Emerging energy and environmental crisis: Can solar energy make a difference?

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1. Energy and environment – present situation

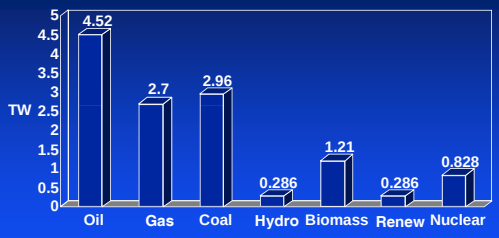
Mankind's most urgent problems:

Hunger, poverty, health, water, energy, environmental degradation, climate change, wars, ….

IF inexpensive energy was available: Hunger, poverty, health & water (& wars?) not a problem.

Energy, environmental degradation & climate change

World energy consumption



Total consumption: approx 13 TW
(in 1998; today approx 14 TW)

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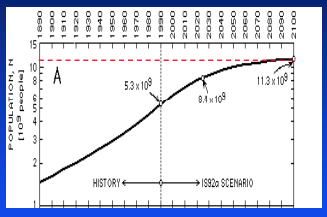
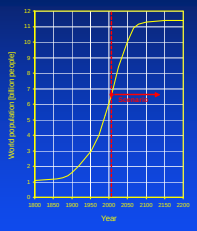
World population: Explosive growth ...





Population expected to reach 11 billion in 2070
(doubling compared to 1990 level !)

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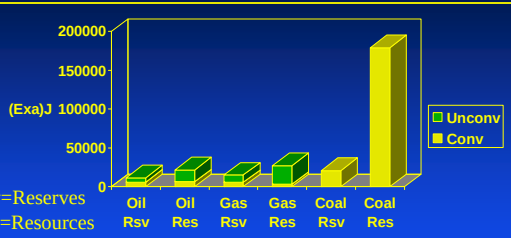
Fossil energies: Reserves & resources



Rsv=Reserves
Res=Resources

Reserves/(1998 Consumption/yr)	
Oil	40-78
Gas	68-176
Coal	224

Resource Base/(1998 Consumption/yr)
51-151
207-590
2160

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Are we running out of energy?

No, not in the foreseeable future. But ...

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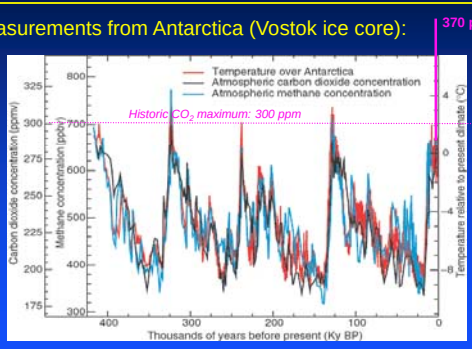
CO_2 and temperature

Measurements from Antarctica (Vostok ice core):



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Key task

Let's work hard to ensure that mankind **does NOT use coal** to cover its future energy needs!

Otherwise we risk a catastrophic global environmental crisis ...

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First hints of global warming?

Example Antarctica (Larsen B ice shelf, 1996-2003)

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Imminent consequences of increased CO_2 levels?

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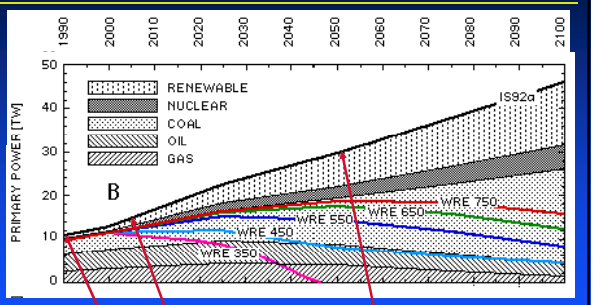
Evolution of world energy demand



1990: 11 TW **2005: 14 TW** **2050: 28 TW**

[IS92a = Energy scenario of the *Intergovernmental Panel on Climate Change* (IPCC) from 1992]

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CO_2 evolution

If we don't act aggressively, the atmospheric CO_2 concentration will increase to more than **700 ppm** in the next 40 years!

➔ Need a carbon-neutral energy economy!

➔ **Renewable energies**

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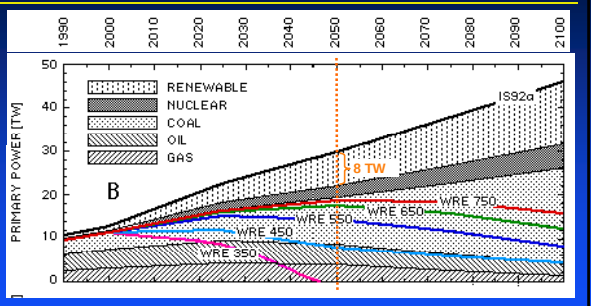
Demand for renewable energy in 2050



To avoid climate catastrophe: Need 10-20 TW (!) of renewable energy in 2050.

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Technical potential of renewable energies

Technical or practical potentials of renewable energies in 2050:*

- Hydropower = approx 1 TW (70% already realised).
- Wind = approx 2 TW.
- Geothermal = 1-5 TW (theoretical potential ~40 TW, however technical breakthroughs with deep drilling required).
- Biomass = 5-7 TW.
- **Solar = approx 600 TW (!!!)** (land & water), including approx **60 TW of solar electricity** (Eff = 10%, land only).

** N. Lewis, California Institute of Technology, 2005.*

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Required land for 20 TW of solar electricity

6 squares @ 3.3 TW each

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Solar energy – Required technologies

a) Solar thermal
Inexpensive & efficient solar thermal systems (collectors, pumps, support structures, building integration, …)

b) Photovoltaics
Inexpensive & efficient PV systems (solar cells, PV modules, inverters, support structures, building integration, …)

c) Energy storage & conversion
Solar district heating, solar hydrogen, electrochemical energy storage (batteries), fuel cells, ...

d) Energy efficiency
Energy-efficient buildings, solar architecture, solar heating & cooling, 3-litre house, 3-litre car (solar hydrogen or electric), ...

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2. Basics of Photovoltaics (PV)

Photovoltaics (PV)

- *Direct* conversion of solar energy to electrical energy via *solar cells*.

Advantages:

- Clean energy.
- Uses an inexhaustible renewable energy source.
- Modular (from mW to TW).
- Very low safety risks.
- Reliable; low maintenance cost.
- Also suited for developing countries.

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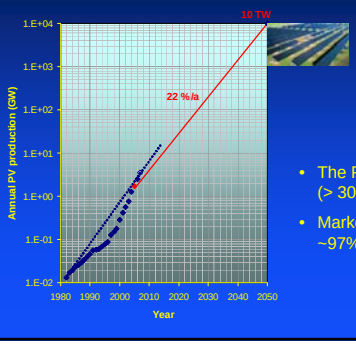
Photovoltaic market



- The PV market is booming (> 30 %/a since 1999).
- Market share of silicon in 2007: ~97% (thin-film Si: ~6%).

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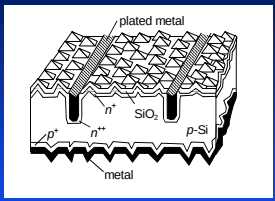
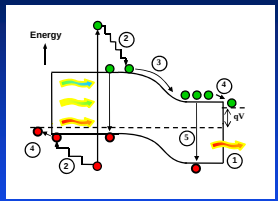
Principle of a p-n junction solar cell



Industrial silicon solar cell



Loss mechanisms in a p-n junction solar cell

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3. Why crystalline Si for solar cells?

PV properties of crystalline Si:

- Excellent bandgap for PV (efficiency limit = 29%).
- Excellent efficiency already realised in lab (24.7%).
- Good electronic and mechanical properties.
- Abundant material.
- Non-toxic.
- PV modules are long-term stable (> 20 years).
- Si dominates the microelectronics industry → large number of machines for industrial production exist already.

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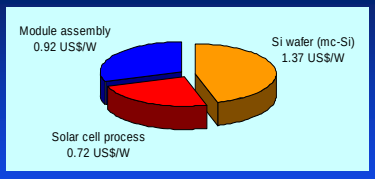
Si wafer solar cells

PV module with Si wafers:

Cost = 3-6 US$/W.



Cost distribution of a PV module with mc-Si wafers (13%, 3 US$/W).

⇨ **Fantastic technology, but: Need dramatic cost reduction! ➔ Huge R&D effort required.**

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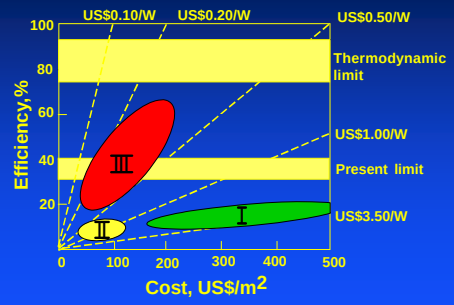
1G, 2G, 3G photovoltaics



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Strategies for crystalline Si PV

Two strategies:

Larger & thinner & cheaper Si wafers

Si thin-film technologies

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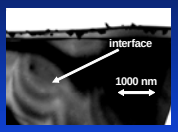
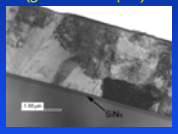
Three types of crystalline Si materials

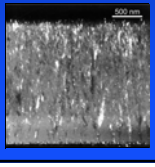
Monocrystalline Si (g = ∞)



Polycrystalline Si (g = 1-1000 μm)



Microcrystalline Si (g = 100-500 nm)



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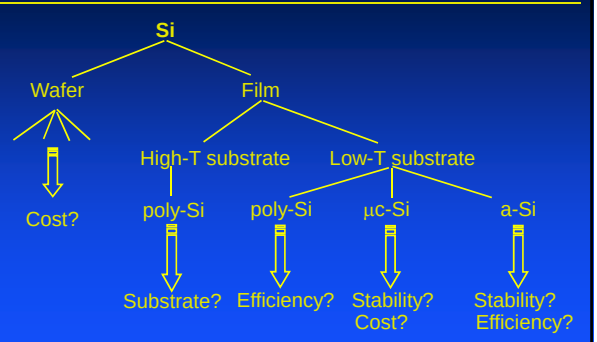
Si PV technologies



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Industrial deposition machines for Si films

Source: http://www.oerlikon.com

Loading of a 1.4-m² glass substrate into a batch-type PECVD machine (KAI-1200 from Oerlikon Solar)

Source: http://www.csgsolar.com

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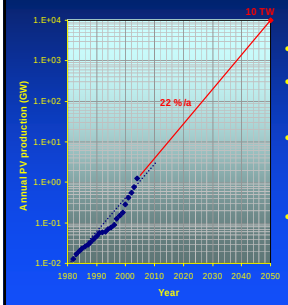
4. Summary of talk



- 10 TW of solar electric power in 2050 is technically feasible!
- Standard material = silicon.
- Si wafer solar cells need continuous development. Eff > 20%.
- In parallel: Development & market introduction of crystalline Si thin-film solar cells. Eff > 10%.
- Also: Highest-eff. tandem cells for concentrator PV systems (GaAs, GaInP etc on Ge). Eff > 40%.

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Summary (cont'd)

Question: Emerging energy and environmental crisis: Can solar energy make a difference?

Answer: From a scientific-technical viewpoint, **definitely YES!**

Prerequisites for breakthrough of solar energy:

- Politicians must create fair boundary conditions („level playing field") in the energy sector (i.e., the CO_2 emissions of fossil fuels must be penalized financially → carbon tax).
- Solar energy must be funded at least as strongly as nuclear energy.
- Need continuous support in all sectors (R&D, industry, end users).

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