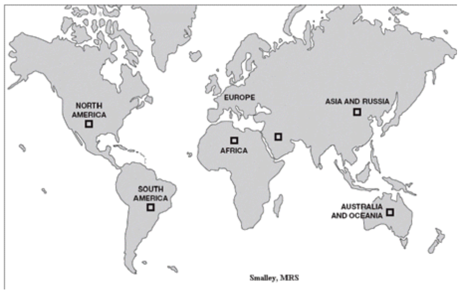
Frequently Asked Questions Concerning Solar Cells

Advanced

Area Needed for Producing Lots of Energy by Solar Cells

- Do we have enough **area** that we can cover with solar cells to produce the energy we need?
  - Let's look at *you* - an average **EU** citizen. Here are your basic data:
    - You need roughly **150 kJ/a** ≈ **40 000 kWhr/a** primary energy.
    - Your direct electricity only (secondary energy) needs are around **2 000 kWh/a**.
    - Your direct plus indirect electricity only energy needs are around **6 000 kWh/a**.
    - Your **1 m^2** solar module with η **= 15 %** solar cells produces in Germany **150 kWh/a**.
    - There are roughly **500** million of you; including **82** million Germans.
  - Obviously *you* need.
    - **267 m^2** for *your* total primary energy needs and **132 000 km^2** for all of you Europeans (**21 900 km^2** for the Germans)
    - **40 m^2** for *your* total electricity needs, and **20 000 km^2** for all of you Europeans (**3 280 km^2** for the Germans)
    - **13 m^2** if *you* don't want to pay electricity bills anymore, and **6 500 km^2** for all of you Europeans (**1 070 km^2** for the Germans)
  - How much available area is there?
    - The **EU** (Germany) covers about **4.2 · 10^6 km^2** (**357 · 10^3 km^2)**. The total needs of all of you are thus **3.14 %** of the area of the **EU** or **21 900 km^2** for the Germans,
    - The German "Autobahnen" alone have a length of **12 000 km** or an area of roughly **12 000 km · 25 m = 300 km^2**.
    - All the other (paved) roads have a length of about **500 000 km** or an area of **500 000 km · 7 m = 3 500 km^2**. The railroads add up to **43,457 km · 5 m = 218 km^2**. All traffic space together (without airports, etc.) thus consumes **> 4 000 km^2** or **> 1 %** of the German area.
    - How much average rooftop area do you have? Count the roof on your home; but also on the places you work and hang out. Let's guess it's around **5 m^2 - 25 m^2**, with a total of **410 km^2 - 2 050 km^2** in Germany.
  - All the German area presently build over with something thus amounts to **(5 000 - 7 000) km^2** in our crude guess, only a quarter or a third of what we would need.

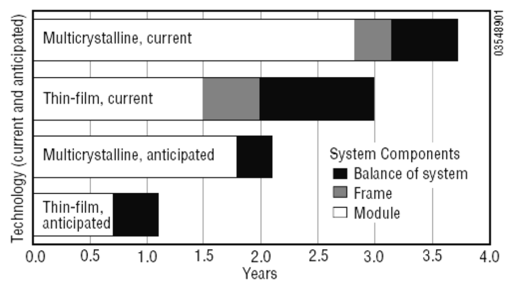
- *Conclusion*: Obviously it is a good idea to also use wind power, solar heating and so on, and above all, to *reduce consumption*, because we don't want to cover even more of the ground by solar panels than we have covered already by concrete and asphalt.
  - But the numbers also suggest that we can produce a lot of electricity by simply covering rooftops with solar cells. Even the low number of **400 km^2** would produce about half of your secondary *direct* electricity needs, i.e. would substitute for power plants with three times the *primary* power capacity.
  - "**Bio fuel**" that is grown and burned in regular power plants for producing electricity is *not* a good idea in this context. Photo synthesis, while remarkable for its adaptability and so on, runs at far lower efficiency than a solar cell. Comparing the energy that one can harvest from a given area by bio fuel and by solar cells shows that solar cells "harvest" orders of magnitude more solar energy per **m^2** than "e**nergy plants**". Bio fuel only comes into its own if used as energy storage medium or if produced as a by-product of producing food, for example.
  - Right now, we Germans import a lot of our energy needs in the form of oil, ga,s and coal. We could just as well import solar energy. Our total area needs add up to a square with **150 km** side length. You could hide an area of this size in the Sahara desert with little chance of someone finding it by accident.
- Here's a world map showing the total area (= squares) needed in some deserts to supply mankind with all the energy it reasonably needs.



From the [article](#) of Nobel prize winner **Richard Smalley** in the MRS Bulletin **30, 2005**

Energy Pay Back Time

- What is the energy **pay-back time** for solar cells? To ask more pointedly: Does a solar cell during its life time (let's say **20** years) produce the energy that it took to make it?
  - The **energy pay back time** thus is simply the time a solar cell has to "work" to generate just that amount of energy that it took to make it. Of course, any regular power plant has an energy pay back time, too
  - How large is the energy pay back time for any energy "producing" contraption? What do you count for a standard coal-fired plant, for example? For sure the energy needed to make its components and to assemble the whole contraption. You should count the energy for digging out the coal and for transporting it, of course. Do you also count the energy needed to tear it down one day and to redo the damage done by the emissions? Should you also count the energy needed to keep the humans alive that run the plant (you must feed them on occasion and transport them to the plant)?
  - You realize that the concept of an energy pay back time is not so easy as it appears on a first glance. If you consider on top of this that the energy needed to build a solar cell also keeps people in business, it becomes even more complicated and questionable.
- Nevertheless, there are useful definitions that allow comparison of different energy producers and based on this one can come with numbers. There is a considerable spread in those number, depending on who produced it. You can bet that supporters of solar energy come up with smaller numbers for the pay-back time of solar cells than the supporters of nuclear power, and vice verse.
  - In any case, the energy pay back time will be several years at the most
- The picture shows some recent data from an unimpeachable source not likely to favor solar energy (George W. Bush ~~is~~ was the Boss!).



From the ***DOE*** (Department of Energy) of the USA government

The Costs of Energy

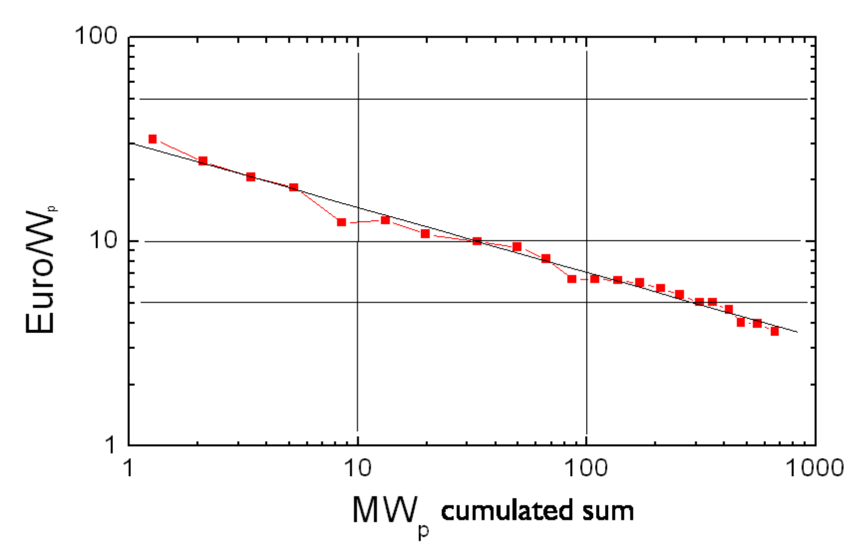
- So we have enough land and solar cells would produce net energy - far more than it took to make them. But can we **afford** it?
  - Right now, in Germany we pay something like **0.10 €** for **1 kWh** of electrical energy delivered to our homes, and something like **1.50 €** for a liter of Gasoline, which [amounts to](#) about **10 kWh**. Solar electricity costs are much higher, it is said. If prices were to double and triple, we simply couldn't afford it and would be reduced to poverty.
- Well **-** yes and no! If prices were to double but consumption would be halved, we have no problem since we can maintain the present quality of life at half the energy consumption if we just try!
  - Of course, halving consumption will need a lot of money for investments, which we cannot *afford*. In particular, we have to build a lot of new and better buildings - heating-wise. But this would be a big boost to the construction business, which would create lots of jobs and lots money.... .

- National economy is just not that easy. Right now (end of **2007**) we are told by the experts that the world faces an unavoidable major financial crisis because the Americans overspend, meaning that they spend money they don't have but borrowed from the Chinese and others. The only way to avoid this crisis, we learn, is if the Americans keep overspending and go even more into debt. There must be reasons why the experts on this are almost always wrong in their predictions. It simply boils down to the fact that money, to a small part, consists of silly pictures printed on paper and to a larger part of bits stored in some computer memory.
- After the war, a lot of Germany was destroyed, nobody had money, and we certainly could no more afford to rebuild Germany then than we can afford to rebuild the energy infrastructure now. However, people then didn't know this and the economic miracle took place. Obviously, all we have to do, is to bomb a large percentage of our buildings (in particular the power plants) ourselves (the Americans are busy in this respect elsewhere, anyway) and rebuild them in energy-smart ways.

1st Conclusion: There is simply no real money problem except for the one in our heads.

Even better, the costs of solar power is coming down exactly on schedule. Costs of technology always come down with experience *and* with mass production, and this always follows an exponential decay curve in the beginning, called the **learning curve**.

- Here is the solar cell learning curve. It it continues like that, we will have "**grid parity**" in **7 - 12** years, i.e. the solar **kWh** costs exactly whatever you will pay for conventional (electrical) power.



Learning curve of solar cell energy costs

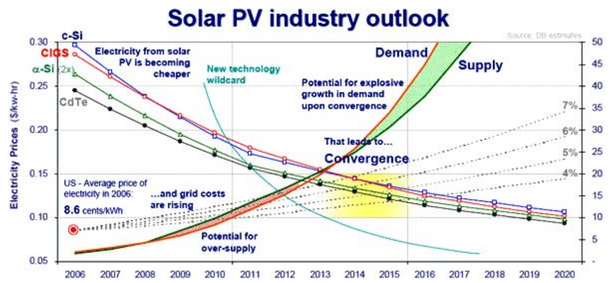
2nd Conclusion: Whatever solar energy money problems there might be, they are small (the problems, not the amount of money needed) and pale in comparison to the no-solar-energy problems looming in the background!

- The war in Iraq so far has run up a direct bill (money out of congress) of about **450 000 000 000 $** (about **$3 \cdot 10^{11}$ €**) and simply shows that large amounts of money are not the problem, when it comes to securing energy (the wrong way, in this case).

So What's Going to Happen?

How the hell should I know? But one thing is certain: if some people out there believe that there is serious money in solar energy, they will go into it. If that means saving the world as a side effect - so be it.

- Here is a scenario put together by a guy from "Deutsche Bank". It contains nothing new to Materials Scientists and Engineers who keep in touch of what is going on, but ... see above.



Scenario for the photo voltaic (***PV***) Industry according to Deutsche Bank research (Spring 2008)

- Even in the most pessimistic scenario, solar energy will simply be cheaper than what you pay to you utility company in **2015**. Then there is a potential for "explosive" demand, meaning that a decent amount of money will be involved - couple thousand billions a year or so.
  - Be sure to buy stock from the right companies at the right time!

Efficiency Limits

- There is a wide-spread feeling in the (published) public opinion that if on would spend a lot of money on solar cell **R&D**, or even better would have spend a lot of money already in the past, we would have much better solar cells now. "Better" in this context seems to be often confused with "higher efficiency".
  - After all, converting just a little more than **10 %** of the energy contained in the sun light into electrical energy is a pitifully small efficiency η; even old-fashioned coal fired power plants have efficiencies around **η = 30 %**.
  - So, give those tinkers more money, and the will (or already would have) come up with the **η = 30 %** solar cell!
- **No!** No matter how many tinkers slave away in their garages for all that time, they will not beat the iron-clad limit for efficiency that comes straight out of semiconductor theory. The first law of engineering science obtains:
  - *There is nothing more practical than a good theory*.
  - There are strict limits for efficiencies. You will *never* be able to make a **Si** solar cell with **η > 25 %**, so don't even try it. We will probably also never be able to make millions of *very cheap* **Si** solar cells with **η = 24 %**; but if you give me lots of money, I could try.
- While we have and will be struggling to increase the efficiency of present-day **Si** solar cells *somewhat* (**0.5 %**, lets say) every year (and thanks for the money!), the real problem is not in semiconductor physic.
  - The only game in town with respect to solar cells is: Make a lot *and* make 'em cheap!
  - It's not physics, it is Materials Science *and* Engineering!

Night

- Half of the time the sun isn't shining and solar cells are not producing any energy. How about that?
  - Now we have a real problem. While we can hope that somewhere in Europe the wind is always blowing, the same is certainly not true for sunshine. A Europe-wide power grid would not help in this case since it's nighti n all of Europe at about the same time.
  - An **AC** power grid actually never helps very much for that task, because the losses in transmission of power via high-voltage cables are too large after a couple of **1000 km** or so. We can thus neither transport "wind energy" from Sicily to Denmark at some reasonable efficiency via **AC** electricity, nor direct solar energy. However, with a high-voltage **DC** grid we have fewer losses and eneryg transport over larger distances (several **1.000 km**) now might be envisioned. Look for "Desertec" in the net to get some idea of what is in the making.
- This is a real and big problem - coming up as soon as solar energy has a sizeable chunk of the energy market. Right now, the fluctuations of the solar energy input into the grid are easily compensated by the other power providers. At night, some gas turbines somewhere run a bit more energetically, and that is all it takes.
  - What we clearly need is some way of storing energy. Unfortunately, there is presently no good solution for energy storage.
  - If you look at the energy density of various energy storage technologies, you realize that any mechanical storage by lifting masses ("$E = m \cdot g \cdot h$") is extremely inefficient. You must lift your liter of gasoline to a height of about **360 km** to have the same potential energy you get as thermal energy by simply burning it.
  - This is not to say that ***pumped-storage hydroelectricity*** is useless, just that it takes large amounts of space to install sizeable capacities.

- The article in the link has a lot to say about the energy storage problem; the author (a Noble prize winner) is cautiously optimistic about this issue.
    - If and how the problem can be solved remains to be seen, the only save bet is that it will provide important and interesting work for scores of materials scientists.