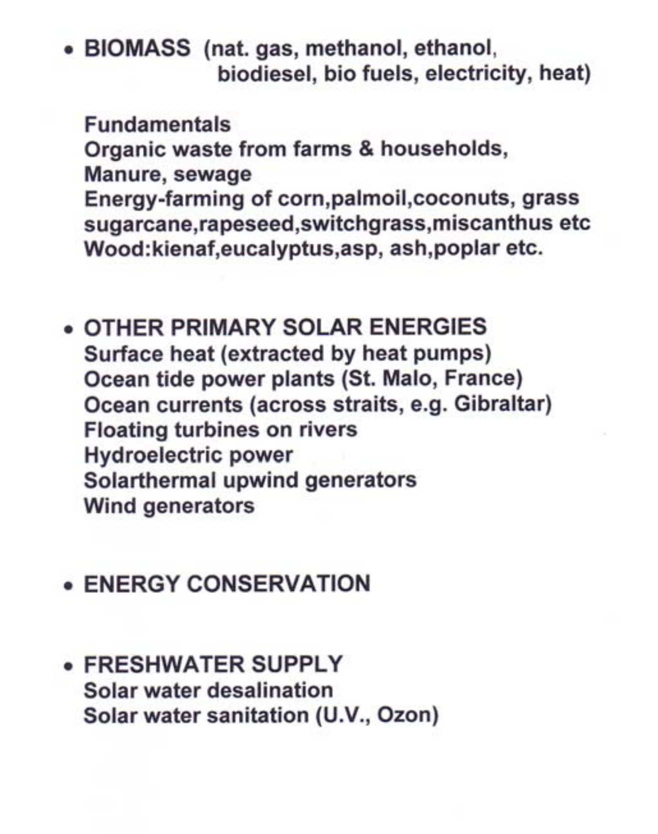


Fig. 2: *Aspects of solar energy 2*

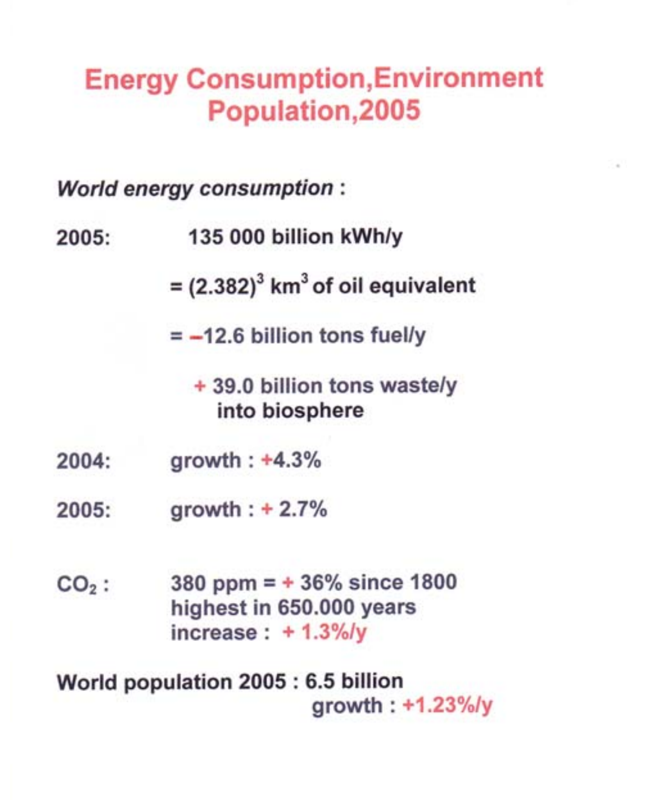


Fig. 3: *World energy consumption*

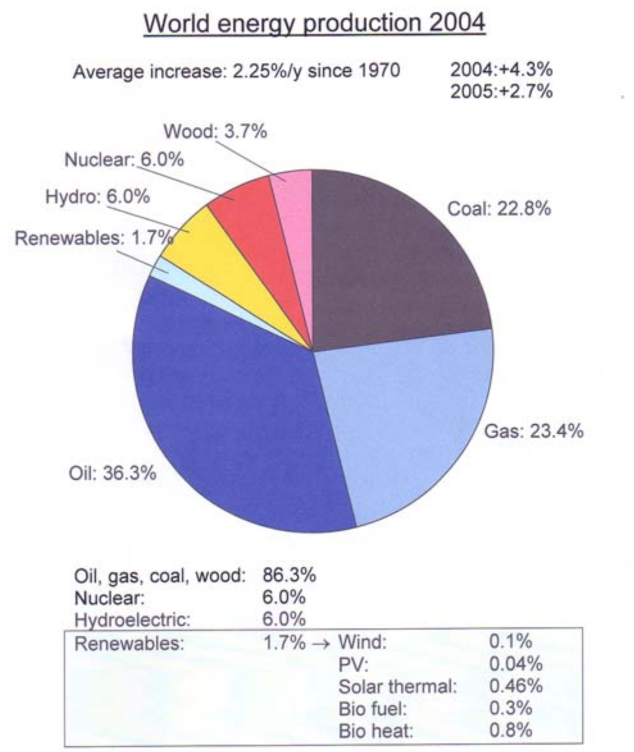


Fig. 4: *Spectrum of world energy production*

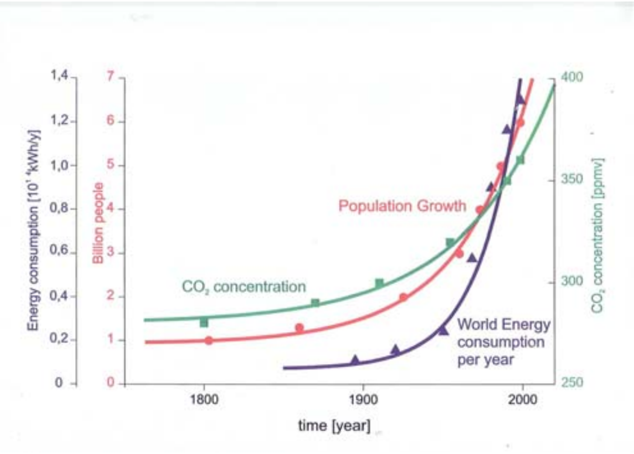


Fig. 5: *World population, energy consumption and CO_2 concentration*

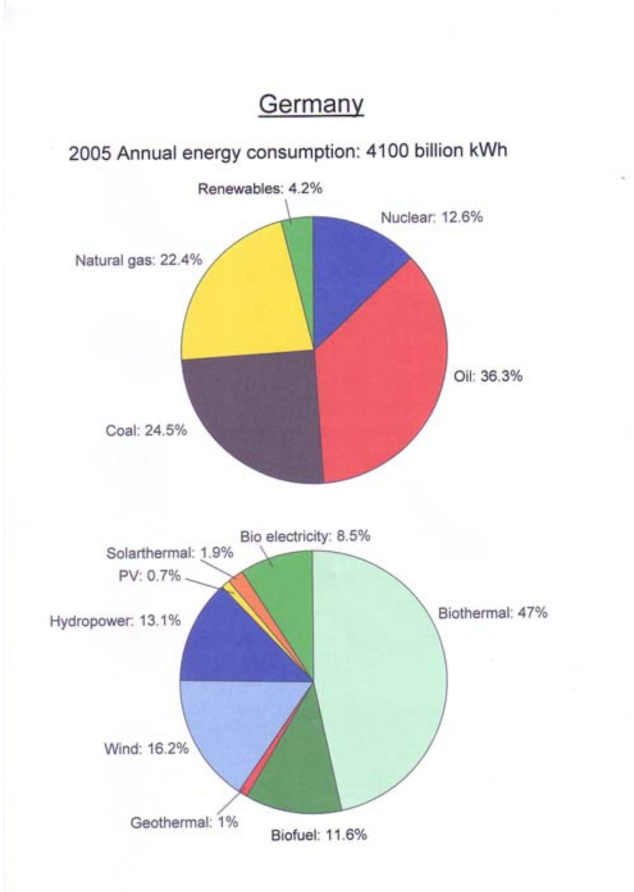


Fig. 6: *Energy consumption in Germany*

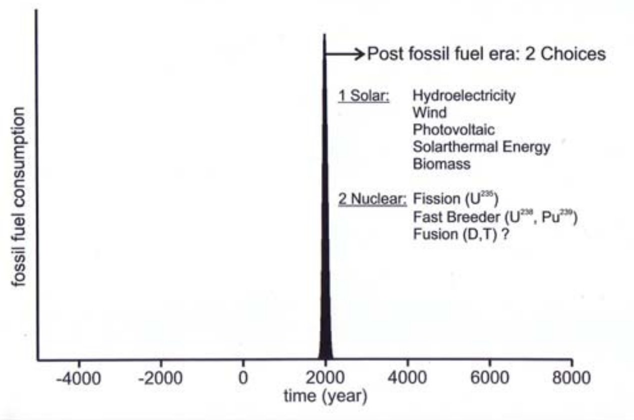


Fig. 7: *Fossil fuel consumption*

Solar Energy

Sun produces : 1.2×10^{34} J/y = 3.85×10^{23} kW

Earth receives : 7.1×10^{17} kW/y = 8.1×10^{13} kW

Annual energy consumption 1.4×10^{14} kWh

***Conclusion* :**
- **within 1.7hrs the sun irradiates the equivalent of the annual energy consumption of the planet earth**
- **the earth receives 7000 times the energy from the sun, it currently consumes**

***Solar "Constant"* : 136.7mW/cm² = 1.367kW/m² (AMO)**
= 1.0 kW/m² (AMI)

Solar Irradiation :		**average**
Germany :	**850-1300kWh/m²y**	**1000kWh/m²y**
Mexico :	**1500-2600kWh/m²y**	**2000kWh/m²y**

***Max* : Eastern Sahara : 2800kWh/m²y**

Energy consumption per capita		**t_{CO2}/P,y**
USA + Canada :	**1.1×10^5 kWh/y**	**20**
Germany :	**5.5×10^4 kWh/y**	**10**
Mexico :	**1.5×10^4 kWh/y**	**2.3**
Bangladesh :	**1.6×10^3 kWh/y**	**0.23**
Average :	**2.1×10^4 kWh/y**	**3.5**

Fig. 8: *Solar energy facts*

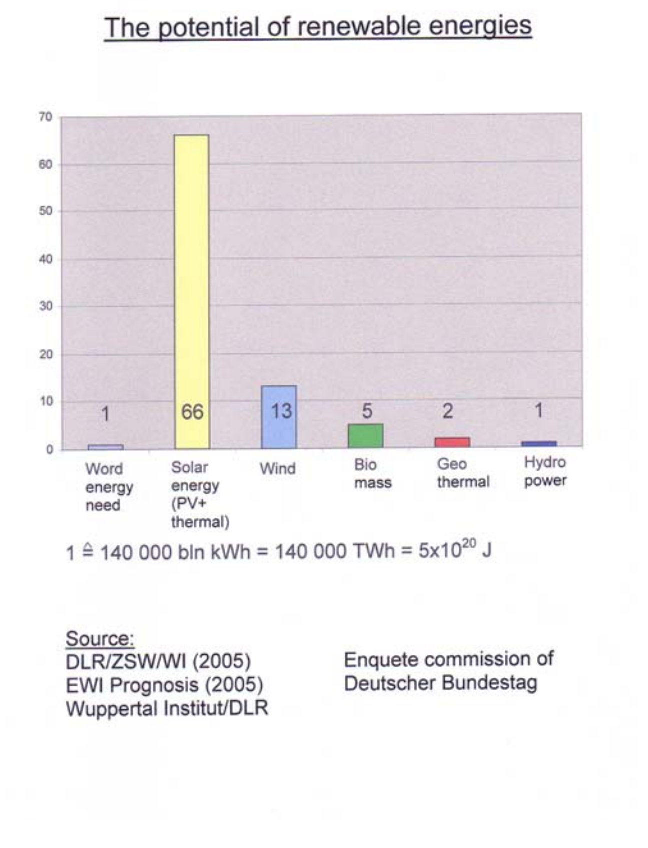


Fig. 9

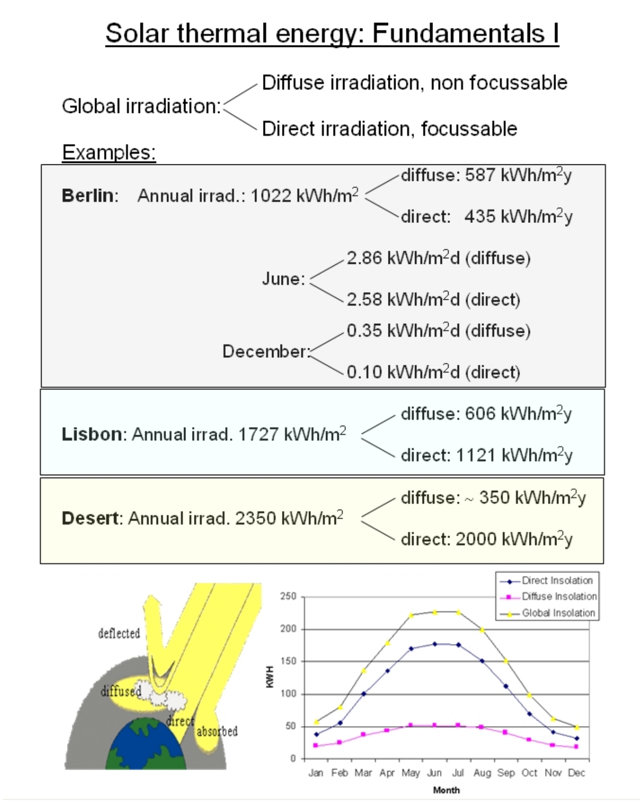


Fig. 10

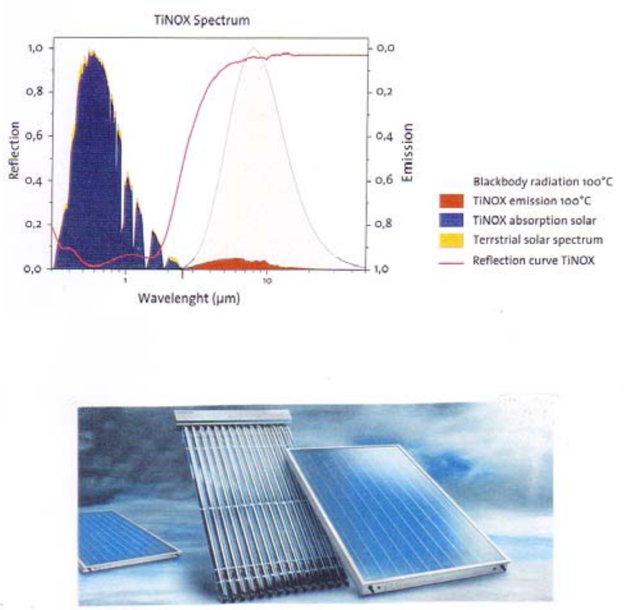


Fig. 11: *Solar thermal collectors*

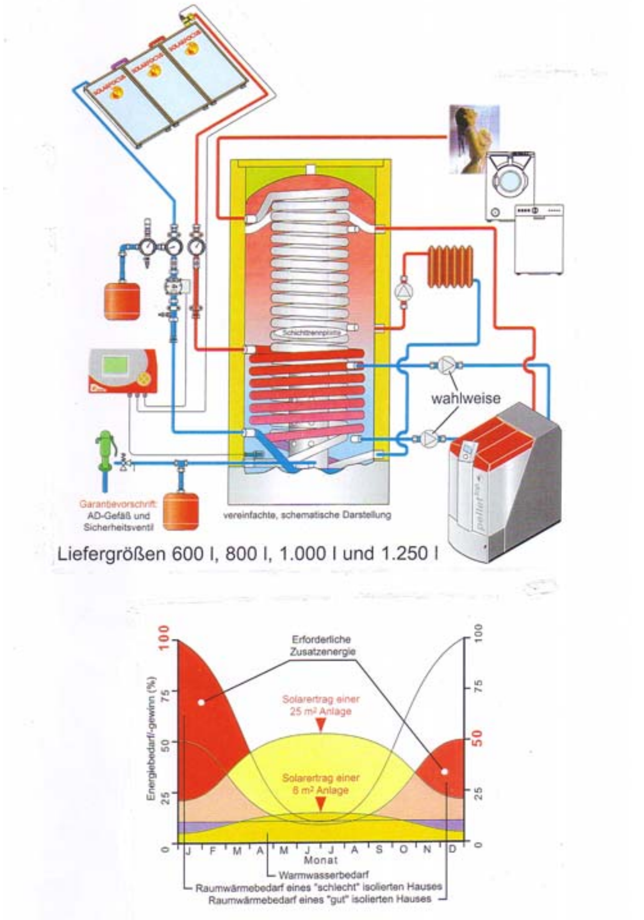


Fig. 12: *Scheme of a solar thermal system*

Solar thermal energy fundamentals for Germany

Warm water generation : 1 household of 4 people
(Central Europe) : 200 l of 50°C needed daily
= 8.3kWh/d = 3030kWh/y

Rule of thumb : 1m² collector/P for warm water use = 2000kWh/y. ~ 66% coverage

Costs : € 3 100
home heating fuel: 300 l = € 200 (annual increase 8%)

Number of years of amortisation at 8% annual increase:

Amortization time : $\boxed{\text{10 years}}$

Heating : for 10m² : 0.7m² collector needed
150m² : 11m² needed => 5 500kWh

Costs : € 6 700 (storage of 1000 l included)
Rule of thumb : 70 – 100 l/m² collector

Fuel savings : 600l/y = € 400/y

Amortization time : $\boxed{\text{11 years}}$

Potential savings :
warm water : 1% of total energy consumption
warm water + heating : 3.2% " " " "
~ 10% household consumption

Fig. 13: *Amortization of a solar thermal system*

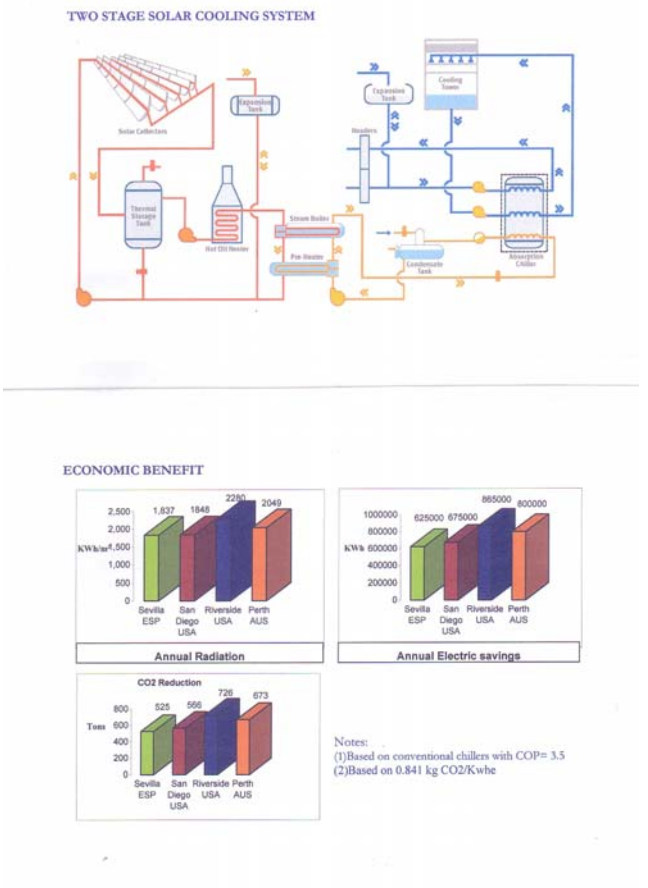


Fig. 14: *Outlay and benefits of solar cooling system*

Alternative Energies 2005

	tot. installed (GW)	gen. energy (TWh)	jobs	sales (bln $)
P.V.				
Germany	1.5	1.1	30 000	3.7
Mexico	0.02	0.03		
World	5.3	6.0	82 000	7.3
Solar Therm.				
Germany	4.7	2.9(6Mio m²)	12 500	0.95
World	115	68	180 000	25.0
Biomass				
Germany	2.2 (el)	14 (2.3%)		
	12.8 (therm)	77 (5.2%)	57 000	7.4
	1.7 bln l fuel	19 (3.5%)		
World	39 (el)	230		
	220 (therm)	1200	1 200 000	
	33 bln l fuel	360 (3%)		
Geothermal				
Germany	0.00023 (el)	0.0004	10 000	0.04
	0.56 (thermal)	1.6		
World	8.8	53	110 000	
Wind				
Germany	18.4	26.5 (4.3%)	65 000	4.5
World	57.0	88	130 000	
Hydropower				
Germany	4.7	21.5 (3.5%)	10.000	1.52
World	770	2800		

Fig. 15

Thermal Collector Area/P. 2004

Country	*m²/P*
Israel	0.74
Cyprus	0.62
Greece	0.28
Austria	0.28
Turkey	0.14
Japan	0.10
Germany	0.073

***Biofuel* 2004**

Brazil	15.4 bln l
USA	13.5 bln l
China	2.3 bln l
Germany	1.0 bln l
Others	1.0 bln l

33.2 bln l = 3% of world gasoline consumption (1200 bln l)

2005: 65% increase in biofuel production in E.U.

Fig. 16: *Thermal collector statistics*

Summary

The potential of alternative energies in Germany

	Potential TWh	*Based on to days energy consumption*	*30% energy savings*
Wind	164	4.0%	5.71%
Hydro	25	0.61%	0.87%
Biomass	250	6.10%	8.71%
P.V.	175	4.27%	6.10%
Solarthermal	200	4.88%	6.97%
Wood	600	14.63%	20.90%
Geothermal	30	0.73%	1.04%
Total		*35.22%*	*50.30%*

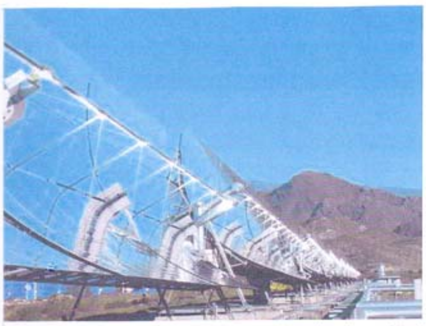
Goal **: from the "6.3kW society" to the "2kW society"**

The renewables could account for 100% of our energy needs.

Fig. 17

Fig. 18: *Solar thermal electric power station in the Mojave desert (USA)*

CESA-1 Solar-Turmkraftwerk auf dem Gelände der südspanischen Forschungseinrichtung Plataforma Solar de Almería (PSA)
Foto: Stefan Franzen



Parabolrinnen der Direct-Solar-Steam-Versuchsanlage auf der PSA
Foto: Volker Quaschning

Fig. 19: *Solar tower (CRS) and solar farm (DCS) system in Almería (Spain)*

Dish/Stirling Versuchsanlage am europäischen Testzentrum Plataforma Solar de

Dish/Stirling Versuchsanlagen auf dem Testgelände der PSA
Foto: Wolfgang Reinalter

Fig. 20: *Dish-stirling concentrator systems, Almería (Spain)*

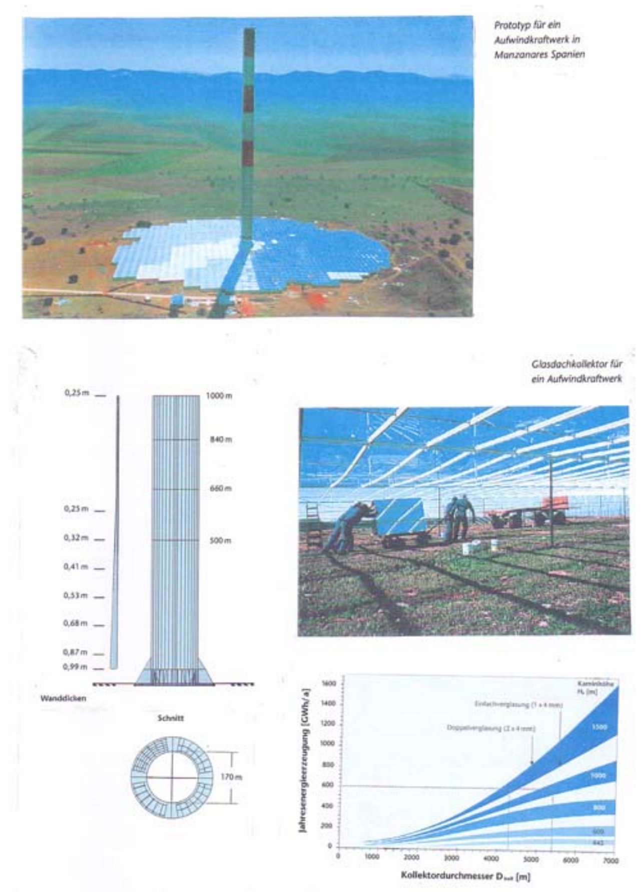


Fig. 21: *Solar updraft tower*

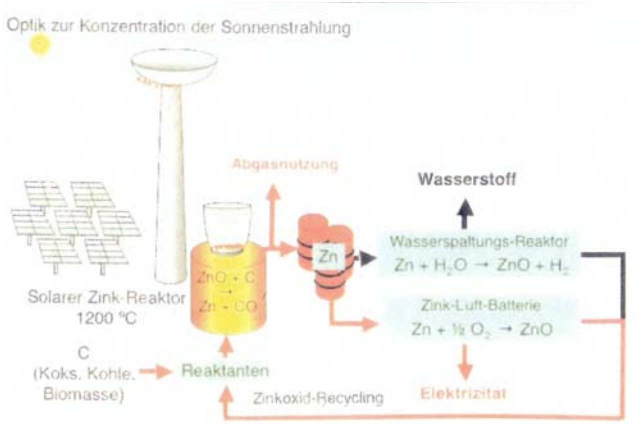


Fig. 22: *Solar thermochemical reactor, PSI (Switzerland)*

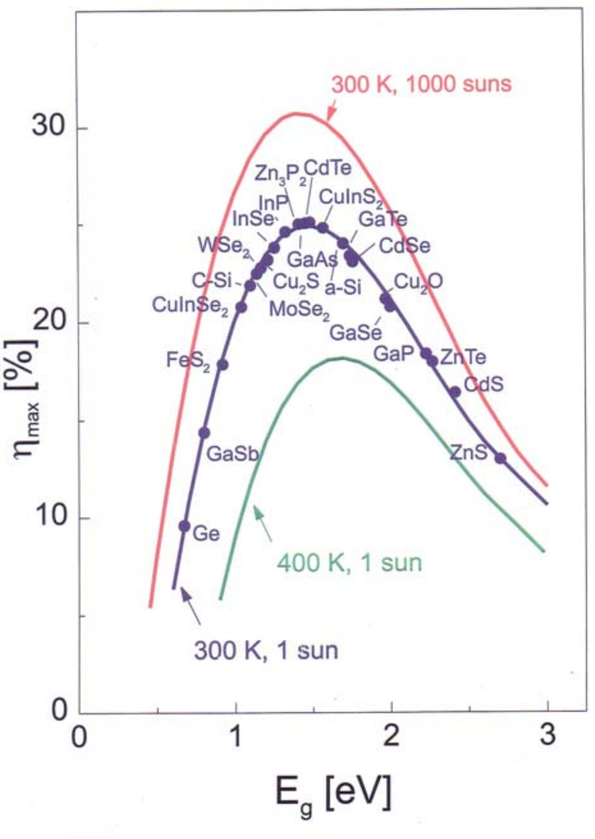


Fig. 23: *Solar cell efficiency vs. bandgap in semiconductors*

Si-Photovoltaics

Material	Production [%] in 2005*	η [%] (lab small)	η [%] (lab large)	η [%] (prod)≥100cm²
mono c-Si	38.3	24.7 (UNSW)	21.8 (Sanyo)	17-20
multi c-Si	52.3	20.3 (ISE)	18.1 (UKON)	>15
a-Si	4.7		9.3	7-8
ribbon-Si	2.9		17.7	15
Total	**98.2**			* Photon international 2006

(CdTe 1.6)
(CIS 0.2)

RD Status	**η [%] (lab)**
Thin Si (48μm)	21.5
Thin Si (20-30μm)	14.7
μc – Si (n-i-p)	11.0
n/p (Si:P)	20.0
RGS-Si	12.8
Transparent solar cells (10-30%)	12-13
Back contact cells (EWT)	16.6
High Voltage cells, 3-12 V	12-13

Fig. 24: *Highest solar cell efficiencies*

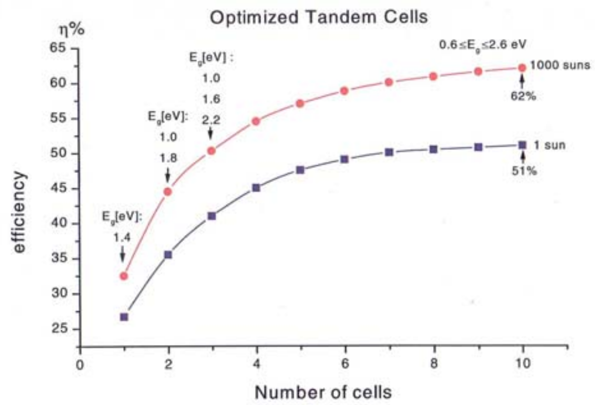
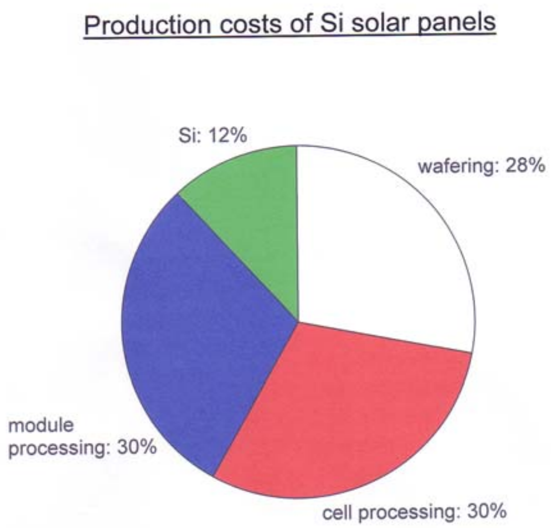


Fig. 25: *Tandem solar cells*

The Best Solar Cells

Material	V_{oc} [mV]	c(suns)	η [%]	A[cm²]	Ref
i) *concentrator cells*					
p/n Si (point contact)		96	26.8	1.6	Sunpower
p/nGaAs		255	27.6	0.126	Spire
p/n GaInAsP		171	27.5	0.075	NREL
p/n InP		99	24.3	0.075	NREL
ii) *Tandem cells*					
p/n GaAs + p/n GaSb	1585	1	34	0.053	Sandia Varian
p/n GaAs + p/n GaSb		500	37	0.053	Boeing
p/n InP/GaInAs		50	31.8	0.063	NREL monol. 3 terminal
p/n GaAs + p/nGaInAsP		40	30.2	0.053	NREL stack 4 terminal
p/n GaAs + p/n Si	1935	347	31	0.32	Varian/ Sandia
a-Si/a-Si-Ge	2357	1	14.6 init. Value	0.25	Guha, USS Troy
	2297	1	13.0 stable	0.25	

Fig. 26



Costs:

Si:	U.S.$ 3.5/Wp (4.7/Wp incl. DC/AC inverter)
Thin films:	U.S.$ 1.5-2.0/Wp (2.7 -3.2 /Wp)

Fig. 27

Fundamentals of P.V. Energy Conversion

	Germany	*Mexico*
Solar irradiation	1000kWh/m²·y (= 100 l oil)	2000kWh/m²·y
Energy harvest	1kWh/W_p·y	2.0kWh/W_p·y
Monoax. tracking	1.35kWh/W_p·y	2.7kWh/W_p·y
Biax. tracking	1.6kWh/W_p·y	3.2kWh/W_p·y
For 1m²	160kWh/y	320kWh/y
El. energy per household (4P)	4000kWh/y	~ 1500kWh/y
Area needed	25m²	5m²
Costs of Installation	$ 16 000	
Electricity costs per year	$ 730	
Amortization time	~ 22 years	

Fig. 28

Land needed for a 100% solar energy supply of mankind

World energy consumption in 2005:	140,000 billion kWh
Solar irradiation in the Sahara:	2350 kWh / m^2
Conversion efficiency:	15%
Land needed:	312,000 km^2
which is equivalent to a square of:	558 x 558 km^2

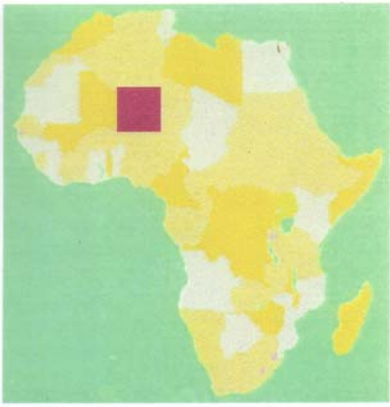


Fig. 29: *Area for total solar energy supply*

Applications in Remote Rural Areas

- Educational programs (for children and adults)
- Telecommunication stations (private + central)
- Water desalination and pumping stations
- Irrigation, reforestation
- Water sanitation (by U.V. and O_3)
- Electrical lighting (public and private)
- Cooking
- Refrigeration (food storage)
- Medical care
- Power supplies for agricultural machines and tools
- Charging units for batteries
- Waste disposal
-
-
-
-
-

Fig. 30: *Applications in remote rural areas*

Fig. 31: *Applications 1: solar bicycle*

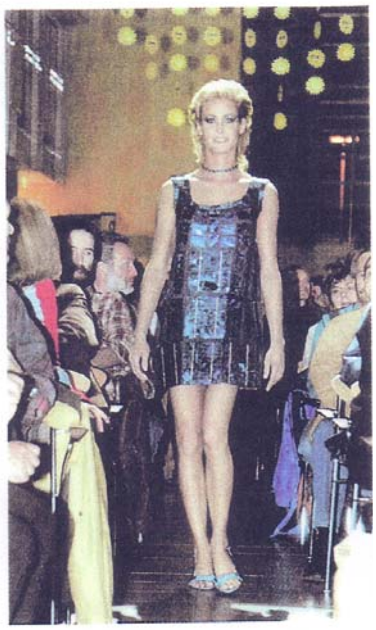


Fig. 32: *Applications 2: solar dress*

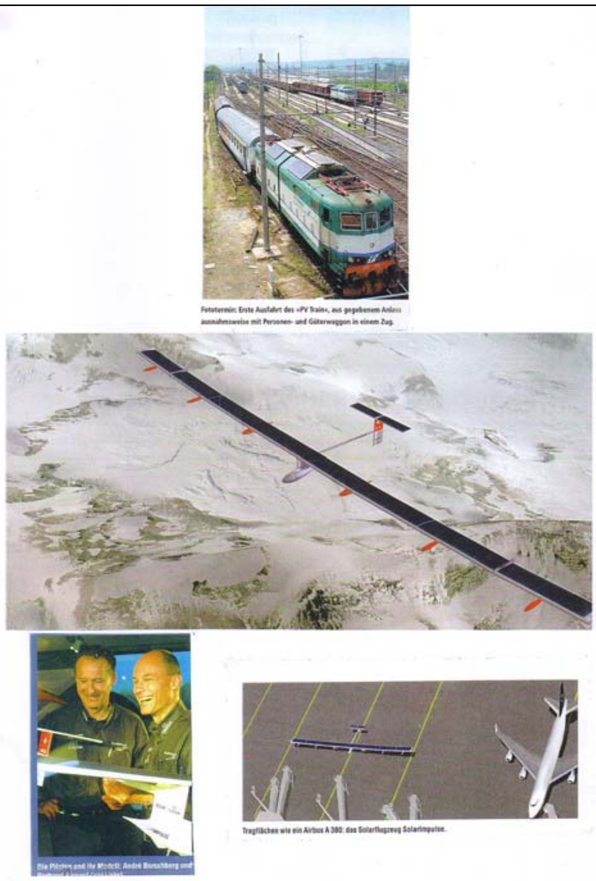


Fig. 33: *Applications 3: Solar train (Italy), solar airplane (B. Piccard, Switzerland)*

Biomass fundamentals 1

organic material →
- biogas → natural gas, heat, electricity
- liquid biofuels → methanol CH_3OH, ethanol CH_3CH_2OH, biodiesel (methylester, ethylester)
- solid fuels (wood pellets) → liquid fuel, heat, electricity

Methods

- 2 stage fermentation (10-20 days)

liquid fermentation 1 (>50% H_2O) anaerobic, 25°-38°C, mesophyllic condition	biogas + solid residue
liquid fermentation 2 anaerobic, 38°-55°C	biogas + solid residue

- anaerobic heating (solid waste, wood) 850°C → biogas $\xrightarrow[\text{Catalytic methanisation}]{350°\text{-}450°C}$ SNG (60%); → charcoal; → residues: tar oil, acids,…

biogas = 50 – 65% methane (CH_4) + 35 – 50% (H_2, H_2O, N_2; CO, CO_2; H_2S, NH_3, PH_3)
→ natural gas (97% methane)

1 t waste → 25 – 150 m³ biogas

Fig. 34

Biomass

- organic waste from farming,gardening and households sewage,manure,animal waste(from slaughter house)
- crops: corn,sugarbeets,wheat,rapeseed,miscanthus, arundo donax,millet,cotton,soybean,castor, switchgrass,sugarcane, grass etc.
- trees: kienaf, eucalyptus, oil palm,coconut palm,birchtree, asptree,ashtree,poplar,willow,elmtree ,firtree etc.
- products: biogas, → nat. gas,methanol,ethanol,biodiesel, other biofuels, heat, electricity
- 3 important key questions:

1) ? kWh/km²,y (photosynthetic efficiency 0.1-10%)

2) net energy gain: (=NEG) output/input= ?

3) cost of kWh for every biofuel product ?

Fig. 35: *Key factors for biomass use*

Biomass fundamentals 2

World agricultural area:	10 million km²
Forest:	40 million km²
Desert & desertlike area:	50 million km²
Photosynthesis /year (dry mat.):	220 billion t/y
Forest (77%):	170 billion t/y
World energy consumption /year:	11.5 billion t/y (oil equivalent)
Dry biomass needed: (2 t dry biomass = 1 t oil)	23 billion t/y =13.5% of forest =5.4 million km²

Energy harvest	dry mass (t/km²,y)	η (%)
Trees: kienaf, eucalyptus, birch,asp,…	1500 – 4000	0.78 – 2.08
Wheat	1200 – 1800	0.62 – 0.94
Corn, sugarcane,reed,…	2000 – 3000	0.80 – 1.20
Solar thermal el. power stations (40-50 MW/km²)		7 – 9
Photovoltaic power		5 – 10
Wind (20 MW/km²=0.09 TWh/km²,y)		9 – 20

Fig. 36

Germany's biomass potential

Total energy consumption in Germany 2005: 4100 bln kWh

Biomass:

- present waste from manure,farming,bioindustry, gardening,households,slaughter industry
  250 million t/y 10.2 bln m^3 biogas — 65 bln kWh/y (=1.6%)

- energy farming:
  total agricultural area: 170 000 km^2
  for energy farming : 13% 20 000 km^2
  used in 2006 : 5 500 km^2
  conversion to biodiesel& ethanol: 115 bln kWh/y (=2.8%)
  dry bioproducts: 1700 t/km^2: 130 bln kWh/y (=3.2%)

- forest:
  total forest area: 105 000 km^2
  unused forest area(30%) 32 000 km^2
  2000 t/km^2 of 70% forest: 74 000 km^2 550 bln kWh/y (13.4%)

- **Total biomass potential: 860 bln kWh/y**
  = 21.0%

Fig. 37

Biomass fundamentals 3

1 m^3 biogas = 0.5 – 0.65 l fuel = 5.3 – 6.9 kWh = 1.6 – 2.1 kWh electricity

1 m^3 nat. gas = 10.4 kWh

1 t dry biomass = 210 l ethanol + 314 kg protein concentrate(animal food)

1 km^2 → ⩾ 1000 t dry biomass = ⩾ 210 000 l ethanol + 314 t animal food

1 t dry biomass = 583 m^3 biogas = 3710 kWh = 1113 kWh electricity

1 l	biodiesel	=	9.4 kWh (= 0.92 l reg. diesel)
1 l	methanol	=	5.0 kWh
1 l	ethanol	=	5.9 kWh (=0.66 l gasoline)
1 l	gasoline	=	9.0 kWh
1 kg dry wood		=	4.5 – 5.8 kWh
1 l	oil	=	10 kWh
1 kg coal		=	8 – 9.5 kWh

Fig. 38

Bioethanol

Plant	Crop yield (ℓ/km²)	Energy yield (output/input)
Switchgrass (USA)	1´075´000	0.67[†], 4
Sugar beet (France, Germany)	665´000	1.9
Sugarcane (Brazil)	620´000	8
Cassava (Nigeria)	385´000	
Potatoes (Germany)	355´000	
Corn (grain) (USA)	352´000	
Sweet sorghum (India)	350´000	
Corn (USA)	330´000	0.7[†] – 1.34[‡]
Wheat (France)	275´000	
Wood	250´000	0.64[†]
Gasoline		1.805[†]
Petroleum diesel		1.843

BIOETHANOL

Rohstofferträge zur Herstellung von Bioethanol

Rohstoffe	Ertrag (Frischmasse) [t/ha]	Kraftstoffertrag [l/ha]	erforderliche Biomasse pro Liter Kraftstoff [kg/l]
Körnermais	9,2	3520	2,6
Weizen	7,2	2760	2,6
Roggen	4,9	2030	2,4
Triticale	5,6	2230	2,5
Kartoffel	44,0	3550	12,4
Zuckerrüben	61,7	6620	9,3

Quelle: Bioethanol in Deutschland, Hrsg. N. Schmitz

Alkoholische Gärung:

$$C_6H_{12}O_6 \text{ (Glucose)} \longrightarrow 2\,C_2H_5OH \text{ (Ethanol)} + 2\,CO_2 \text{ (Kohlendioxid)}$$

Fig. 39: *Bioethanol fundamentals*

Biodiesel

Plant	Crop yield (ℓ/km²)	Energy yield (output/input)
Oil palm	475´000	
Coconut	215´000	
Castor	125´000	
Rapeseed	97´000	3 – 4
Peanut	84´000	0.85[†]
Sunflower	77´000	0.79[†]
Soybean	52´000	0.64[†]
Flaxseed	44´000	
Linseed	41´000	
Average		3.2[‡]
Gasoline		1.805[‡]
Petroleum diesel		1.843

[†] D. Pimentel and T.W. Platzek
Natural Resources Research 14 (1), p.65-76, Springer 2005

[‡] Sheehan et al.
An overview of biodiesel and petroleum diesel lifecycles
NRL, DOE and USDA Study 1998

Fig. 40: *Biodiesel fundamentals*

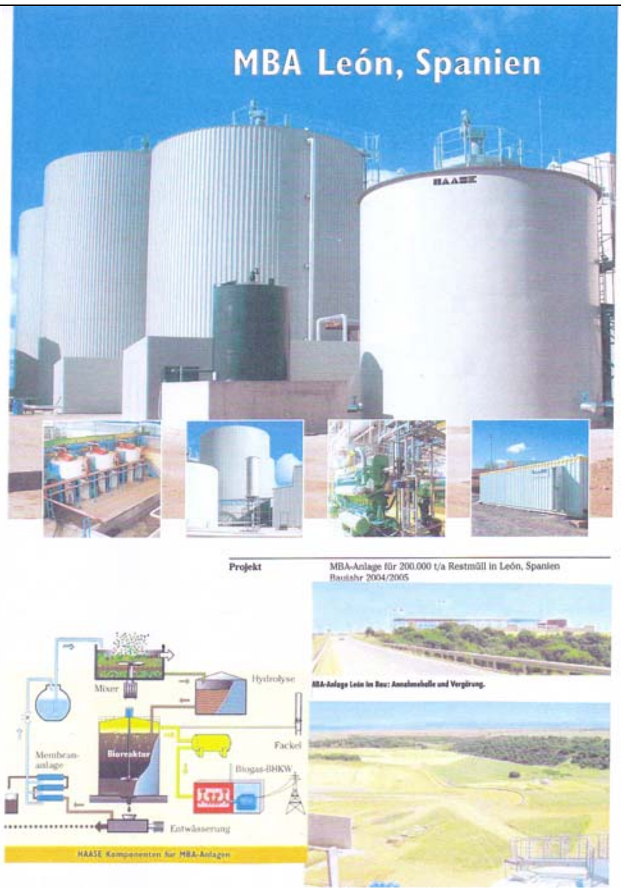


Fig. 41: *Biomass processing system in León (Spain)*

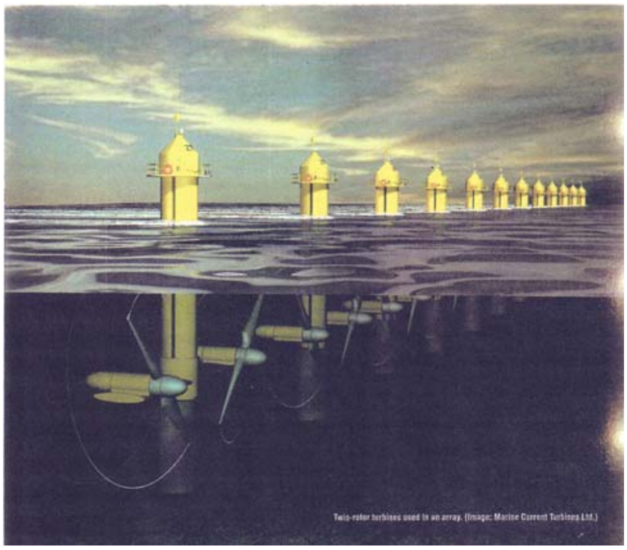


Fig. 42: *Scheme of an ocean-current electric power station*

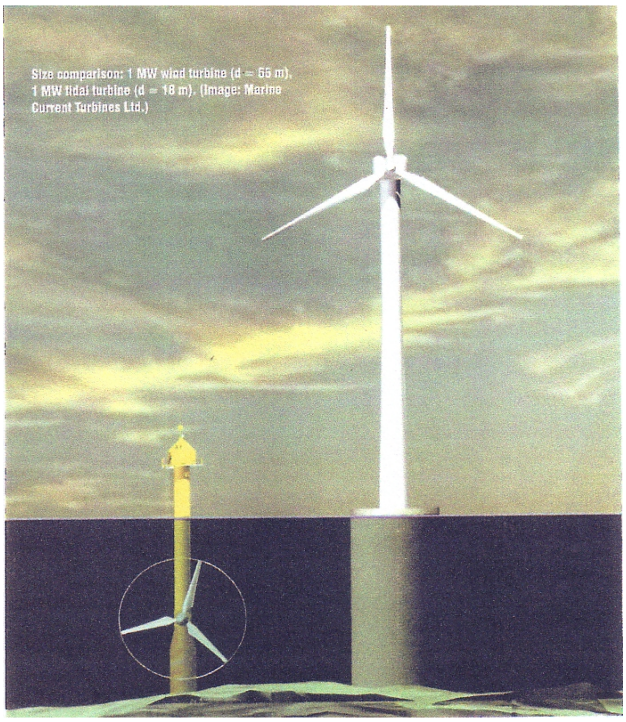


Fig. 43: *Scheme of ocean-current and off shore wind electric power station*

Recycling (in Germany)

Paper:	saves 8 kWh/€ of paper
Glass:	saves 25% of production energy
Aluminum:	saves 40% of energy

100% recycling can save 4% of annual energy consumption

Households (4 persons) responsible for 28% of the total energy consumption

	Consumed energy (kWh/y)	Relative fraction (%)	Total fraction (%)	
Heating	17´000	20	5.60	
Electricity	4´500	5.5	1.54	
Food ('gray energy')	19´000	22.5	6.30	2 kWh/€
Clothing	9´500	11	3.08	2.8 kWh/€
Car (15000 km/y)	15´000	18	5.04	1 kWh/km
Expendables	20´000	23	6.44	
Total	**85´000**	**100**	**28.00**	

Fig. 44: *Energy savings by recycling*

Saving energy in households

Heating: • lowering temperature by 1°C saves 7% of energy
• shower instead of bathtub saves 80% of warm water
• better thermal insulation of buildings: 75%
• boiler setting to 55 – 60°C
⇨ possible saving: up to 70% **3.9% total**
⇨ household waste to biogas **1.0% total**

Food: • red meat takes 10 times more energy than grains, vegetables and fruit
• fight overeating and obesity
⇨ possible saving: **2.0% total**

Car: • carpools, usage of bikes and public transportation
⇨ possible saving: **3.5% total**

Electricity: • usage of energy efficient models
⇨ possible saving: **0.5% total**

Expendables: **2.1% total**

Total possible savings in households: **13% total** (of 28%)

Traffic: 18.5% total (cars: 760 billion km driven in 2004)
Production of 1 car costs 80´000 kWh
Driving 1 km costs 0.9 kWh (mostly (73%) driven by 1 person)
Usage: 45% business + 55% leisure
⇨ Possible savings in traffic: **9% total**

Savings in household and traffic: **22% total**
Saving per person (6 cts/kWh): **660 €/y**

Fig. 45: *Energy saving potential in households*

The freshwater problem 2006

- 1.6 billion people (25%) suffer from inadequate drinking water supply
- 2.7 billion people do not have sanitary equipment
- 8 million people die every year from contaminated water
  35 million die every year from hunger
- the situation is getting worse every year:
- by 2025 3.5 billion people(50%) will not have adequate water supply
- all these people live in the tropical or subtropical area

Solution:

- solar seawater desalination
- windpower seawater desalination

Fig. 46

Freshwater consumption

Dubai (UAE)	1000 l/d,P	(=700 000 m^3/d)
Switzerland	480 l/d,P 270 l/d,P	(total) (household)
Africa	3-5 l/d,P	(desert areas)

2006: daily world freshwater production: 35 million m^3/d
= 0.21% of total freshwater consumption

Biggest RO plant: Ashkalon,Israel 275 000 m^3/d

Energy costs: regular freshwater: 0.25 kWh/m^3
desalin. freshwater: 4-5 kWh/m^3

Fig. 47

Methods of desalination

- thermal methods: distillation
  multistage flash evaporation (MSF)
- membrane methods: multistage ultrafiltration (MSU)
  reverse osmosis (RO)
  electrical dialysis (ED)

costs of desalination

method	temp.(C)	energy(kWh/m^3)	costs(US$/$m^3$)
solar distillation	65	700	1.2
MSF	70 – 115	70 - 80	1.0
windpower	65	45 - 55	0.8
RO	amb.	4 – 5	0.5
ED	amb.	3 - 4	0.6
minimum needed for salt elimination	amb.	0.7	--

Fig. 48

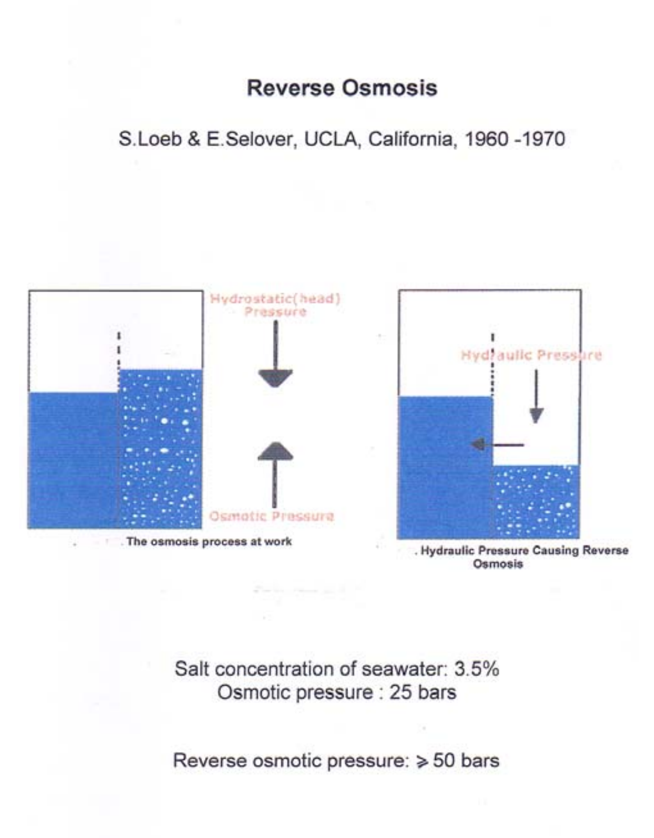


Fig. 49: *The principle of reverse osmosis*

Freshwater need

- **immediately** — **need**

1.5 bln people,100 l/d,P — **150 million m^3/d = 55 bln m^3/y = 0.91% of annual waterconsumption = 4.3x 2005 fresh-water production**

energy need by RO (4 kWh/m^3): — **220 bln kWh/y = 0.16% of world annual energy consumption 2006 = 110 GW PV = 18x existing PV power in 2006**

- **by 2025**

3.5 bln people,100 l/d,P — **128 bln m^3/y = 2.13% of annual waterconsumption = 10x 2005 fresh-water production**

energy need by RO (4 kWh/m^3): — **513 bln kWh/y = 0.36% of world annual energy consumption 2006 = 256 GW PV = 42x existing PV power in 2006 = 20.5% growth/y of PV needed for 20 years**

total costs: — **2400 bln US $ = 0.38% of annual world budget of the warindustry**

Fig. 50: *The world´s need for freshwater and costs to remedy it*