research report [x]
This template should be used in all FoAM research projects for purposes of evaluation and documentation. When you write your report, please include the section titles and use the text in italic as a guide.

Project Title:

PhoEf: Photons' crush on the creative worlds.

Context

- **introduction**

"The Sun is the width of a human foot." *Heraclitus*

PhoEf is a research project about photovoltaics, more commonly known as solar energy. The aim is to provide insights and information that will allow artists, designers and other creative people to engage (more) with this renewable source of electrical energy, to question , investigate, experiment. At the same time the aim is that the research can contribute to bridge the technological, scientific and arts worlds by identifying the concerned actors, actions and processes.

PhoEf's body of knowledge will consist of an overview of artists and arts projects using photovoltaics in one way or another. A theoretical section will look at the dominant and emerging and experimental technologies with special attention for the aesthetics, versatility and environmental issues in the so-called 'off-grid' applications. Also, in more general terms insight will be provided in the underlying scientific processes of PV and the key elements driving research and market. Finally, an extensive overview provides information about handy PV-tools such as 'Design and Installation Guidelines', Do-It-Yourself resources and a who's who in research, institutions, media and on the market.

The research started off in a way at the Luminous Green hands-on workshop where Marko Peljhan showed how to size a PV-system, calculate the energy requirements of an electricity requiring system and how to set-up an of-the-grid system. A rather important observation was the presence of a (lead-acid) battery which stores excess power that can be used when the energy production of the PV-system is not sufficient. We experimented also with more recent PV-technologies such as the Dye Sensitized Solar Cell which is using plant matter as a semiconductor and is imitating the photosynthesis process.

The rapidly growing PV-industrie wants... to grow. But - acknowledging entroy- the idea behind the research is certainly not to contribute to the rise of electricity consumption -it will happen anyway. It's aim is rather to raise the sensibility to light and the electrical energy that can be obtained from it through the photoelectric effect.

- **brief summary of the cultural/scientific/social/... context within which the research took place**

If energy is the essence of our existence...
... than power is the extent to which useful energy is flowing. For every life form energy is needed and sufficient power to keep the flow of energy going. In the combination men, intelligence, energy, it's the source of energy, and not human inspiration that ultimately is the limiting factor for human progress. The struggle for survival in between organisms and with others is a fight for conquering useful energy and to assure the flow of energy through these living systems. In the beginning of the 21st century more than 85 percent of the world's energy comes from fossil fuels, 40 percent from oil, 22 percent from coal and 23 percent from natural gas. They are expected to account for almost 90th of the growth in energy demand between

now and 2030.[1] Nuclear and hydroelectric power account for an additional 7 percent each while only 1 percent comes from geothermal, solar, wind, wood and waste sources. World energy has increased seventy fold since the onset of the fossil-fuel era and how we are now living has been made possible by coal, oil and gas and every form of progress -commercial, political or social- is in one way or another related to the enormous increase of the amount of available energy that could be generated through the burning of fossil fuels. Over the last 200 years Western society has consumed more energy than all other societies together in the history of men. By the end of the 21th century, if current trends continue, the world's population is likely to have almost doubled and its wealth increased by a factor of between 8 and 16 times. World energy demand will probably have doubled and possibly quadrupled, despite major improvements in energy efficiency. How can this enormous demand be supplied, cleanly, safely and sustainably?

The renewable energy sources are essentially carbon-free and appear to be generally more sustainable than fossil or nuclear fuels, though many technologies are still under development and the costs of some are currently high. But remarkable progress has been made in the field and recognition increased that renewable energy could provide a major proportion of the world's needs by the middle of the 21st century.[2]

> During the course of economic development man has been forced over and over again to change the resources he depended on and the methods he used to exploit them. Slowly he has had to involve himself in more and more complicated processing and production techniques as he has changed from the more easily exploitable resources to the less easily exploitable... In its broadest ecological context, economic development is the development of more intensive ways of exploiting the natural environment.[3]

Mankind's drive to Auto-destruction (?)
New scientific insight and new research have confirmed that global climate change is taking place and is projected to continue. Impacts of climate change on society and natural resources are already occurring worldwide and are projected to become even more pronounced.
The impacts of climate change, including those on natural ecosystems, biodiversity, human health and water resources such as floods and droughts, are already being observed and are projected to become more pronounced. The least developed countries are among the most vulnerable, having the least financial and technical capacity to adapt, for example, to droughts or increased flooding.

> The rules of thermodynamics learn how far we can go in the attempt to dominate the environment. The energy system imposes restrictions on a society, and when these are not acknowledged than this society is risking it's downfall.[4]

Air
Much of the recent global warming can be attributed to greenhouse gas (GHG) emissions from human activities. The average temperature — globally and in Europe — continues to increase. Globally it has increased 0.74 °C between 1906–2005. The energy sector is the main contributor to total greenhouse gas emissions and generates significant environmental impacts, such as emissions of other air pollutants (acidifying substances, ozone other precursors and particulates), oil spills, and nuclear waste. World wide coal is the most important source for electricity generation (almost 40 percent). We burn three times more coal now than in the '70ies. Top 5 coal consumers are USA, China, India, Germany and Japan.[5]

> Total energy consumption throughout the pan-European region is growing and remains dominated by fossil fuels. Despite large reductions in some air emissions in parts of Europe, the energy supply sector remains a major contributor to air pollution and greenhouse gas emissions. Current policies are unlikely to be sufficient to meet long-term climate change and air quality objectives.

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1 Philibert, C. Solar Energy and Climate Change. International Energy Agency. Buenos Aires (AR), December 14, 2004. p.2.
2 Rifkin, J. (2002). The Hydrogen Economy: The Creation of the World-Wide Energy Web and the Redistribution of Power on Earth. Jeremy P. Tarcher/Penguin. New York (US). pp. 64-70.
3 Wilkinson, R. Poverty and progress (1973). Praeger. New York (US). pp. 90-102.
4 Rifkin, J. Ibid.
5 Europe's environment | The fourth assessment - Chapter 3: Climate Change. European Energy Association (EEA). 2007. p.147.

Land, water etc.
Fossil fuel addiction may have an equal or even more serious consequence than global warming. The world's oceans currently absorb about one metric tonne of $C0_2$ produced by each person each year. It is estimated that the oceans have taken up approx. one hundred and twenty thousand million tonnes of carbon, about half of all that generated by human activities since 1800. The oceans have buffered the effects of atmospheric climate change but the reaction of $C0_2$ with seawater forms carbonic acid which results in a greater acidity. And such changes have not occurred for the tens of millions of years during which existing marine organisms have evolved.[6]

But not only the emissions are a problem. Although power plants occupy relatively small geographical areas, the associated mining, transportation and waste can have significant impacts on land. These differ in nature and intensity according to the activity and the fuel used. The extraction of oil and natural gas can destroy natural habitats for animals and plants. Waste products, such as waste water sludge and residues, can cause land contamination if not properly disposed of.

The important and increasing energy trade will affect energy transportation and this will augment the risk on pipeline accidents and oil tanker spills.
The storage and transport of radioactive waste from nuclear power production (e.g. spent fuel) and uranium mining may also exert environmental pressures. Tailings from historic mining operations represent a significant amount of low-level radioactive waste in Europe.[7]

But also renewable energies can cause disturbances. Due to the increased demand for energy out of biomass (for biofuel mainly) for example, agricultural land has been transformed into land for the production of biomass. Especially in developing countries this may cause problems for providing sufficient and affordable food for the local population. Recently worldwide the price of cereals went up together with the oil prices.

It's all about energy *(and where it ultimately comes from...)*
The worldwide peak in oil and gas-production will have two consequences:
1) Countries and energy companies look out for alternatives and will focus on the dirty fossil fuels like coal, heavy oil and tar sand. This will cause further and faster damage to the planet's surface and atmosphere with consequences for the biosphere that will be even more severe than predicted (e.g. The melting of the permafrost will release methanol which will have an unforeseeable impact on the velocity and scale of global warming).

2) a shift in global power as most of the remaining oil reserves will be located in the Middle-East and one third in Africa. The incredible wealth that this will generate in such a short time is going to deeply affect Arab culture, regional politics in the Middle East and it will further heighten geopolitical tensions between the Muslim countries and the West, leading to more-open conflict, and a long and protracted struggle between the two forces.[8]

In 2003 a study was carried out by the German Advisory Council on Global Change. The authors are a group of internationally known, high ranking scientists.
The main conclusion of this generally acclaimed study on global environmental change policies is that there is an urgent need to turn energy systems towards energy based on renewable sustainable sources world-wide, in order to 1) protect the natural life support systems on which humanity depends, and 2) eradicate energy poverty of 2.4 billion people in developing countries. 3) promote peace by reducing dependency upon regionally concentrated oil reserves; and it is not only economically feasible but also cheaper. The scientists stress that such a reconfiguration of energy systems is feasible and fundable if rapid and resolute action is taken in the coming two decades.[9]

These conclusions are repeated in a new report of the same advisory council published in January 2008: *World in Transition – Climate Change as a Security Risk*.

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6 Turley, C. The other $C0_2$ problem. Www.opendemocracy.net/debates/article-6-129-2480.jsp
7 Europe's environment. Ibid. p. 333,334
8 Rifkin, J. Ibid. p. 123
9 World in Transition – Towards Sustainable Energy Systems. German Advisory Council on Global Change. http://www.wbgu.de/wbgu_jg2003_engl.html

> ...the likelihood of increasing tensions and conflicts in a climatically constrained world and spotlight places where possible conflicts may flare up in the 21st century unless climate change is checked. The report makes it clear that climate policy is preventative security policy.[10]

How the concentration of energy in the hands of only a few companies that are influencing heavily the political decision taking process is demonstrated with this testimony of a participant of the *UN Framework Convention on Climate Change Conference* (FCCC) that took place in December 2007.

> My perspective comes as one who was intimately involved in the process, not only as a delegate to the Conference, but also as someone who helped write the original draft of the treaty.
> In Bali the Island Nations took the moral lead. But we were opposed by the world richest and most powerful countries, a coalition of oil producers and coal burners. The US, with the backing of Canada, and Japan, refused to consider any limits on their rights to burn fossil fuels. The Arab oil producing states tried incessantly to block every initiative to reduce greenhouse gas emissions. And, with the covert backing of the US, China, India, and Russia claimed that any limitations on their right to pollute our atmosphere was a plot to keep them from developing using the same destructive dirty methods as the western countries. The EU, who we counted on, backed down to the dirty polluters in order to achieve any sort of consensus.
> That China and India, with their thousands of years of advanced civilization and science, should have fallen for this instead of leading the way towards cleaner sustainable development paths, is truly sad. And by placing their short sighted greed, ignorance, and stupidity first, the unholy polluting coalition of oil producers and coal burners has told the world that they don't care who else they hurt by continuing their dirty addiction, killing reefs and drowning islands and coasts, and imperilling millions in poor countries.
> Even worse, they have shown that they do not care for the rights of future generations, not even of their own people. That is why this shameful agreement is a capital crime against the environment that must be undone as soon as the Bush regime leaves office.[11]

And apparently the European Union is well aware of the long term effects of the choices of the industrialized world and it's decision takers on the Earth and it's inhabitants:

> Even if global emissions of greenhouse gases are drastically reduced, some unavoidable climate change impacts are still projected to occur in most sectors of the economy and on natural resources. It is therefore also urgent to adapt to those impacts in developing and implementing policies and measures in all sectors of society.[12]

Sustainable energy for all?
As mentioned above countries and (global) energy companies look out for alternatives for the traditional fossil fuels. But besides investing in the dirty fossil fuels, some part of the investments go to renewable energies. The question is if the contemporary energy organization which is centralized and hierarchic, with a complying economic structure (where the concerned companies and organisations have a top-down structure) will be continued for the organization of the renewable energy system or if a new and more democratic model will be introduced with access guaranteed for all?

> Power companies are going to have to come to grips with the reality that millions of local operators, generating electricity from (PV-powered) fuel cells on-site,

10 Achim Steiner. UN Under-Secretary General and Executive Director, United Nations Environment Programme (UNEP). Quote on http://www.wbgu.de/wbgu_jg2007_engl.html
11 Dr. Tom Goreau. December 15, 2007 (e-mail).

12 Europe's environment | The fourth assessment. Ibid., p. 146.

> can produce more power more cheaply than can today's giant power plants. When the end users also become the producers of their energy, the only remaining role for existing power plants is to become 'virtual power plants' that can manufacture and market fuel cells, bundle energy services, and co-ordinate the flow of energy over the existing power grids.[13]

Solar radiation for electricity

Based on an analysis of the different possibilities of extracting energy out of the environment, research center IMEC concluded that '...the most efficient solution often lies in the conversion of light into electricity as in a solar cell.'[14] Also, 'The environmental impact of PV is probably lower than that of any other renewable or non-renewable electricity generating system.'[15]

Solar cells used for energizing calculators, toys, parking ticket machines, satellites, water pumps, public phones, and domestic and non-domestic housing are commonly known. The last decade serious improvements have been made in the field of photovoltaics. The technology becomes more efficient and less expensive and new products are being launched: solar powered battery chargers for portable electronic gizmos, lighting systems, fabric-integrated PV, robotics etc... Nanotechnology makes it possible to print solar cells directly on metal, glass and other materials mainly used in the building industries (Built Integrated PV) as well as to introduce photovoltaic fibers, textiles and garments.

Solar power is doubling worldwide every two years and could provide energy for more than 1 billion people, creating over 2 million jobs by 2020, and 26% of global energy needs by 2040, according to a report released by the European Photovoltaic Industry Association and Greenpeace.[16]

All life on earth is ultimately solar powered and this energy is the invisible means of exchange on which all science is based.[17] The scientific research of photovoltaics -the conversion of light into electrical energy- is multidisciplinary as mainly chemistry, physics and quantum physics, optics natural sciences and engineering are involved. Applied research is mainly concentrated in research centres, at universities and institutes and at R&D departments of private companies. Until recently the main drivers for applied research were the space industries and the military apparatus. But recently the PV-field come into the spotlight again (cf. infra) due to the rising awareness of global warming and the depletion of the easy accessible oil reserves with increasing prices as a consequence. This leads to new developments and technologies in a rapidly expanding market. This is also made possible due to developments in nano-science. Photovoltaics is also strongly entangled with the issue of storage of electrical energy as the (excess of) electrical energy produced by a PV-cell/panel in most cases will have to be stored somewhere, either in the grid or in a storage battery.

As mentioned higher in the second half the 20th century photovoltaic technologies have been used mainly for space, military and security applications (e.g. sign post). Since the late 70ies and 80ies slowly the technologies were being used in the building industries either connected to the grid or 'stand-alone' (mainly in remote areas or with an unreliable/insufficient power from the grid). As the technologies have become more diverse, cheaper, lighter, smaller more effective and efficient they are entering our public and private day to day lives in all kinds of applications and products.

Gradually the creative worlds start to engage with the technology, experimenting and willing to investigate the knowledge and practices where it is based on. In this context solar cells/panels are used as a source of electrical energy or as a sensor/actuator making use of the increasing freedom in terms of aesthetics and materials integration. Examples are Sarah Hall who integrates solar cells in stained glass, Bjoern Schuelke who makes solar cell powered interactive media works and Hiro Yamagata who in 2012 will try to revive the destroyed Buddhas of Bamyan with solar powered lasers.

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13 Rifkin, J. Ibid. p.228
14 Imec: Interuniversity Microelectronics Center Leuven (BE). Www.imec.be
15 Boyle, G. Ibid. p. 95
16**S.N.** (2001) *Solar Generation: Solar Electricity for over 1 Billion People and 2 Million Jobs by 2020.* EPIA, European Photovoltaic Industry Association in association with Greenpeace. http://www/cleanenergynow.org/resources/solargenback.pdf
17 Rifkin, J. Ibid.

> Time rushes on. That famous picture of earth that Apollo beamed back in the 1960's already, that's not the world we inhabit; it's poles are melting, its oceans rising. We can register what is happening with scientific instruments, but can we register it in our imaginations, the most sensitive of our devices?[18]
>
> ...Jack Johnson's new CD was recorded in a studio in Haïti powered with solar energy...

[19]

- **brief summary of the cultural/scientific/social/economic context within which the research is applicable**

Most obviously the research can be used by artists/creatives who want to engage with photovoltaics. Also it can be of use for arts professionals who might use the information for their artistic program and/or their educational initiatives.

The research will be applicable in the scientific context as it provides cases that show how the technologies can be (ab)used in less typical ways and in contexts they were not designed for. Also, probably diy-projects and hacked technologies will also contribute to the body of knowledge of the PV-sience.

It might be of use for policy makers (from the scientific, arts and economic field) who might discover new opportunities and needs.

In general the research can enhance the awareness of the encompassing primary importance of energy for the individual from micro level to macro level interconnecting all living beings with the planet, the cosmos and beyond (where there is energy)...

- **description of how the work relates to other works in the field of inquiry**

During the research period it appeared to be that most of the existing research is mainly: scientific, about technology aimed at PV-professionals; economic, about the market (applications/products), aimed at companies, research centers and political decision takers, NGO's and other more institutional end users or trying to integrate both the technological and the market. Gradually initiatives are emerging who try to enhance the (mainly) practical knowledge of the people active in the creative/arts worlds.

In this sence this project is a complement to the existing ones as it has a different scope and aims (it is of course possible that there is a similar project that was overlooked or that remained invisible due to the language and internet search engine bias (see methodology). searches were mainly done in English and to a lesser extent in Dutch, Spanish, German and French).

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18 McKibben, B. Can you imagine? A warming world needs art. www.opendemocracy.net/globalization-climate_change_debate/article_2447.jsp

19 Heard on radio program Exit, Radio 1, March 5, 2008 in Brussels at 8.24pm - www.radio1.be)

Problem/Aim

- **concise summary of the problem domain/s that the research explores, or the specific aims of the research undertaken.**

The main aim is twofold: the first is to develop the knowledge of an electricity generating technology used for terrestrial applications that is using the sun's radiation as primary resource. At the same time the aim is that the research can contribute to bridge the technological, scientific and arts worlds by identifying the concerned actors, actions and processes.

Generating electricity by using light is -indeed highly poetic- but also very attractive as it frees you from the main grid. Hence, less cables and more autonomy. Also, it seems -under some circumstances- to be a 'green' alternative for the tiny batteries –the best distributed, most penetrating all areas and 24h available global product- cordless but also rapidly powerless, ready to be disposed or to be recharged.

Secondly, I believe that by looking more profoundly at this one specific technology, it can contribute to a better understanding of what electrical energy really means, for ones personal use as well as for society. And this insight could contribute to a more conscious way of using and inspired ways experimenting. It could lead to more use of electricity, but even so it can lead to less use of electricity. At least there will be an enhanced awareness of electrical energy.

A third reason concerns a different aspect. Since the beginning of the 21th century photovoltaic applications and products are entering the personal, intimate spheres. Till then the technology had been mainly the playground of the military, space and constructing industries. Hence, it is high time that other driving forces can enter the 'arena' as well. Possibly more critical voices that will ask other kinds of questions and that might have different opinions on how the different PV-technologies should be further developed.

It seems that only few artists have been working with photovoltaics, so, in this research I will try to identify -together with the key actors in the PV-field- these early adapters, make them and their projects visible in order to inspire and motivate others, artists, but also scientists and decision makers, in order to create new possible ways of interacting that might influence or open up new ways of thinking, (re)searching, developing, producing, and ultimately living.

Finally, Besides theoretical information about the technology and the market and the identification of the people, companies, organisations and media that are active in this field, I will try to provide practical information in order to invite people to start playing with the different technologies as quickly as possible.

- **justification of the aims (scientific/artistic/historical/etc...)**

It is the role of society to produce energy, to regulate it, for best ways of use. As the era of fossil fuels is coming to an end:

> ...a new energy system is awaiting us – a big change compared to the present situation. A change that in its being and character will be as big the as past change from a charcoal based system to a system based on fossil fuels.[20]

It is the role of the artist to comment on the way society is dealing with energy.[21]

Professor Wilson is founder of the Conceptual/Information Arts, Art Department, San Francisco State University. Looking at the definition of *Information Arts* below, one could pretend that this research can be categorized under this discipline:

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20 Rifkin, J. Ibid. p.17.
21 After a quote of Ai Weiwei in the documentary of the exhibition 'Fuck Off'. Shanghai (CH), 2000.

> *Information Arts* offers one of the only comprehensive international surveys of artists working at the frontiers of scientific inquiry and emerging technologies. Its goal is to describe this art, explore its theoretical rationales, and alert readers to possible future directions. It is also one of the only sources available that reviews cutting edge techno-scientific research in a way accessible to those without extensive technical backgrounds. It will be of interest to artists, art historians, electronic media designers, technologists, scientists, researchers, and more general audiences interested in the future of research that will have significant impact on the culture.[22]

The following text is based on professor Wilson's further explanation of Information Arts, that will make clear the relevance of this research.

Cultural Importance of Scientific Research & Technology Development[23]
Many artists have begun to engage the world of technological and scientific research - not just use its gizmos- but rather to comment on its agendas and extend its possibilities. Their work can be seen as part of this essential rapprochement and as a clue to what art may look like in the twenty-first century. If artists enter into the heart of research as core participants, the shaping of research and development agendas could benefit from the involvement of this widened range of participants. Using summaries from the artists' writings, it introduces their rationales and explanations of their work.

Many possibly significant theories and technologies are ignored, new technologies with fascinating potential are abandoned because they are judged not marketable. Our culture must develop methods to avoid the premature snuffing of valuable lines of inquiry and development. The arts can fill a critical role as an independent zone of research. They could become the place where abandoned, discredited, and unorthodox inquires could be pursued. They might very well value research according to criteria quite different from those of the commercial and scientific worlds. The roles of artists could incorporate other roles such as researcher, inventor, hacker, and entrepreneur. Even within research labs artist participation in research teams could add a perspective that could help drive the research process. Several traditions of the arts uniquely equip them for this function:

* Artistic traditions of iconoclasm mean that artists are likely to take up lines of inquiry devalued by others.
* The valuing of social commentary means that artists are likely to integrate widely ranging cultural issues in their research.
* Artists are more likely to incorporate criteria such as celebration and wonder than commercial enterprises.
* The art's interest in communication means that artists could bring the scientific and technological possibilities to a wider public better than peers in other fields.
* Artistic valuing of creativity and innovation meant that new perspectives might be applied to inquiries.

> I have seen many inventions and emerging technologies killed because marketing departments judged that no money could be made. I have seen entire R&D departments and their years of research blown away by the winds of corporate politics. Government and corporate support for basic research has almost disappeared and the concern with the bottom line has shortened the payback horizon to the point that few risks are taken. I have encountered debates in the scientific community that devalue approaches that do not fit the paradigms currently in favour.
>
> I am worried that the invisible hand of the marketplace might not be so wise as many would like to believe. The judgements that make short term sense for stockholders do not make sense for the culture. The peer review referees of scientific journals cannot always see beyond their disciplinary blinders. Many good ideas are orphaned, unheeded in the wilderness. Scientific and technological research are so critical that we cannot afford the premature

22 Wilson, S. Ibid.
23 Based on Wilson, S. (2002) Information Arts: Intersections of Art, Science, and Technology. Conceptual/Information Arts, Art Department, San Francisco State University. http://userwww.sfsu.edu/~infoarts/

elimination of these ideas and efforts that do not find favour through traditional channels.

Scientific research will have profound practical and philosophical implications. Exploring the idea of techno-scientific research as cultural acts, it also reviews the research projects, agendas, and future plans of scientists and technologists working at the frontiers of inquiry. It also lists resources (organizations, publications, conferences, museums, research centres, and art-science collaborations); books useful for further study; and Web sites for artists, theorists, and research centres.

Artists can augment the research process in several ways. They can define new kinds of research questions, provide unorthodox interpretations of results, point out missed opportunities for development, explore and articulate wide ranging implications of the research, represent potential user perspectives, and help communicate research findings in effective and provocative ways. They can bring centuries of artistic experience to bear on the technological future. They often approach problems in ways quite different than those of scientists and engineers. The critical role of designers and artists in computer human interface research over the last years demonstrates this new model of interdisciplinary research.

The "research" that artists created will most likely look different than that produced by traditional researchers. It would work like art always does - provoking and moving audiences through its communicative power and unique perspectives. Still it might simultaneously work as research - using systematic investigative processes to develop new technological possibilities or to discover useful new knowledge or perspectives.

There is an acknowledged danger that technology is advancing much faster than the culture's ability to make sense of it. The arts have traditionally been a place where understanding, integration and preparation for future developments takes place. There are several competing visions of how artists can most fruitfully work with emerging technologies: treat them as new media, deconstruct their cultural implications, or participate in the processes of invention and extension.

Critical theory and cultural studies offer compelling tools for understanding some aspects of contemporary technological society. Furthermore, these theory based approaches offer powerful concepts and methodologies for practising artists to use in responding to the realities of an electronically mediated world. However, while these approaches are useful for understanding what exists, they are problematic for envisioning what might be. Furthermore, these approaches, in their their scepticism about progress and about the possibility of innovation to transcend specific contextual discourses, are at odds with values of the researchers and inventors who believe they are working to create new cultural possibilities. Artists who work with emerging technologies are faced with the challenge of positioning themselves in these conflicting world views.[24]

- **expected outcomes of the research**
  (if the actual outcomes are different than the expected outcome, the reasons for this should be explained in the "discussion" section)

The expected outcomes as formulated at the start of the research

Provide insight and information in the area of Photovoltaics on:

- The available & expected technology with pro's & contras, possibilities and limitations;
- Good practices; examples of applied solutions that work (focus on the arts)

24 Wilson,S. From http://userwww.sfsu.edu/~swilson/papers/artist.researcher.html

- The main players: Artists/creatives; Research centers; Institutional bodies; Companies.
- The ecological footprint; how green are PV-systems?
- The cost; what's the cost of the main components (from small size to medium size)
- Are there better alternatives? Some examples
- Resources: DIY; events/agenda; media etc...

Methods

- **concise description of the way the research will be (has been) developed from establishing the problem definition to the final results**

In general: desk- and field research between September-December 2007. Ongoing experiment of a hybrid PV/wind energy system and own small-scale experiments since the are reported online. Writing, filling gaps and trying to keep up with updates from January -March 2008.

The approach was rather caleidoscopic, transversal, intuition mixed with spinnings in the brain which means that the result probably will at sometimes be too horizontal for some and too vertical for others. Also, it has to be clear that is by no means scientific research.

Due to the unexpected dimension and speedy growth of the global activity in photovoltaics I had to rethink the scope of the project. A difficult task when you end up in brand new or echoing playgrounds involving a range of natural sciences (having a Communication Sciences past myself). Therefore, besides the desk research and the Intersolar-experience of major importance was the encounter with several PV-experts of research centers and companies. They guided me through the expanding PV-landscape.

Two findings are worth mentioning here: Relatively few artists / arts projects are exploring photovoltaics and consequently there is not much practical context specific information available. More in general, there is little data available on the irradiance indoors as a result of artificial lighting or natural light that enters through windows.

Focus Limits
It is easy to indicate which applications are not the main interest of the research: PV-technology for space applications, the off-grid centralized systems (power plants) and the grid-connected applications (connected to the utility electricity network). Also, the process of an ongoing experiment of a hybrid PV/wind energy system are reported online. The theoretical part will not be covered in this document.

Rather, focus is on terrestrial off-grid systems that can provide electricity for low power loads, the latest technologies that are more versatile and that have different looks and feels compared to the first generation crystalline silicon-based ones. So-called 3rd Generation technologies and applications often based on nanoscale components allowing easier integration with other materials. Some of them are becoming readily available now, like the Dye Sensitized Solar Cells (DSSC) but a lot of these technologies are still at the experimental stage and according to some PV-experts most of them will need at least 5 years before being able to appear on the consumer market. Especially these newer 'inventions' -like printable and sprayable PV-cells based on bioplastics- are very promising in terms of versatility of use and aesthetics.

Time & Space
The publishing of the own research findings will start from the end of 2007 and will continue throughout January. After that the evolution will become mostly dependent of the contribution of the creative community. Findings will be published on http://luminousgreen.org

Language
As mentioned before, there is an inevitable bias in the research due to the limitations of language: although the dominant language is English in the PV-field, it is more than probable that a lot of knowledge and important information remained invisible. The main languages that were used were in the order of importance English, Dutch, Spanish, German and French. Secondly related to this language bias are the limitations due to the use of the internet as a

main information resource: 1. Search engines: the main search engines that were used were google and lycos; others would have come up with different results; the online resources that were not indexed by the search engines. 2. Key words: some accessible resources might not have been found due to the choice of key words in a limited amount of languages.

Limited PhoEf

In this highly vibrating and rapidly expanding environment where weekly new products and actors pop up- I explored the horizontal and vertical dimensions within the limits of time and space.

The PV technologies for satellite power, terrestrial Off-grid centralized power generation (power plants) and Grid-connected domestic applications are mentioned only sideways. The main focus, especially in the practice section lies on **Off-grid non-domestic DC-**applications consisting of Stand-Alone systems and Consumer products.

I apologize for not having covered what I might should and could have. I tried to present the findings in a multi-layered way, with links to supporting AV-material hoping to address the diversity, the differences in experience and expertise of the audience. And needless to point at the use and choice of words in the texts: English with a Dutch accent.

Invitation

Nevertheless I hope that this research contains sufficient elements and energy to motivate you to engage in the use of light for powering your inventions and creations. Especially, as the information will be out of date due to the rapid evolution in PV-land, hopefully you will find the time to participate in keeping what exists up-to-date and add new discoveries and findings. So, this is an open invitation to become an active participant, a knowledge node in this ongoing networked collaborative research project. Make it a usefull tool for yourself and the creative community; Http://luminousgreen.org is awaiting you.

If your knowledge about PV is still peripheral, hopefully this research can be a centripetal force that brings it closer to the epicenter of your activities.

Overview of visits events, meetings, training, theory in practice

Visits/Events

- Intersolar - Solar Fair (June 22, Freiburg, GE) – (most relevant contact: Korbinian Kramer of Fraunhofer ISE)
- Ateliers de la rue Voot. Presentation hybrid PV/wind-system (Sept. 4, Brussels, BE)
- Kamp C – Center for renewable energy (Sept. 14, Westerlo, BE)
- Photovoltaics Conference at the Sustainable Energy Week of the E.U. Commission (Jan. 31st, Brussels, BE); See: http://www.epia.org/ - Broadcasts: www.managenergy.tv
- Lecture from Dr. Gauthier Chapelle, Executive Director of Biomimicry Europe – www.biomimicryeurope.org (at the 'Planet Attitude' Fair – Dec. 17, Brussels, BE)

Meetings

- **Prof.dr.ir. Van Humbeeck, Jan.** (Prof.) University of Leuven, Fac. Engineering Sciences, Dept. MTM. Leuven (BE). July 3rd, 2007.
- **John I.B. Wilson** (Prof.)**, Bryce S. Richards and Anna-Helena Lind** - School of Engineering and Physical Sciences, Heriot-Watt University. Edinburgh (SCO). Oct. 3rd, 2007
- **Szlufcik, Jozef** (Ph.D.) **,** R&D Manager Photovoltech, PV-cell manufacturer. Tienen (BE). Oct. 31st..
- **Poortmans, Jef** (Ph.D.) Program Director Photovoltaics Imec (Microelectronics Research Center; Research Group Solar Cells. Leuven (BE). Nov. 19, 2007.
- **Palmers, Geert. (**CEO) 3E, Sustainable energy consultants. Brussels (BE). Dec. 11, 2007.

Training for PV-system installation

Workshop Ellentriek – electrical energy powered media/electronics. By Constant vzw/asbl. Brussels (BE), Dec. 8-10 2007.
Training PV-Installation – By Conergy. Kamp C, Westerlo (BE), Jan. 11, 2007

Practice
- Réseaux Citoyen/okno/Bartaku: Developing a PV-system for powering a meshed network and electronic hardware that is as mobile and energy efficient as possible. (at Okno, Brussels, BE)
http://thoughtsandtalks.so-on.be/2007/12/26/solarpanel-first-set-up/
www.reseaucitoyen.be; www.okno.be
- Own experiments with PV-cells: powering small motors (vibrating, rotating...) etc...
Sun for my Father. Short movie using sunlight for shade projection (personal space scan).
http://nl.youtube.com/user/bartaku

Not listed:
Numerous talks about the subject with a multidisciplinary blend of people.

- **justification of the methodology**

Halfway the research, the decision was taken to keep on investing time in the evolution of the market and energy policies. The book 'The hydrogen economy' was an eye-opener that contributed highly to this decision because of the clear explanation of the history of energy use by mankind.

As the areas of Silicon-based technologies and applications in the Building Integrated PV, Grid-connected are best covered, I have considered to leave them out of the scope of the research. But finally I decided not to due to the quick evolution in this area and the fact that these systems can be ....

Solution/Results

- **Concise description of the actual outcomes of the research**

Shaken beliefs

After having swum to the Tori (bird perch) shrine with my youngest sister, we observed it from the Island's sand beach. Not noticing that our skin was becoming rapidly a reddish radiating heating. One year before, sudden and brutal movements of the Earth's skin had a severe impact on its inhabitants. For many Japanese looking in the mirror became an ordeal as their belief of having mastered nature and their small outstretched piece of rocky and mountainous land, collapsed together with earthquake resisting dwellings, buildings and bridges.

The sun, the mirror and the cock on it's 'Tori' play an important role in Japanese mythology. *Amaterasu OmiKami* is as the Sun goddess virtually the supreme deity as well as the ancestor goddess of the imperial family. There are several versions of this creator story. In the in *Kojiki* (712 C.E.), Amaterasu ruled over the Kami, those small beings that help everything grow. Born from the left eye of her father Izanagi, her glow helped the rice grow, made the flowers bloom. Her beauty radiated such that everyone who felt it on their skin felt beautiful themselves.

Amaterasu's brother, *Susano-O* was the impetuous and violent god of storm. They never really got along, but were always drawn to each other like magnets. Susano-O would often go to seek out his sister in order to bathe in her calm radiance. And when things grew stagnant, he was the only one who could get them moving again.

After feuding again with his sister, Susano-O threw a dead horse amidst Amaterasu's weaving maidens. The deities were so heavily shocked that many of them were heavily injured and some of them died. When Amaterasu heard about the incident, she was so appalled that she hid herself in a deep cavern in the center of the earth and sealed it with a huge rock. The world plunged into a cold darkness and the Kami entered a death-sleep.

The senate of 800 Gods gathered in front of the cave with the Eight-Handed mirror and curved Jewels which they hung on the sacred Sakaki tree that was located outside the cave. By means of these devices, they hoped to beguile Amaterasu into believing that there was light in the world even in spite of her absence. They started a loud party and as they hoped, Amaterasu became curious. As soon as she peeped from the mouth of the cave; the cocks began to crow, the jewels glittered, and the mirror hanging by the tree reflected her light. She thought that there must be someone or something equal to herself illuminating the world. Finally, impressed by her own beauty, she decided to stay, filling the world with light and warmth, awaking the Kami from their death-sleep...[25]

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25 www.uwec.edu/philrel/shimbutsudo/amaterasu.html
www.womensig.com/amaterasu/amaterasu.html

For me, sustainable development is really a part of a cultural revolution, and like a cultural revolutions, it hurts. So, it's a major challenge and it's urgent.
Françoise Hélène Jourda[26]

An architect who is as committed as an architect should work, i.e. answering the question of time in an artistic way, has to be a solar or ecological architect in today's world. *Georg M. Reinberg*[27]

Solar cells are a nearly perfect energy source, as they generate electricity without emitting harmful greenhouse gases. And because they are so durable they can transform nearly any surface into a clean, long-lasting energy source. Moreover, they come in a wide range of colors, allowing an unlimited range of designs. By forging an image with a source of energy we create a powerful story about how we can live in this world: it gives us a chance to dream about who we can be.
Sarah Hall[28]

PhoEf's Assumed Origins

Deep respect and fascination for Andean Cosmovision, based on millenia of profound observation of the earth-constellation relation- coexists with that for the massive *bombardment* by the sun's particles that also appear to be waves...

Discovering new interesting and promising technologies probably made me undertake ***PhoEf****.* With the support of FoAM, the interdisciplinary lab which I got to know due to their fascinating workshops (with okno and nadine) and gatherings. Also the dependence of the main supplies, the grid, with always-in-the-way- cables and converters and the omnipresent A, AA or AAA tiny chemical containers contributed highly to the eager of finding other ways to power what inevitably and ultimately has to be (low-)powered.

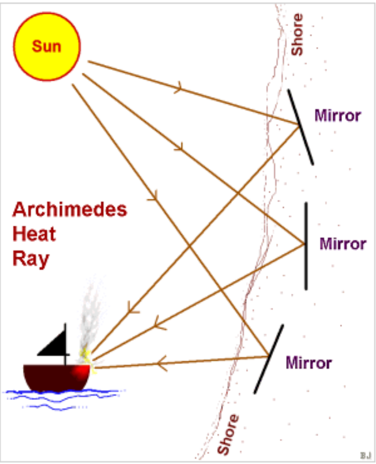
Luminous Green
The research had a kick off at the Luminous Green hands-on workshop where Marko Peljhan -based on his experience with his polar station- explained how to size a pv-system, calculate the energy requirements and how to set-up an of the grid system. A rather important observation was the presence of a (lead-acid) battery in the system. A back up that is needed in case electricity is required when there is not sufficient light. We experimented also with newer pv-technologies such as the Dye Sensitized Solar Cell, one of the newer technologies using plant matter as a semiconductor, based on the photosynthesis proces.

PhoEf > the photovoltaic effect
The subject of this research is generally indicated by either solar energy (solar products, solar cell, solar panel etc...) or Photovoltaic (PV) energy (and -product, -cell, -module etc...). This is a bit confusing as all energy sources depend or originate from the sun. Photovoltaics, the generation of electricity (volt) by the use of light (photons) is one solar energy technique using the energy available as sunlight. Other examples are active and passive thermal solar energy but strictly speaking other renewables like hydropower, wind energy, and biomass, are also forms of solar energy. Also, new technologies -although most are in the experimental low efficiency phase- appear to be able to capture spectra of the irradiation which do not require the presence of the sun, not at daytime nor at night. And finally, it is also possible to

26 Françoise-Hélène Jourda, Achitecte, Paris (France). In: Last Call for Planet Earth. A film by Jacques Allard (Architects for a better world). 2008. - euraf.eu;archiworld.com)
27 Georg M. Reinberg; Architect, Vienna (Austria). In: Last Call for Planet Earth. Ibid.
28 Hall, Sarah. Glass artist (US). From her website www.sarahhallstudio.com/photoglass

generate electricity using articificial light for PV-applications.
Conclusion, the best way to denominate the subject of this research is arguably *PhoEf,* the photovoltaic effect: the generation of a voltage and/or a current by absorption of light in some material or combination of materials.

PV-Introduction



As is the case for most 'inventions', the invention of the solar cell is the result of a historical and continouing process involving a lot of people with diverse angles, paradigmas and backgrounds such as chemistry, physical sciences and quantum physics, physical electronics, optics, photonics, (advances) materials science and engineering, electric sciences, cosmology and astronomy. It is generally acclaimed that the photovoltaic effect was first discovered in 1839 by the French nature scientist Alexandre Edmond Becquerel. In 1883, the American inventor Charles Fritts produced the first selenium-solar cell with an efficiency of only 0,1 %.

After making its commercial debut in solar-powered toys and games, solar energy was used to power satellites in the space program; the first time a PV-System was used in space was on the NASA Vanguard I satellite launched March 17th, 1958. Solar energy was a more functional and efficient source of energy than batteries that burned out within a week of orbit. Solar cells are since terrestrially used/integrated in a growing number of contexts and applications such as houses/buildings, water pumps, electronic hand held devices, naval navigation devices and many developing modes of transportation.

You can find a historical overview of key people and inventions here

"That night the old woman went to the moon as a flying spark of light. She circled the moon three times before attending the meeting of other lights from all over the world. In the morning when she returned full of the energies and enlightenment the journey had given her -the life extension and the weight of future sight- she resumed the weaving of our narrative."
(Infinite Riches - Ben Okri)

PV & senses
A lot of new technologies are being developed, some building further on the well documented use of Silicon as a semi-conductor, others explore newer areas with other organic semi-conductors such as polymeres and Zinc-derivates New aesthetics
This leads to a present situation where -after 50 years of dominance of crystalline blue/grey- there is a lot more diversity though with a lot of developments still at an experimental or maybe prototyping stage. In general one of the most important influences on the rapid evolution of the photovoltaics impact on the senses comes from nanoscience leading to much tinier, thinner, either still solid, flexible or even printable and sprayable solutions. This facilitates integration with other materials including fabrics, which allows the PV-techology to enter the realm of the intimate.

Besides the variation in materials (components) and flexibility also the range of shapes -from flat to spherical- and colours is rapidly expanding. But -again in general- versatility and aesthetic freedom means a sacrifice of efficiency and durability.
An absolute advantage of using a photovoltaic system is it's silence. Unless you are using a pick-up coil, it does not produce audible sound frequencies.

Ecology
Photovoltaic energy is one of the most promising ways to contribute towards a greener planet, lowering carbon footprints and ensuring the earths balance remains intact. The generating component produces electricity silently and does not emit any harmful gases during operation. Environmental issues do exist ranging from CO²-emission in the production process, scarcity of materials to the use of toxic materials in the fabrication of modules.

The basic photovoltaic material for most common Silicon modules made out of silicon is entirely benign, and is available in abundance. Si-based, second-generation, thin-film technologies and Third-generation approaches to photovoltaics use materials that are both nontoxic and not limited in abundance. This opposed to thin-film solar cells based on compound semiconductors like CdTe (toxic Cadmium) and chalcopyrite compounds CIS, CIGS (Cupper, Indium, Gallium and Selenium; not limited in abundance).

The technologies also need to have acceptable energy payback times, the time taken for a device to generate as much energy as was needed to fabricate the device. Crystalline and multicrystalline devices typically have energy payback times of 3–4 years and the thin-film technologies, 12–18 months.

The picture becomes a bit more complicated as soon as the PV-cells/panels/arrays are set up in a PV-system with the appearance of -depending on the system- some of the following parts: an array DC disconnect, a storage battery, a charge controller, an inverter a system meter and mounting and wiring systems.

The market
Solar energy is receiving worldwide attention due to the rising global warming awareness and in the 2nd half especially due to the oil prices breaking almost daily new records. The photovoltaics industry is rapidly expanding with manufacturing plants of increased capacity and implementations materializing. Scientists and engineers all over the world are exploring the potential for improved cell efficiencies and above all reduced production cost. Innovative processes and materials are being studied promising flexibility, printability and lower manufacturing, implementation and maintenance costs. Also other pv-related components such as mechanical support (including integration techniques), regulators, dc/ac inverters, batteries, etc. are improved.

BIPV is receiving much attention, as using photovoltaic cells in this way minimizes land use and offsets the high cost of manufacture by the cells (or panels of cells) acting as building materials. Although crystalline Si solar cells were the dominant cell type used through most of the latter half of the last century, the most successful technology at present is based on the use of multicrystalline Si. Recently other cell types have been developed that compete either in terms of reduced cost of production or in terms of improved efficiencies. The most successful technology at present is that based on the use of multicrystalline Si, which has expanded even faster.

The key aim of all the technologies is to reduce production costs to 1 $/peak Watt (1 $/Wp) to compete on cost with other forms of power generation. Cells based on the use of crystalline and multicrystalline Si cost more than four times this amount. It is generally accepted that this target is most likely to be reached using thin-film fabrication technologies when expanded for large scale production. Nanosolar claims to be the first company to have achieved this. The technologies also need to have acceptable energy payback times – this is the time taken for a device to generate as much energy as was needed to fabricate the device. Crystalline and multicrystalline devices typically have energy payback times of 3–4 years and the thin-film technologies, 12–18 months.

In 2006, the largest production of PV-cells and modules took place in Japan, Germany the US and Spain. Prices per PV-module depend on the technology and the local market conditions and vary from 3-6EUR/Watt (USD 4-8; 2006).

"In this vision of the future, a thin film covered city might drive the electrical grid itself, essentially functioning as its own powerplant. Increasingly you will see it everywhere, or, you won't see it but it will be everywhere, powering your life exactly the way you live it today."
Nanosolar's Vice President of Engineering - July 3, 2007 - www.kqed.org/quest/television/fullscreen?id=399

Wanted right here right now

Coinciding with the high pressure to come up with the cheapest and most efficient technology is very high, a lot of Research centers, universities and companies show the awareness of the need for new ideas and experiments for further development of -the aesthetics and functions of- photovoltaic technologies.
Simultaneously there is a growing number of 'creatives' throwing out their first stones in the PV-stream wanting to take the first steps. So, if you have a somewhat crystallized project in mind and on paper, look for an appropriate PV-partner in the 'neighbourhood'; see the PV-overview as well as some things to think about before contacting them).

Laurie Anderson's Aimulet

An example of a fruitfull collaboration that has lead to a rather poetic result is the *Aimulet LA.* "It's is a device, "an electronic samurai's pillbox", slightly larger than a credit card, utilizing *SphelarVoice technology* enabling visitors to learn information

about their environment. It delivers a low-volume audio signal to the user via an earphone speaker that is connected to a solar battery. One may simply point the Aimulet at an item of interest in an exhibition powered by SphelarVoice technology, and infrared light projected by Sphelar modules carries audio information that is decoded by the card." It is designed by Laurie Anderson in collaboration with the Japanese electronics company Kyosemi for the Aichi Expo in 2005. The AimuletLA is now mainly used in museums.

Shit, a Battery?!

Clean storage of renewable energy is at present problematic. One of the major drawbacks to storing PV-generated electricity is that we store the electricity in chemical storage batteries, relying on the electrical energy to produce a chemical change, which is later reversible. Things like cadmium, lead and sulphuric acid come to mind and -although to some extent recycling is possible- suddenly the grid suddenly pops up again as a cleaner alternative, especially when it functions on... PV-, wind-, tidal- or another renewable power.

So, at some point you will have to decide if a **storage battery** is needed or not in your power design. You will not need them if you wish to use the PV-cells' response to changes in irradiation to determine if your electric devices are working or not. Mind you that some devices like cameras do not switch on automatically after they went off due to a lack of electricity. On the other hand, if your installation has to be up and running under -at some point- (too) poor natural or artificial light conditions, then you will need a battery back up that takes over when your PV-cells are pretty unable to absorb the bouncing photons.

Ever since childhood the junkie metaphor installed itself in my relationship towards batteries. Feeling bad whilst purchaising them-or 'borrowing'- knowing that their shot of energy would not last for long. Right after the short high, one feels awfull due to deprivation and guilt feelings. Tiny as it is, it would stay at eye-sight for a long time. Or, when it did stay out of sight, it destroyed the inner core of those beloved toys. Together with plastic bags, they must be the most widespread junk on Earth.
Bartaku, September 2007

If you DO decide to work with a storage battery, you better do your homework as they behave differently and require special care and caution. You can find an overview with the strong and weak points of the most common and most recent types as well as install precautions here.

PV-General Overview

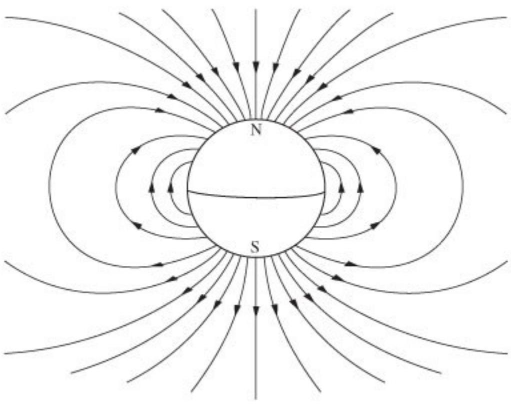
A core component of the research project consists of a pv-overview. It's a spreadsheet (a database if you wish) consisting of useful information about artists (arts projects using PV), research centers, companies, institutions, DIY-projects, PV-events and -educational programs and finally PV-oriented media. The information about the arts projects and the DIY-section are the result of active searching whereas the other sections emerged rather in the course of the research. This implies that this is not an exhaustive overview and that in this hyper rapidly changing field the information and data are continuously in danger to be outdated.

In brief:

- Autonomous: as in not connected to the main grid; stand-alone;
- Versatile and flexible; combinable with other materials in different contexts;
- Battery storage: is storage needed and what are the consequences of the Yes/No;
- PV-overview with the following 8 categories:
    1. Arts projects
    2. PV-technology
    3. Research Centers
    4. Companies
    5. Institutions
    6. DIY
    7. Events / Education
    8. Media

Post script: The sun's destiny is ours

If mankind survives the end of the 4th Sun on the increasingly becoming mythical December 21nd of 2012, one will more than ever be aware of the fact that the future of the planet is closely tied to that of the Sun. The ancient Maya-calendar 'states' the sun is approaching the end of it's 4th Period, on the 21st December 2012. The birth of the 5th Sun



means according to some “A shift of the ages”. www.shiftingages.com/synopsis.html. Others tend to believe that the poles will switch because of the massive amount of solar irradiation and that this would cause mass-destruction on Earth.

Scientists predict that as a result of the steady accumulation of helium ash at the Sun's core, as part of its solar lifespan,the star's total luminosity will slowly increase by 10 percent over the next 1.1 billion years (1.1 Gyr), and by 40% over the next 3.5 Gyr. Climate models indicate that the rise in radiation reaching the Earth is likely to have dire consequences: the orbit of the Earth may have expanded to about 1.7 AUs because of the diminished mass of the Sun and so the planet might escape envelopment by the expanded Sun's sparse outer atmosphere. But most (if not all) existing life will have been destroyed by the Sun's proximity to the Earth including the possible loss of the planet's oceans.

Sun Awareness

online version to be brought here

The PhoEf Overview- Guidelines

The PhoEf Overview is a central document in the research, a spreadsheet (a database if you wish) consisting of useful information about artists (arts projects using PV), research centers, companies, institutions, DIY-projects, PV-events and -educational programs and finally PV-oriented media. The information about the arts projects and the DIY-section are the result of active searching whereas the other sections emerged rather in the course of the research. This implies that this is not an exhaustive overview and that in this hyper rapidly changing field the information and data are continuously in danger to be outdated.

Here follows some helpful information for easier use of the document.

Note: for quick search in the sheets use the <find> command and/or the <sort> function.

The 8 sheets contain the following categories:

1. Arts projects
2. PV-technologies
3. Research Centers
4. Companies
5. Institutions
6. DIY
7. Events / Education
8. Media

1. Arts projects
The first datasheet contains more than thirty examples of arts projects where the technology of photovoltaics has been used in one way or another. Where possible the PV set up and used technology has been included.

2. **PV-technologies** (see corresponding section)

3. Research Centers
Here you can find an overview of a number of PV-research centers that passed along in one way or another during the research. It gives an idea of the possible technologies that will

emerge in 5 till 15 years. In most cases these knowledge centers are embedded within a company (R&D), private owned and financed with public and/or private funding (often a university spin off) or situated within the science (fysics) departments of universities.

4. Companies
This list contains manufacturers and/or vendors of photovoltaic cells and/or -panels selling either to other companies (B2B) or to end-users directly.

Field/product/service: it is likely that solar wafers and cells are produced in one company to be assembled in a solar module/panel in another one. But there are exceptions (e.g. Showa Shell Solar K.K.).

PV-type: see the legend below in the overview for the abbreviations.

As mentioned above, special attention has been paid to the aesthetics, which are listed if they differ from the 'classic' blue, dark blue or grey look of the crystalline cells and modules.

How to buy: Most of the wholesale vendors sell various PV-products online. The cell/module manufacturers mostly have to be contacted via e-mail or via an e-form. The easiest way to find the necessary information on the sites is via the <Contact> button. Some manufacturers produce from wafer to panel, and some only one of these. Most of the cell manufacturers only sell to module manufacturers hence business to business (B2B). In any case most of the companies ask to fill out a form online or send an email.

Where possible the location (country and city) of the Main Office is mentioned, with in between brackets the countries of the subsidiary branches.

Finally, in the notes section you find remarks about technology, environmental impact, collaboration with the military apparatus, acquiring product samples, company size & -structure etc.

5. Institutions
In the field of photovoltaics there are a lot of intermediary organism at work. The ones that are listed here are mainly national and international not-for profit umbrella or member organizations. Through advocacy and networking they promote sustainable development and the use of renewable energy in general or of photovoltaics specifically in Europe and/or worldwide. They are mostly funded by supranational bodies, both by government and the private sector or by its members.

6. DIY
This sheet is the result of an active search for interesting DIY (Do-It-Yourself) projects that can be inspiring but especially that can be of immediate practical use in the process of developing a simple PV-system: calculating the power requirements, determining the battery type, where to find and how to use radiation data, measuring electricity, making a solar cell yourself etc.

7. Events / Education
Information about PV-events and the offer of training and education possibilities.

8. Media
That the field of photovoltaics is growing at high speeds is demonstrated as well by the increasing amount of specialized media appearing, online as well as offline.
A selection of over fifty resources can be find on this sheet.

Refresh
Coinciding with the start this research project, the PV-field started vibrating and expanding more than ever mainly due to the drastic rise of oil prices with the 'oil peak' approaching inevitably and other fossil fuels that will also become scarcer and hence more expensive.

Almost every week new technologies, companies, mergers & take-overs, projects, experiments and PV-media emerge. Also, as indicated before the research has mostly been done in English. As a consequence this overview is per definition incomplete, a living being that needs to be nurtured continuously with updates.

Your contribution
So, if you believe this data is or can be of any use to you and/or others, it would be more than welcome to help us to keep it up-to-date. At this moment they are presented in a rather vernacular way, so, in the meanwhile if you would like to add/modify please send a mail to info@fo.am with 'PV-overview' in the subject line.

PhoEf CASES – PV in arts projects

see separate pdf

Photovoltaic Technologies

This section is about the most important parts of a PV system: the cells which form the basic building blocks, the modules which bring together numbers of cells into a unit, and in specific situations the electricity storage equipment (batteries and charge controller) and the inverters for transformation of direct current into alternate current. Also an interesting application is shortly introduced being a hybrid electricity generating system combining and integrating wind energy with photovoltaics.

A personal account of the history of PV can be found here

The photovoltaic effect and the explanation of the mechanism behind the different technologies -how it all works- are well documented in online resources. The focus here lies on the variables that can help determine the choice of a PV-technology with special attention on (the somewhat less covered) aspects of materials integration (versatility and aesthetics). The choice of the PV technology determines how integral the energy solution will be. Detailed information about the technologies (on the consumer market or experimental) who does what and where to purchase can be found in the *PhoEf Overview*. Remarks on environmental issues are given where necessary.

Here and now it is suffice to keep in mind the following two lines:
LIGHT IS ENERGY. WHEN LIGHT COLLIDES WITH A SUITABLE SEMICONDUCTOR, ELECTRONS ARE SET IN MOTION. ELECTRICITY BEGINS TO FLOW.
And now add the following six lines:
Light is both wave and particle. Einstein described light as a conglomeration of projectiles. If these projectiles, the photons - packets of energy from the sun - , have sufficient energy and hit a free electron that is in a conductor or semiconductor, it is set in motion: electricity silently starts to flow. No moving parts come in to play.

Here we have the first true quantum power device.
- John Perlin[29]

For a detailed explanation of the theory of PV a highly recommendable resource is the project The Power of the Sun -> http://powerofthesun.ucsb.edu/ where one can find the visualization (embedded flash) of the photovoltaic effect in Silicon-based technologies. It is recommended to go through this presentation before continuing the reading of what follows.
The understanding of how atoms absorb and emit light reveals secrets of the electronic structure of the atom, and is crucial for the discussion of the modern silicon solar cell.[30]

Wikipedia and especially Peswiki provide an up-to-date overview of the main technologies in their photovoltaics sections:
- http://en.wikipedia.org/wiki/Photovoltaics
- http://www.peswiki.org/DIY#Solar

For a more profound insight an excellent resource is the Volume 10, Issue 11 edition of the e-magazine *Materials Today* (November 2007. Pp 20-50 (4 separately downloadable PDF's) including: the structure of the different devices that have been developed, a discussion of the main methods of manufacture, and a review of the achievements of the different technologies.

And finally, it is advisable to check the websites of the research centers and manufacturers.

Different needs equals different

29 http://www.solaraccess.com/news/story?storyid=2281
30 The Power of the Sun - http://cs.sbcc.edu/physics/solar/sciencesegment/

tech

Most of the classifications in the PV-literature besides the semiconductor type, use the evolution over time (the history) of the technological achievements as a distinctive criterium: from first generation (wave) PV to Fourth Generation. In this research another existing classification is used which is based on the type of semiconductors. An overview of the technologies can be found in the second datasheet of the PhoEf-Overview.[31]

One thing the different PV-technologies have in common: unlike most other renewable energies, they convert the light into electricity in a silent way (at least, for the ears of the human being).

Light-absorbing materials
All solar cells require a *light absorbing material* contained within the cell structure to absorb as many as photons as possible to generate as many electrons as possible via the *photovoltaic effect*. The materials can often be used in *multiple physical configurations* to take advantage of different light absorption and charge separation mechanisms. The original choices were motivated mainly by material availability and processing possibilities. The 'traditional' crystalline blue/grey Silicon-based PV accounts for more than 90 percent of the market and it is the most-researched and best documented technology in both *bulk* and *thin-film* configurations. The recent boost in interest for PV has also triggered a more systematic search for new materials and cell structures that may (also) fulfill the ultimate requirements of efficiency, cost, stability, and environmental effects. New discoveries from nanoscience f.i. Contribute substantially to an increased diversity of PV-technologies as they lead to tinier, thinner, flexible, printable and sprayable solutions. This facilitates integration with other materials like glass, ceramic, fabric, etc., bringing the PV-techology into the realm of our day-to day, intimate life.

*Many currently available solar cells are configured as **bulk** materials that are subsequently cut into wafers and treated in a "top-down" method of synthesis (inorganic silicon being the most prevalent bulk material). Other semi-conductors are configured as **thin-films** (inorganic layers, organic dyes, and organic polymers) that are deposited on **supporting substrates**, while a third group are used as **quantum dots** (electron-confined nanoparticles) embedded in a supporting matrix in a "bottom-up" approach.*

Silicon wafer-based bulk material

Like many conventional semiconductors, the inorganic silicon offers excellent, well-established electronic properties. Silicon is as it is derived from sand, very common. Making up 25,7 percent of the earth's crust it is the second most abundant element[32]. It has no moving parts and can therefore in principle, if not yet in practice, operate for an indefinite period without wearing out.

Solar cells are usually manufactured using existing industrial semiconductor processes and facilities. There are two types of silicon solar cells – "crystalline" (wafer-based) and "amorphous (non-crystalline)."

Wafer-based Crystalline solar cells can be further classified into: a) single crystal type (c-Si) or Monocrystalline Silicon (m-Si) which have high conversion efficiency, and b) the polycrystalline type (poly-Si) or Multicrystalline Silicon (mc-Si) which are less expensive but have lower efficiencies. As mentionned before this three decades old PV-tech accounts for over 90 percent of the market. It is most-researched, best documented -also as DIY- and most easy to acquire on the market as cells or panels in various ways from new to used ('scrap'), by piece or as 'Cell by the Watt'.

The use of large amounts of silicon in photovoltaics created a shortage of crystalline silicon

31 Unless indicated most of the information in this section originates from the articles about PV in: Materials Today - Volume 10, Issue 11, November 2007. Pp 20-50.
32 Wikipedia. "Silicon". http://en.wikipedia.org/wiki/Silicon

cells which has prompted the development of innovative technology that aims to decrease consumption of costly raw material while improving usability and adoption of photovoltaic technology. The use of silicon or other conventional semiconductors in photovoltaic devices has to date been limited by the high cost of production — even the fabrication of the simplest semiconductor cell is a complex process that has to take place under exactly controlled conditions, such as high vacuum and temperatures between 400 and 1,400 degrees Celsius. Efficiencies of more than 20% have been obtained with silicon cells in the laboratory, but production cells are currently averaging 13-14% efficiency. According to realistic design primaries in 2006, 23 % is the practical efficiency Si-limit.[33] The efficiency of c-Si cells is higher than that of pc-Si.

It is important to accentuate that any part of a cell can become another cell: if one part of these rigid and breakable cells is broken, it is possible -with adequate power measuring- to reuse them and recombine them (see DIY-section in PhoEF-overview). As this technology is modular one can interconnect as many as cells/modules in series (or in parallel if necessary).

This also means that any c-Si production facility equipped with a laser could cut properly a broad variety of shapes.

Environment
The production process involves environmental unfriendly solvents such as Chloride and Benzene. There is ongoing research on the use of more environmental friendly solvents based on alcohol. The cell lifetime in theorie could be... millennia. But most warranties foresee 20-25 years, due to the packaging (plastic...) and the solder joints (thermally cycling fatigue).[34]

c-Si cells
...are high-grade, single-crystal ingots, high-efficiency PV cells sliced from a single crystalline bole of purified silicon. Their color is mainly anthracite. c-Si solar cells are the most common cells available. The manufacturing process and materials are expensive but quite simple and reliable to operate.

- **The Semiconductor**
  Pure silicon wafers are doped with impurities to create a semiconductor that serves as the core of the solar cell and converts sunlight into electric current. The process of creating this semiconductor is the same as the ones used in the computer and electronics industry.
- **Electrical Contacts**
  After the silicon cell is created, electrical contacts are placed to connect one solar cell to another to form a larger module. The contacts must be very thin (at least in the front) so as not to block sunlight to the cell. Metals such as palladium/silver, nickel, or copper are vacuum-evaporated through a photoresist, silk-screened, or merely deposited on the exposed portion of the cells.
- **Anti-reflective Coating**
  Because pure silicon is shiny, it can reflect up to 35 percent of the sunlight. To reduce the amount of sunlight lost, an anti-reflective coating is placed on top of the silicon wafers. The most commonly used coatings are titanium dioxide and silicon oxide, though others are used. The material used for coating is either heated until its molecules boil off and travel to the silicon and condense, or the material undergoes a process known as sputtering.
- **Encapsulating the Cell**
  The finished solar cell is then encapsulated between a **superstrate** layer on the top and a **backsheet** layer on the bottom. The superstrate is traditionally made of glass, and the backsheet is made of mylar or tedlar plastics. This cell is then placed inside an aluminum case to create a module that can be placed/installed wherever there is sunlight available at some point (rooftops, gardens, walls, gardens, integrated into buildings...)

33 www.parc.com/cms/get_article.php?id=543
34 Ibid.

Polycrystalline Silicon Cells

... are many crystals of silicon in a semi-chaotic state, typical of medium-grade, medium-efficiency PV-material. Manufacturing starts with melting the material followed by a solidification process with a predetermined crystal orientation structure resulting in mc-Si blocks with different visible parts with different kinds of (steel) blue.

This movie illustrates the production process of Si-cells by German market leader Q Cells.[35]

In order to reduce the amount of Silicon used a lot of research goes to the making of Thin-wafer based solar cells expected to enter the market by 2010 (100 to 150μm-thin wafers instead of conventional 220μm-thin wafers).[36]

35 The Production of PolyCr-Si Cells.mp4 (German, English subtitles) Juin,27, 2007 www.qcells.com
36 Interview Poortmans, J., Imec.

Thin Film PV

The use of large amounts of silicon in photovoltaics contributed to a temporary shortage of the material on the market and increasing prices. This has prompted the development of innovative thin film technology that became commercially available at the end of the 90ies. (Although the most well known application was introduced in the 80ies, a-Si solar cells in pocket calculators...).

Unlike their rigid c-Si counterparts, most thin-film solar cells are naturally flexible, lightweight and unbreakable (except for glass-PV). And as one of the characteristics of PV is that the solar cells have to be integrated on the most diverse surfaces, flexible solar cells are extremely useful in this respect as they are compatible with the existing large-scale implementation of Pvs (BIPV) but also with intelligent miniature electronic systems that must have a certain degree of energy autonomy. In these changing contexts, they must work at much lower energy densities than traditional solar cells, which are placed in the best possible position in relation to the position of the sun. Thin film PV (except for CISG) still has lower efficiencies than it's c-Si counterpart, but it is less effectively less depending on direct sunlight.

Research into a higher conversion efficiency in a cost-effective way (decreasing consumption of costly raw material and the amount of primary energy required during the production process) while improving usability, versatility and adoption of photovoltaic technology are therefore important drivers for the ongoing research. Finally, with the increasing amount of PV-applications the diversity of the aesthetical qualities (shapes, dimensions, colors) is gradually growing.

There are many different **manufacturing technologies** for thin film solar cells but in general, they follow the process below:

- **Substrate**
  Unlike c-Si manufacturing, thin-film starts with a thin layer of flexible **substrate** and metal contact, and builds the solar cell layer by layer from bottom up. Everything is deposited on top of the substrate layer using well known processes such as chemical vapor deposition or simpler and higher-yield printing processes in roll-to-roll manufacturing[37]. The substrate is normally coated glass, stainless steel or plastic.
- **Thin-Film Semiconductor**
  The actual semiconductor materials including semiconductor ink are deposited on top of the substrate. Depending on the technology, there may be several layers of semiconductor material to maximize solar cell efficiency.
- **Electrical Contacts**
  A transparent conducting oxide layer (such as tin oxide) is deposited at the end to form the front electrical contact of the cell. Or a conductive substrate is directly used as electrode (and thus avoiding bottom-electrode deposition cost) achieving a low-cost top electrode of high performance.[38]
- Encapsulating the Cell
  The cell is then laminated with a superstrate material to produce a weather resistant and environmentally robust module with lower balance-of-system cost.

37 “Some of these other thin-film technologies, as well as crystalline silicon technology, employ also a step-and-repeat batch process, not a continuous roll-to-roll manufacturing process.” http://www.ovonic.com/eb_so_thin_film_pv_technology.cfm

38 http://www.nanosolar.com/conductivesubstrate.htm; http://www.nanosolar.com/LowCostTopElectrode.htm

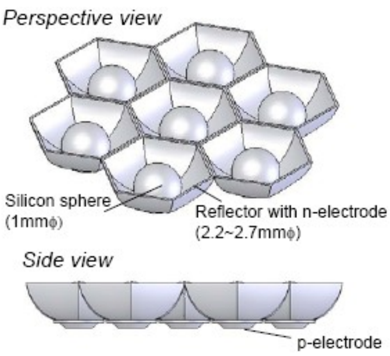
Spheral solar technology (Silicon Spheres)[39]

Spheral solar cells are relatively new in the solar market. They offer potentially lower costs, higher flexibility and use, while using less silicon. It allows the use of a versatile substrate (background material holding light-sensitive semiconductors) that can be integrated in different applications.

The technology of spheral solar cells includes substrates made of lightweight and flexible materials. This ensures adaptability of the solar modules to a variety of applications, surfaces and designs. These modules also do not use glass, unlike other fragile solar products, and as a result are more durable, can be rolled over, walked on, and are protected against breakage during installation, vandalism or inclement weather conditions.

The technology involves bonding tiny millimetre sized polycrystalline silicon embedded at regular intervals between thin sheets of lightweight and flexible substrates (usually aluminium). This allows relatively cheap, low-grade silicon to be used as starting material and it ensures adaptability of the solar modules to a variety of applications, surfaces and designs. Energy conversion efficiencies for solar modules based on the spheral technology range between 11-15%.

Recently an enhanced type of spheral technology has been introduced on the market (10kW modules) which is a 'mini-Concentrated PV' as each of the one-millimeter-diameter silicon spheres is placed in its own hexagonal aluminium reflector. This way the arrays are made up of thousands of tiny silicon spheres surrounded by hexagonal reflectors. These work like car headlights but in reverse, ensuring that any light hitting the reflector *is directed toward the sphere. When this approach is used, even the* underside of the sphere is utilized. The hexagonal shape of the reflectors allows them to be slotted together without dead space between them. The cells use one-fifth of the raw silicon material compared with traditional PV cells and currently have efficiencies of about 10 percent.[40]



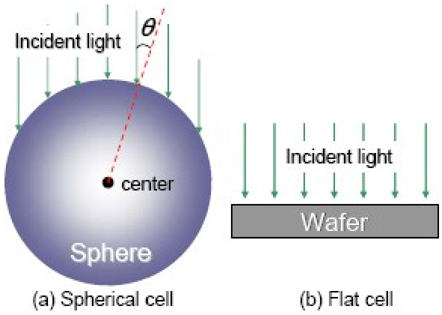


Fig. Left: Schematic images of spherical silicon solar cell with semi-concentration system
Fig. Right: Schematics of a spherical and a flat solar cell.[41]

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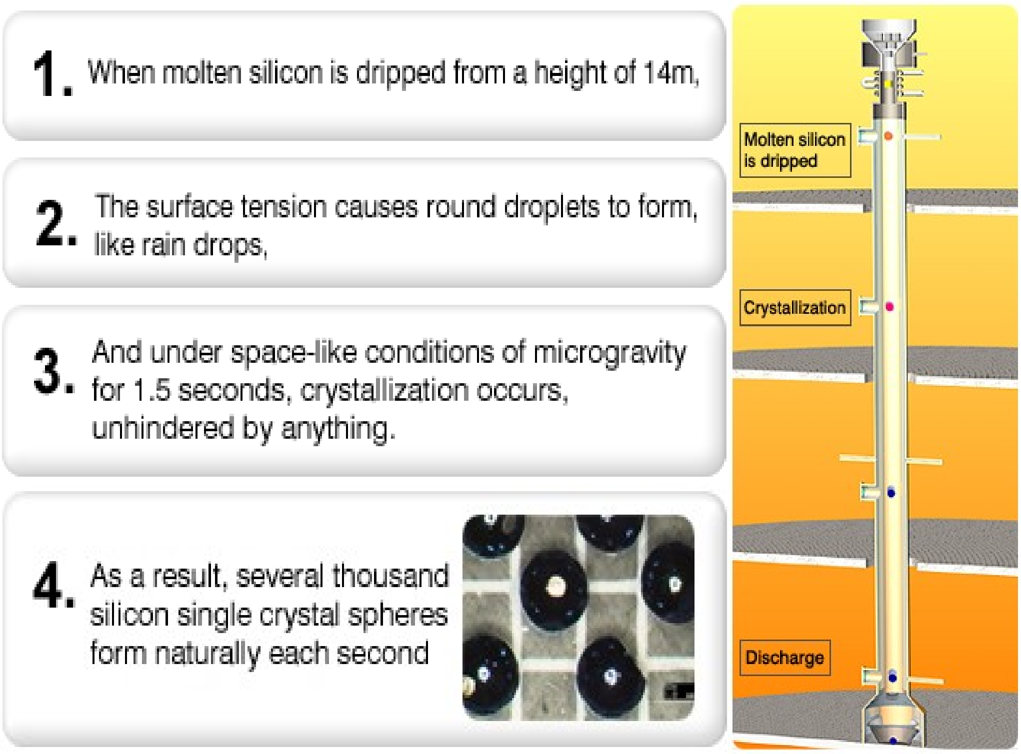
39 **S.N.** (2005) *Spheral Technology in the Photovoltaic Industry.*In: PV Industry Note. August 8, 2005. Prometheus Institute for Sustainable Development. www.prometheusinstitute.org – p.2

40 **Rowe, D.G.** *Focusing Light on Silicon Beads. Placing tiny spheres of silicon in reflective trays could be the key to cheap, efficient solar cells.* In: Technology Review – MIT. November 13, 2007. http://www.technologyreview.com/Energy/19696/?nlid=676

41 **Takashi M. et.al.** (Fac. of Science and Engineering, Ritsumeikan University, Kusatsu, Shiga (JAP)). Design Strategy and Development of Spherical Silicon Solar Cell with Semi-concentration Reflector System. S.E. Nov. 13, 2003. p.1,2.

Environment
By not using materials such as cadmium or rare elements in production, spheral solar cells do not pose any environmental or health hazards. Some studies reveal that they have shorter lifetimes than the regular crystalline silicon-based cells because of the design. Data available at present indicate a cell lifetime of less than three years.

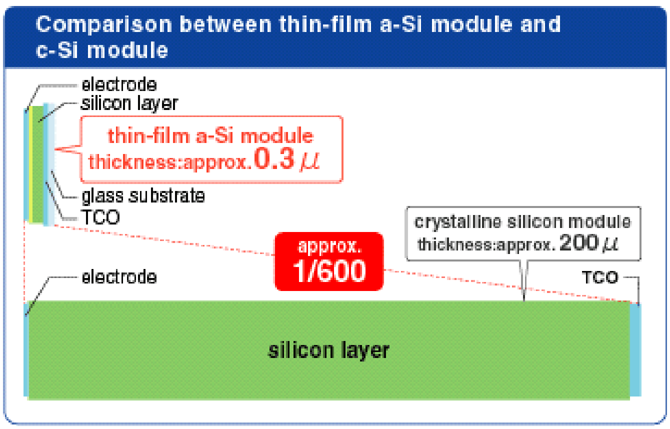
Microgravity – a key factor behind spherical solar cells[42]



A rather poetic application can be find in the Aimulet LA designed by artist Laurie Anderson. The tiny device is made of *bamboo and contains a speaker which provides decoded infrared light audio information- and the spheral pv-cells.* (More info see PhoEf Cases).

Amorphous silicon (a-Si) Thin Film

Thin films of amorphous Si should be world famous as they were introduced in the 80ies in the pocket calculators and wrist watches demonstrating succesfully that no direct sunlight is needed for thin film PV. Usually a-Si is produced using Plasma Enhanced Chemical Vapor Deposition (PECVD) of gases containing silane (SiH4) requiring a very small amount of Silicon. The layers may be deposited onto both rigid substrates (e.g. glass) and flexible substrates (e.g. thin metallic sheets and plastics), allowing for continuous production and diversity of use from BIPV to consumer electronics.



In terms of efficiency they are most frequently installed with a cell-efficiency of 7-9%. (50 to 60 Wp/m2). For a fixed power quantity this requires almost double the covered area compared to crystalline silicon modules. (see image[43]

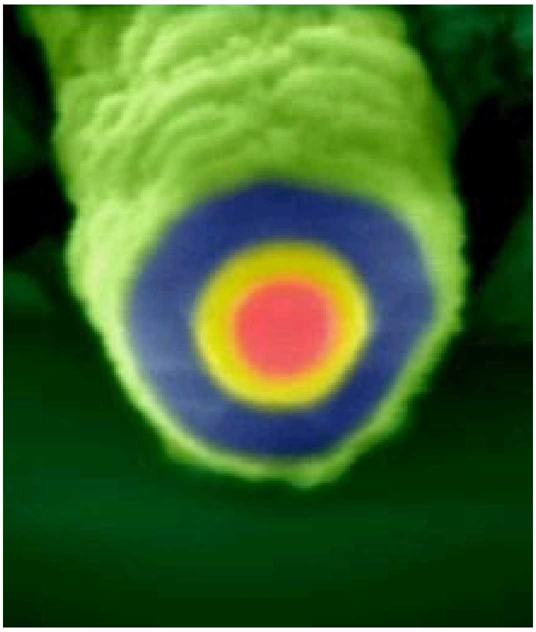
42 *www.kyosemi.co.jp/product/pro_ene_sun_e3.html*
43 Kaneka Silicon PV - www.pv.kaneka.co.jp/why/index.html

Recently crystalline/amorphous hybrid types have started to appear in a bid to improve conversion efficiency.

It is possible to absorb the solar spectrum more efficiently and to improve cell stability by using multiple *p-i-n* structures with different energy bandgap *i*-layers to produce 'double junction' or 'triple junction' structures.

'Microcrystalline Si' ('nanocrystalline Si').

If the silane gases used for deposition of amorphous Si are diluted in hydrogen, the deposit consists of regions of crystalline Si immersed in an amorphous matrix30. This two phase material is known as 'microcrystalline Si' or sometimes as 'nanocrystalline Si' (see picture). There are various approaches each with different ways of depositing different layers on different substrates with various thicknesses and efficiencies. The advantages are the very high durability, a low silicon consumption and a complete independence from bulk silicon supply.



HIT PV Cells

In this device, layers of amorphous Si are deposited onto both faces of a textured wafer of single-crystal Si. (developed by Sanyo). Recent research showed that UV-light could be efficiently coupled to correctly sized nanoparticles and produce electricity. By placing a film of Si-nanoparticles onto a Si-cell it will produce more power with less heat and with prolongued cell life. (In conventional solar cells, ultraviolet light is either filtered out or absorbed by the silicon and converted into potentially damaging heat, not electricity.)[44]

III-V compounds and alloys

The III-V compounds such as GaAs, Ge, InP and GaSb are excellent materials for high-efficiency-cells are not readily available and are more expensive than silicon solar cells, but especially the multijunction cells show high efficiencies (up to 35%) and radiation resistance. The disadvantage of using III-V compounds in photovoltaic devices is the very high cost of producing device-quality substrates or epitaxial layers of these compounds. These materials are also easily cleaved and are significantly mechanically weaker than Si. They are mainly used in space and in terrestrial CPV-systems.

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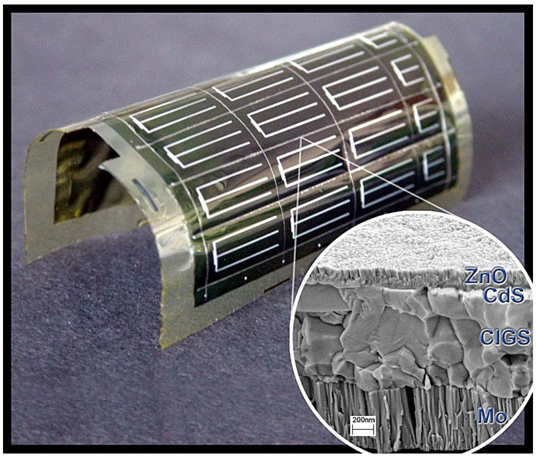
44 **Kloeppel, J.E.** *Silicon nanoparticles enhance performance of solar cells* In:Physical Sciences. August 20, 2007.

Inorganic Thin Film based on (Chalcopyrite) compound semiconductors

CIS/CIGS-based thin film cells



CIS and CIGS stands for the chalcopyrite compound semiconductors Copper, Indium, (Gallium) and Selenium. The thin film-PV using CIGS is the most recent one with higher efficiiencies than the older CIS due to the addition of Gallium. CIGS solar cells are currently the only thin-film technology having achieved efficiencies comparable to silicon solar cells (from 13,4 to 19,5).

They have a multi-layer structure stacked on a substrate, in this case a high-temperature polyimide substrate that is coated with molybdenum, CIGS, cadmium sulfide, zinc oxide and indium tin oxide (see detail picture) . All the component films of this structure can easily be processed on flexible substrates. The panels made from these cells are mainly for use in the BIPV (on rooftops).

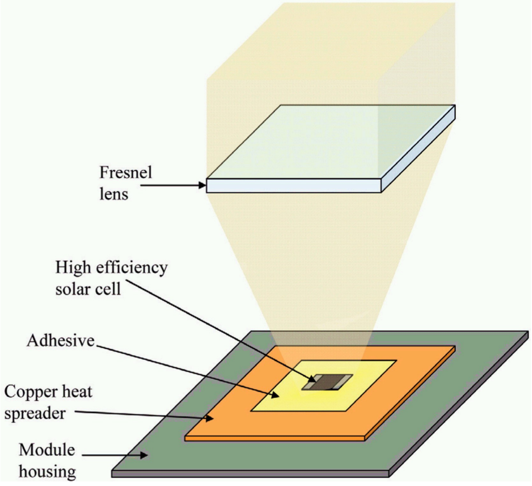
Cadmium-telluride-based solar cells

Only a few microns of CdTe are needed to absorb most of the incident light. Because only thin layers are needed, material costs are minimized, and because a short minority diffusion length (a few microns) is adequate, expensive materials processing can be avoided.

Environment
The main materials that are used in this category are not abundant and the rhythm of depletion will depend only the growth of the market. And in the case of Cadmium, although nano-quantities are used, it is a toxic heavy metal, a cumulative poison, even in small amounts. The manufacturers (First Solar) have undertaken recycle programs but this requires extra energy for transport and machinery, responsibility of the clients (including measurements in case of fire) and it is not sure what might happen if the initial manufacturer disappears from the market or what the health risks in case of a fire would be...

Cadmium-telluride panels in particular seemed finished five years ago when BP Solar, shut down what had been the largest cadmium-telluride commercialization effort. BP Solar had opened a cadmium-telluride module plant. Creating films to exacting specifications proved harder than expected a nd the company was concerned about the product's image, given the use of the toxic heavy metal cadmium. First Solar addressed concerns about the toxicity of cadmium by creating a recycling program guaranteed to take back panels at the end of their useful life. Nevertheless, In August 2007, First Solar CdTe modules were installed on the roof of a logistic centre in Ramstein, Germany. The installation is capable of generating 2.5 MWp of power, currently the largest thin-film BIPV generation project using thin-film solar cells.

Concentrated PV: optics for more light



Concentrator PV (CPV) systems are one of the ways to optimize the capturing of the available amount of light energy. Like the mini-concentrated PV in the earlier mentionned spheral cell PV these systems use optical lenses (fresnel; see the figure) or low-cost mirors to capture the light and transmit it highly concentrated to high efficiency solar cells, mainly the multijunction III-V compounds and alloys.

As discussed above they achieve the highest avaiblabe efficiencies (up to 35%) and radiation resistance as they originate from research for PV for use in space. They are more expensive than silicon solar cells and not that readily available on the consumer market. Overall the concentrator cells have an efficiency of 20 percent or more.

Concentrators require direct sunlight and do not work with an overcast sky so they can only (best) be used in these parts of the world where there is unimpeded sunlight. Also, for best conditions they have to be pointed to the sun which requires a (automated) tracking system. With all these components these systems are expensive and complex, requiring high investments. But they can deliver of the highest outputs so they tend to be more appropriate for large-scale systems, ground-based PV utilities with an output of more than 20 to 30 kWp., located in inland areas where cloud cover is low. They are mainly used for large projects owned by governments and or private energy companies. Spain is one of the countries where this technology is most used.

Although the idea of this ancient technique is very interesting and simple, there is surprisingly little DIY-stuff to find. Another characteristic of concentrating techniques using mirrors is that they can be used for photon transport in case the sun has to be 'moved', from one sunny place to provide (more) electricity in a shady or utterly dark place.

CPV using luminescent dyes on Perspex/Acrylic (PMMA)

One of the more experimental approaches is CPV using luminescent dyes on Perspex/Acrylic (PMMA). Light travels through the acrylic surface which is colored with a dye (e.g. Yellow, purple and a red composite) capturing different bandwidths of the light. Si Solar cells are placed against the acrylic on the sides (e.g. laminated/adhesive). The technology does not need direct sunlight, it works under diffused light conditions. Efficiencies are estimated from 4,5% up to max. 12%. [45] The experimental design allows besides different colors also various rigid shapes. It is aimed for use in Building Integrated PV applications.

Note: for other -still experimental PV-technologies based on multiple energy level approaches or Thin-film tandems, hot-carrier cells etc., download the before mentioned resource: **Conibeer, G.** (ARC Photovoltaics Centre of Excellence, School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney (AUS)). *Third Generation Photovoltaics.* In: Materials Today - Volume 10, Issue 11, November 2007. Pp 42-50.

45 Richards, B.S. Interview at School of Engineering and Physical Sciences, Heriot-Watt University. Edinburgh (SCO). Oct. 3rd, 2007.

Organic PV

A radically different approach is to produce cheap electricity from organic molecules instead of pure semiconductor metals. The aim is to use new materials, production processes and installation technologies to make the organic solar cells more efficient and cost effective, the generic drivers so to say for the PV-field in the whole. As they are pliable, light, unbreakable and available in different colors and shapes they can serve as a cover layer on buildings, windows, cars, clothing or electrical appliances. Main disadvantage today is the low efficiencies (max. 5 years) and the short life span (max. 3 years). Nevertheless they are slowly appearing on the consumer market and will continue to do so.

Dye Sensitized (organic) Solar Cells (DSSC)

One of the new designs has been pioneered in 1991 by researchers at the Swiss Federal Institute of Technology in Lausanne led by physicist Michael Grätzel. Their devices use molecules, liquids directly derived from plants. Therefore they are photoelectrochemical and strictly not photovoltaic which implies a solid-state device. This idea of harnessing photoelectrochemical effects to produce electricity from sunlight is not new since Becquerel's pioneering PV-experiments where with liquid-based devices.[46]

Some have called this emerging PV technology the most promising advance in PV since the invention of the silicon cell. Compared to conventional c-Si, it has lower cost and embodied energy in manufacture, it requires no direct sunlight, it does not use high-priced raw materials, emits no toxics during the production and it provides more freedom in design.

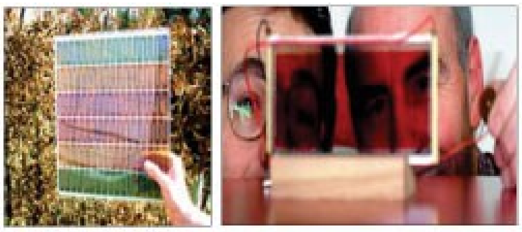


Figure 4: (Left) Various colours in a series-connected dye-solar-cell module developed by Andreas Hinsch's group at ISE-FHI Freiburg, Germany, in collaboration with RWE Schott GmbH. (Right) See-through DSC producing electric power from diffuse light to drive a fan.

Some believe that the future of DSSC is uncertain because the technology might "fall between two chairs": first of all DSSC are much less efficient than Si-cells and they show a poor long term stability. Secondly, they are less easy to produce than organic polymer cells (DSSC consist of three layers, one more than the organic cells. The electrolyte could be integrated leading to two layers, but then the efficiencies would drop to 2 to 3 percent, comparable to those of Organic Cells) .[47]

DSSC-technology can best be described as 'artificial photosynthesis' using an electrolyte, a layer of titanium (a pigment used in white paints and tooth paste) and ruthenium dye sandwiched between conducting glass. Other materials involved are Nanocrystalline oxides and glass soldering for sealing. Light striking the dye excites electrons which are absorbed by the titania to become an electric current many times stronger than that found in natural photosynthesis in plants.[48]
Chlorophyll and anthocyanin organic dyes can be extracted from e.g. citrus leaves, raspberries and blackberries. These various natural components give the cells a range of colors which together with the partial transparency of dye solar cells offers new design options for various applications (glass façades etc...).

In theory natural organic dyes can be used to make home made cells. And although there is DIY-literature available, it is not easy to obtain some useful amounts of electrical power. (link to LumGreen WS). An interesting resource is the paper ***'Design of a Cradle to Cradle Biophotovoltaic System'.*** It outlines the design of a cradle-to-cradle PV system combining a zero-infrastructure approach with biomimicry to create a system with maximized simplicity and potentially universal applicability. A lot of issues are still to overcome but the author states that 'Dye sensitized PV cells are found to be the best solution to the underlying energy problem.'[49]

46 Boyle, G. Ibid. p. 81
47 Poortmans, J. Interview at IMEC, Leuven (BE), November 19, 2007.
48 Visualisation of Principles of operations and description see: http://lpi.epfl.ch/solarcellE.html
49 Eng, N. (2005) *Design of a Cradle to Cradle Biophotovoltaic System. A solution to aid leapfrogging to*

Organic Polymer based PV

The polymer PV technology is very new and in many ways still in its infancy. While many gaps need to be bridged before large scale application of this technology can be envisaged the technology houses some very attractive features concerning the way polymer PVs are produced. Low-cost materials, solution processing and printing techniques in principle allow for fast high volume (bulk) production on flexible substrates with low thermal budgets. Organic solar cells are flexible and as thin as a sheet protector. They are both light and color tunable which makes them in theory very versatile and useful in the worlds of household and more intimate close-on/in-body appliances. Their main area of application is expected to be in the construction industry from 2015 onwards, where the cells will be used in the form of a thin layer of plastic on roofs, windows or facades.[50][51]

But plagued by poor transport and strong environmental sensitivity of organic materials, efficiencies have been limited to the 2-4% range and potential products have faced impracticable degradation when exposed to air limiting life span to 1-1,5 years.

PV cells based on a blend of organic polymer and semiconductor nanocrystals have played a significant role in increasing efficiency, these hybrid cells are still limited by the presence of organic polymer. [52]

Environmental note: use of bio-based polymers

Today, petroleum-based plastics -as a result of enhancements to some widely available bio-based polymers- are used in the production of virtually all solar cells and modules. However, the cost of these plastics has been steadily increasing due to rising oil prices, and petroleum-based plastics are not environmentally neutral. These bio-based polymers are derived from renewable plant sources their costs are not tied to high oil prices.[53]

More details about what kind of plants and how many are needed on what amount of land have not been found. The question rises of what the environmental consequences would be when be this technology would become massively popular (as the oil prices will continue to rise).

PV from Soluble small molecules

Solution-processable small molecules have attractive features for application in photovoltaic cells. They offer the facile processing associated with polymers, yet are easier to synthesize and purify, are monodisperse, and typically show higher charge carrier mobilities. Recent progress in solution-processable small molecule blends has yielded PV-cells with efficiencies exceeding the modest 1 percent. Research is still in its early stages.[54]

sustainable electrical energy supply from zero infrastructure. Faculty of Engineering and Applied Science Department of Graduate Studies. Ryerson University (US). p.2.

50 Krebs, F.C. et. al. (The Danish Polymer Centre, RISØ National Laboratory, Roskilde, Denmark). *Strategies for incorporation of polymer photovoltaics into garments and textiles. In: Solar Energy Materials & Solar Cells 90 (2006). p.1062* - www.elsevier.com/locate/solmat

51 Initiative Organic Photovoltaics - http://www.bmbf.de/en/10413.php

52 Ibid.

53 www.biosolar.com/howsolar_technology.html

54 Lloyd, M.T. et.al., (Department of Materials Science and Engineering, Cornell University, Ithaca, New York (US)). *Photovoltaics from small soluble molecules.* In: Materials Today - Volume 10, Issue 11, November 2007. p.40.

Overview cell and module efficiencies[55]

Note: the efficiencies in this table are integrated in the PV-tech-sheet in the PhoEf Overview

Table 1 Best efficiencies reported for different solar cells and modules.

Type of solar cell	Highest reported small area cell efficiency			Highest reported module efficiency		
	Efficiency (%)	Area (cm^2)	Reference	Efficiency (%)	Area (cm^2)	Reference
Crystalline Si	24.7	4.0	UNSW[i], PERL[ii,2]	22.7	778	UNSW/Gocherma
Multicrystalline Si	20.3	1.0	FhG-ISE[iii,4]	15.3	1017	Sandia/HEM[5]
Amorphous (and nanocrystalline) Si	10.1	1.2	Kaneka, single junction[6]	10.4	905	USSC[iv], triple junc
μc-Si/αSi:H micro-morph cell	11.7	14.2	Kaneka, minimodule[8]	11.7	14.2	Kaneka, minimodu
HIT[v] cell	21.8	100.4	Sanyo Corporation[9]	17.3	11 000	Sanyo Corporatio
GaAs cell	25.8	3.9	Kopin Corporation[10]	Not relevant	Not relevant	
InP cell	21.9	4.0	Spire Corporation[11]	Not relevant	Not relevant	
$GaInP_2$/GaAs/Ge multijunction cell	39.3*	0.4	Spectrolab, concentrator[12]	Not relevant	Not relevant	
CdTe	16.5	1.0	NREL[vi,13]	10.7	4874	BP Solarex[14]
CIGS[vii]	19.5	0.4	NREL[15]	13.4	3459	Showa Shell[16]

[i] UNSW, University of New South Wales.
[ii] PERL, passivated emitter rear locally diffused.
[iii] FhG-ISE, Fraunhofer Institute for Solar Energy Systems.
[iv] USSC, United Solar Systems Corporation.
[v] HIT, heterojunction with intrinsic thin layer.
[vi] NREL, National Renewable Energy Laboratory.
[vii] CIGS, copper indium gallium diselenide.
*Boeing-Spectrolab (Sylmar, CA) announced a 40.7% efficient cell under 240x concentrated light in December 2006 (unpublished).

About efficiencies & power rating

A solar cell's energy conversion efficiency is the percentage of power converted from absorbed light to electrical energy and then collected when a solar cell is connected to an electrical circuit. The efficiency of a PV-module is usually lower than that achieved by cells in the laboratory because:[56]

- it is difficult to achieve as high an efficiency consistently in mass-produced devices as in one-off lab-cells under optimum conditions;
- lab-cells are not usually glazed or encapsulated;
- in a PV-module there are usually inactive areas, both between cells and due to the surrounding module frame, that are not available to produce power;
- there are small resistive losses in the wiring between cells and in the diodes used to protect cells from short circuiting;
- there are losses due to mismatching between cells of slightly differing electrical characteristics connected in series.

Although the existence of a widespread international agreement that the performance of PV cells and modules should be measured under a set of standard test conditions, a critical reading of the communicated efficiencies of PV-cells/modules is recommended due to 1/ the strong competition, high investments (and nervous shareholders)-exaggerations have been reported. These (marketing) practices have been criticized by numerous researchers as -in the end- it creates unrealistic expectations which may lead to a disbelief in the overall capacities of PV.
2) "...efficiency estimates are notoriously unreliable because each research group

55 Miles, R.W., Zoppi, G., Forbes, I. (Northumbria Photovoltaics Applications Centre, Northumbria University). Inorganic Photovoltaic Cells. In: Materials Today - Volume 10, Issue 11, November 2007. p. 21.
56 Boyle, G. Ibid. p.74

tests efficiency under its own approximation of the solar spectrum."[57] (see also in Glossary).

Furthermore the communication about the power of the cell/power should be read critically as in practice a solar panel reaches in general only 80% of the Watt-peak power. In practice a solar panel reaches in most cases 80% of the communicated Watt-peak power. Other sources speak of 20 to 40 percent introducing this correction formula:

Manufacturer Module Rating x 0,6 = Real Power Rating.[58]

57 Shaheen,S. University of Denver in: *www.technologyreview.com/Energy/19044/page2/*

58 Kemp, W.H. (2005) The Renewable Energy Handbook. A Guide to Rural Energy Independence, Off-Grid and Sustainable Living. Aztext Press/New Society Publishers. Ontario, Canada. p. 240.

PV-applications & components

Many components make up a complete solar system:

1. PV cells or modules or arrays
2. charge controller(s),
3. batteries
4. DC – DC inverter
5. DC-AC inverter(s) + accessories e.g.
6. Junction box and wiring
7. Optional:
   1. Monitor software & Control for all important parameters of the solar system.
   2. Support structure: to attach the panels
   3. Tracking device (see CPV)

The ones that ultimately will be used in the PV-system depends on its context of use, on the application type. There are four main application types for terrestrial PV power systems[59]:
1. Off-grid domestic systems provide electricity to households and villages that are not connected to the utility electricity network (also referred to as the grid).
2. **Off-grid non-domestic installations** for remote power for a wide range of applications where electricity grids are non-existent or rudimentary (rural areas) and all forms of energy are usually very expensive.
3. **Grid-connected distributed PV systems** are installed to provide power to a grid-connected customer or directly to the electricity network (specifically where that part of the electricity network is configured to supply power to a number of customers rather than to provide a bulk transport function).
4. **Grid-connected centralized systems (PV power plants)** perform the functions of centralized power stations.

As mentioned before the focus here lies on the so-called Off-grid PV, where one can differentiate between the immobile Stand-Alone systems and the mobile Consumer Products. As a consequence the numbers 1-4 and 7.1 of the list above will be further discussed below. Documentation on how to connect to the grid is easily and abundant available on the internet.

Off-grid PV

-> Autonomous / Stand alone Systems

Off -grid non-domestic PV serves a variety of applications such as water pumping, remote communications, safety and protection devices. This is the main type used in the arts context (see the 'Cases' section). These applications are non-moving as opposed to the mobile so-called *consumer product applications*, products with a low DC-energy need.

In this set up a PV-cell or panel is used to provide DC current either with or without storage in the form of battery back-up. For example if the application has to respond to the available radiation, then a PV-cell can be used as an actuator/sensor device (see movie waterpump Intersolar). When storage is desired than a **battery** will be needed to provide power at the moments when the output of the PV-cells or panels is insufficient. In this case the electric dialog between the PV-panel and the battery has to be controlled by a device called a **charge controller** (regulator). It's primary function is to protect the battery bank from overcharging. by monitoring it: when the bank is fully charged, the controller interrupts the flow of electricity from the PV panels. It will also prevent that the electric current would flow back from the battery to the panel.

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59 **S.N.** (2007) *Trends in Photovoltaic Applications. Survey report of selected IEA countries between 1992 and 2006.* International Energy Agency. August 27, 2007. p.4. www.iea-pvps.org

It is also recommended to measure the system with a **System meter** which displays several different aspects of the solar-electric system's performance and status, tracking how full (empty) the battery bank is; how much electricity your solar panels are producing or have produced; and how much electricity is in use.

Whenever it is necessary to change DC electrical power efficiently from one voltage level to another **DC-DC converters** are used. Unlike AC, DC can not simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the DC equivalent of a transformer. Typical applications are when e.g.: 1.5V from a single cell must be stepped up to 5V or more, to operate electronic circuitry or where the 340V DC obtained by rectifying 240V AC power must be stepped down to 5V, 12V and other DC voltages as part of a PC power supply. The conversion has to be done with the highest possible efficiency but some energy is inevitably used up by the converter circuitry and components in doing their job. There are many different types of DC-DC converter, each of which tends to be more suitable for some types of application than for others. For convenience they can be classified into various groups. For more information see Jaycar Electronics Reference Data Sheet: DCDCCONV.PDF (1) - *DC-DC Converters: A primer.* January 15, 2001

About storage batteries[60]

Incoming solar energy is directly available to each of us only during the time our part of the planet is facing the Sun (we call that "day".) And if it's a cloudy or rainy day, most of that solar energy is bounced away from us. So for during the times we are turned away from the Sun (we call that "night"), or on cloudy winterly days, or when there is not sufficient artificial light we need some way to store previously solar-produced electricity.

One of the present drawbacks to storing solar-generated electricity is that we store the electricity in chemical storage batteries, relying on the electrical energy to produce a chemical change, which is later reversible.

Things like cadmium, lead and sulphuric acid come to mind and -although to some extent recycling is possible- suddenly the grid suddenly pops up again as a cleaner alternative, especially when it operates on PV-, wind-, tidal- or some other renewable energy.

So, at some point you will have to decide if a storage battery is needed or not in your power design, for the storage of excess energy or the storage for creating a reserve for when there is not enough light energy available or when demand is too high.

You will not need them if you wish to use the PV-cells' to respond immediately to changes in irradiation, hence a as a light sensor device, let the amount of light influence in some way in real time how your electric devices are behaving. Mind you that some devices like cameras do not switch on automatically after they went off due to a lack of electricity.

On the other hand, if your installation has to be up and running under -at some point- insufficient light conditions (natural or artificial), then you will need a battery back up that complements -or takes over- from your PV-cells.

If you DO decide to work with a storage battery, you will have to look a bit deeper into the tech specs as they do require knowledge and (safety) care. Batteries in PV systems can be dangerous because of the energy they store and the acidic electrolytes they contain, so you'll need a well-ventilated, non-metallic enclosure for them. You can find an overview with the

60 Based on Michael Bluejay's Battery Guide - Brussels Observatorium voor Duurzame Consumptie - www.practicalaction.org

strong and weak points of the most common types below (fuel cells are not discussed here). Although several different kinds of batteries are commonly used, the one characteristic they should all have in common is that they are **deep-cycle batteries**. Unlike your car battery, which is a shallow-cycle battery, deep-cycle batteries can discharge more of their stored energy while still maintaining long life. Car batteries discharge a large current for a very short time -- to start your car -- and are then immediately recharged as you drive. PV batteries generally have to discharge a smaller current for a longer period (such as all night), while being charged during the day.
The most commonly used deep-cycle batteries are **lead-acid** batteries (both sealed and vented) and **nickel-cadmium** batteries. Nickel-cadmium batteries are more expensive, but last longer and can be discharged more completely without harm. Even deep-cycle lead-acid batteries can't be discharged 100 percent without seriously shortening battery life, and generally, PV systems are designed to discharge lead-acid batteries no more than 40 percent or 50 percent.

Chemically-charged batteries became quite common in the mid-nineteenth century to provide power for telegraphs, signal lighting, and other electrical apparatus. By the 1890s central stations were providing both heating and lighting, and many did both. Electric systems were almost all direct current (DC), so incorporating batteries was relatively easy.[61]

Also, the use of batteries requires the installation of another component called a **charge controller**. Batteries last a lot longer if care is taken so that they aren't overcharged or drained too much. That's what a charge controller does. Once the batteries are fully charged, the charge controller doesn't let current from the PV modules continue to flow into them. Similarly, once the batteries have been drained to a certain predetermined level, controlled by measuring battery voltage, many charge controllers will not allow more current to be drained from the batteries until they have been recharged. The use of a charge controller is essential for long battery life.

TYPE	**GENERAL**	**POS - NEG**	
SECONDARY CELLS Rechargeable cells & batteries			
Lithium		Good as a Reserve battery. Can be rejuvenated by putting in freezer during 24hrs (at own risk)	
Lead-Acid		**+** * Price: Least expensive option for any significant size of electrical battery storage * Nominal fully charged voltage of 2V per cell (6 cells for 12V) **-** * Discharge: should be limited to 50 to 70 per cent of its rated capacity. * Withstands a more limited number of charge-discharge cycles: The greater the depth of discharge, the fewer cycles it will survive[2]. Temperature: Battery-life decreases with increased temperature, but Capacity increases with increased temperature: approx. 1 per cent per 1°C, going up from 25°C to 40°C. It is reduced by 1 per cent per 1°C going down to 0°C.	

61 www.energy.rochester.edu/storage/

1. Automotive	Suited for heavy currents, and therefore poorly suited to supplying smaller currents for many hours before being recharged.	**+** * Price: usually the cheapest compared by rated capacity; * Often produced locally, widely available and repairable. **-** * Poor capacity for their size and a poor cycle life. * Cycle life: 20 deep-discharge cycles * Easily damaged if left discharged for any length of time	
2. Deep-discharge / traction	Commonly used for electric' vehicles	**+** * Can tolerate discharge to as much as 80 per cent of their rated capacity * Cycle life: 1000 to 1500 deep cycles. **-** * Relatively expensive * Need frequent maintenance; tend to lose water at a faster rate than other types of lead-acid battery. * Not often locally available	
Stationary (stand-alone or standby batteries)	Designed to supply power when there is a grid failure. In most applications they are kept fully charged by the mains supply and are ready to take the load whenever needed.	**+** * Extremely reliable * Low self-discharge rate * Long cycle life with shallow cycles lasting up to ten years **-** ***** Usually over sized for stand-alone applications, to ensure that they only run with shallow cycles and last a long time.	
Low-antimony solar battery	Designed for photovoltaic systems. Similar to stationary ones.	**+** * Self-discharge rate and distilled water consumption are both low. * Cycle ranges from 1200 to 3000 depending on the discharge rates. - * Price: Fairly expensive * Available only via PV-systems suppliers.	
Sealed or valve-regulated battery	The hydrogen produced by these batteries is absorbed by chemicals inside them and they contain enough electrolyte for their entire life, so they are often called 'maintenance-free'.	**+** * They have a low rate of self discharge and can support a full discharge, but must be recharged as soon as possible to prevent permanent damage. **-** * Short cycle life for deep cycles. * Must be recharged asap at a full discharge to prevent permanent damage. The main disadvantage is their need for regular recharging to prevent sulphate build-up. Batteries in storage will need to be recharged about once every three months, more often in countries with high ambient temperatures where self-discharge will happen more quickly. * Likely to have a shorter life than a well-maintained unsealed battery with the same alloy contents, but will obviously last longer than a poorly	

		maintained unsealed battery.	
NiCD (Nikkel Cadmium) AAA, AA or D, Vented or sealed.		**+** * Can be recharged and re-used from 100 to 1000 times. * Withstand a greater depth of discharge than lead-acid batteries, so a smaller capacity can serve a given duty. * Last 10 to 20 years longer for the larger ones. * Can be discharged 100 per cent * Less easily damaged by over-discharge or overcharging, so simpler and cheaper charge control systems can be used to compensate for extra unit costs. * Temperature: more tolerant of extreme temperature variation and can operate at sub-zero. **-** * Nominal voltage is 1.2 volts: nominal 12V ni-cad system needs 10 cells. * Self-discharge more quickly: need regular recharging and are less useful for occasionally used loads Memory effect[1] : full discharge before charging Reversing the polarity when recharging usually destroys it completely (when one cell in a battery of is weaker than the rest, the good cells can cause reverse charging of a weak one in certain circumstances, destroying the weak one completely) Environment! Particularly well suited for small PV application where they are being charged with daily sunshine.	
NiMH (Nikkel Metal Hybrid)		40% more energy than NiCD – limited memory effect – have to be used at least once a month to avoid discharge	
LiON (Lithium Ion)		2x more energy than NiMH Not AA-size; special charger	
HUMAN BODY		/	
PRIMARY CELLS Dry batteries (AA, AAA, C, D)		**-** * Limited energy yield can be obtained before the battery has to be thrown away. * Price: One of the least cost effective electrical power sources in terms of the cost per unit of useful energy delivered. Temperature / Capacity: increases above 20°C; decreases below. Warming batteries before use gives extra power.	
- Zinc-carbon cell	Most widely used	**+** * Capacity: better retained than any other type of portable electrical power source. * Price: Cheapest form of primary cell. Temperature: Self-discharge rate is adversely affected by high temperature. Store cells at between 10-25°C and at relative humidity of below 65 per cent.	

- Alkaline cell (aka manganese dioxide cells, 'heavy duty' or 'long life' batteries)		**+** * Electrical capacity much larger than Zinc-carbon.	
RECENT TYPES (suitable For Primary And Secondary Cell Designs			
Thin and flexible Lithium Ion battery (information from the manufacturer; www.solicore.com)	Supports Volatile Memory And Power Microprocessor; Provides Power For Active Card Components; Applications: RFID Electronics; Time and temperature labels; Smart / active labels; Printed display modules.	+ 1. Solid Polymer 2. Environmentally Friendly 3. No Flammable Solvents 4. No Swelling Or Out-gassing 5. Flexible, Optimized For High Temperature Lamination 6. High Performance 7. High Energy Density Lithium Ion 8. Flexible Form Factor - Can Be Produced In Different Shapes Voltage: 3V Dimensions: 25x29mm; 48x23mm; 76x24mm	9.
High-performance lithium battery anodes *(using silicon nanowires)*		+ “10 times the amount of electricity of existing lithium-ion, A laptop that now runs on battery for two hours could operate for 20 hours” See: www.nature.com/nnano/journal/vaop/ncurrent/full/nnano.2007.411.html	10.

[1] Memory effect
The memory effect is the tendency of a battery to adjust 'its electrical properties to a certain duty cycle to which it has been subjected for an extended period of time. Vented pocketplate batteries do not develop this effect, but sealed NiCD-cells, such as the AAA, AA, C, and D sizes do. To remedy this problem, they need to be 'awakened' by being fully charged and discharged for three or four cycles before their memory is 'stretched' enough to hold a full charge.

[2] Discharge
For example a battery that is discharged regularly by 80 per cent of its total capacity may last 800 cycles, but if it is discharged by only 20 per cent each time it may last 6000 cycles. If the battery were discharged at 20 per cent rather than 80 per cent, the rated capacity will have to be four times larger to deliver the same energy, but will last at least four times as long. The size of the battery is therefore a compromise between making it large but too expensive, and small and affordable but too easily discharged and therefore too short-lived.

Safety and environmental hazards of lead-acid batteries

Vented Batteries: Care is obviously needed as, part from the battery acid being extremely corrosive, hydrogen gas is produced, which is highly flammable and potentially explosive when mixed with air. Thus care should also be taken to avoid naked flames or sparks in the battery enclosure, especially if the battery is housed in a confined space. Never check the electrolyte levels with a naked flame such as a kerosene lamp or a candle. For the same reason, battery storage areas should be well ventilated

Sealed Batteries: These contain the electrolyte in ‘dry’ form so that no electrolyte can be spilled, and so there is less of a hazard. Even so, care must be taken not to damage the casing.

Recycling: Both types of batteries should be deposed of safely. Where practical, it is a good idea to give away lead-acid batteries to local battery manufactures for lead and plastic-casing recycling. Ni-cad batteries should be disposed of carefully to avoid cadmium pollution

More information on the set up of a Stand-Alone system can be found in: S.N. Managing the Quality of Stand-alone Photovoltaic Systems: Recommended Practices. international Energy Agency, Report IEA PVPS T3-15:2003. January 2006. Pp 14-24.

-> Consumer products[62]

The energy system of consumer products is similar to an off-grid PV system: PV cells charge a (set of) batteries and the load is withdrawn from the batteries.

Consumers increasingly possess electrically powered appliances and esp. portable devices using electricity, today in particular in the information, (tele)communication sector and audio and video sector, domotics and soon increasingly in Wearable Computing, Body Area Networks, Intelligent Wear and Electronic Clothing; electrical appliances integrated with the human body for medical purposes. In these products batteries continue to be the main source of power and since the volume of consumer electronics is increasing heavily the same goes for the batteries.

> ...due to the expected further growth of portable products and the increased use of batteries, it might be useful to find ways to reduce costs, user inconvenience and environmental impact of batteries in portable products. Hence, we will further focus on options for the application of PV-solar energy, a renewable energy source in the design of portable products.[63]

Depending on the type of battery used the products above are operated at voltages ranging from 1 to 6 Volts. For that reason the number of PV cells connected in series or parallel depends on the type of battery and the type of PV cell used. The need for DC electricity is ideal since that is what PV systems output directly. Indoor (Thin Film PV; DSSC) or (mainly) outdoor conditions (crystalline Si) determine the choice of PV-tech. Below some advantages and disadvantages of use of PV in portable applications are discussed[64].

The use of PV systems in portable applications is favored by the following
The PV system is operated independently from a fixed grid. Because of the self-supporting energy system the user of a PV powered product does not need to take care of recharging of batteries, resulting in a **convenient use** of the product and an **increased personal mobility**.

Given the present high costs of the use of rechargeable batteries (more than 3.5 USD/kWh, photovoltaic solar energy under optimal light capture is cheaper now (about 0.50 USD/kWh) and might become much **cheaper** in the future. Therefore, it is sensible to partly substitute batteries by PV cells.

Because of the regular charging of batteries in the case of PV powered products the capacity of batteries can be decreased in comparison with batteries in products that are charged by the grid once in a while. The reduced use of batteries will result in a decreased costs and **environmental impact.** By integrating PV cells with for instance rechargeable Li-ion batteries, smart cards, sensors and tags can be powered permanently. By using an replaceable standardized battery-PV unit the energy system can be used in different types of portable products and be used longer than the lifetime of a consumer product. This concept indicates a

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62 Reinders, A. (2003) *Options for Photovoltaic Solar Energy Systems in Portable Products.* Dept. of Design Engineering. Fac. of Industrial Design Engineering, Delft University of Technology. 13p.
63 Ibid. p.4
64 Ibid., p.8,9

possibility to integrate Li-polymer batteries with flexible solar cells.

Batteries are being improved continuously so that their environmental impact is decreasing. However, without a major technology break-through it is not expected that due to this improvement batteries will become as sustainable as PV cells.

The regular charging of batteries in PV systems results in **long stand-by times**. If the energy system is sized well, the reliability of electricity supply in PV powered products can be very high. For an explanation about sizing of PV systems see the pdf

Drawbacks of PV in portable products

Due to mobile operation and indoor use, light capture in PV powered consumer products can be far below that of optimally oriented fixed systems placed outdoor. Changes in user behavior can only partly correct for this problem. A more convenient solution might be found in the use of PV cells that respond to low irradiance.

Consumer products have a relatively short lifetime: in the range of 2 up to 6 years. Hence, compared to off-grid and grid-connected PV systems the lifetime of PV systems in small consumer products is short. In combination with low light capture the energy payback time of PV systems in consumer products might exceed the product's lifetime.

Due to the use of glass substrates PV cells can be relatively heavy, which is not favorable for portable products. Therefore, light substrates are advisable.

Aqnu Inti llipipimuy[65]

Somewhere in between research, in between land, amidst Lapidarium.

As I learn more about it, I tend to see less. I am creating long distances between *Inti* and me. Looking at the horizon, turning round thoughtless, insensible, slowly, very slowly. On top of the two fingers of the clock. Or on the other side, but still with the time. Following the seasons, gravity surrounding the Sun. Gravity surrounding itself. But in whatever direction spinning with eyes wide open, tension builds up with the increasing amount of light entering. First in the right eye, next in the left. Or first in the left eye and then in the right.

Observation bothered by thought; Dare! Dare to look into the luminous circle with it's fierce edges but soft middle, joining for playing the fiercest of all lights. How long before the show burns the eyes?

Gently the rotation speed slows down. The light of all lights moves towards the perfect middle. At first it comes from the corner of the right eye. The immense amount of diffused light abruptly comes to an end in a thin circle. It's sharpest of all lights surrounds an inner core with a soft blue-greyish gloom. As the rotation direction changes, what occurs is identical. This time it starts from the corner of the left eye.

Ever changing places on the ever changing waves carry along tiny Sun dots. There are hundreds of them, thousands: blinding diamonds at the neck of an eternal moving fluid body. A white line connects the laid-down horizon with the boat. Slowly, Very slowly, insensible it moves it's content to the right against the darkish blue-green backdrop. The Sun holds the line that leads it towards the opposite direction. Only when this cloud passes by, or the colourful containers, only then the thin white line is cut into two new pieces. But only to become one again. Where it starts, ends, or where it becomes a great white lake, only there it is where water and air are separated from their Sun above.

Bartaku. North-Sea, somewhere between Edinburgh and Zeebrugge. October 4, 2007.

* 'In areas where people don't own watches, they tell the time by the sun's movements.'[66]
Inti siqay – Inti lluqsimuy: 'the Sun comes up'
Inti llipipimuy: 'flickering Sun' (Sunrise)
Inti t'iksuy – qhata Inti: 'the Sun leans' / 'sloping Sun' (late afternoon)
Inti haykuy – 'the Sun goes down behind the horizon'
Intiq lluqsinan – 'where the Sun comes up'
Intiq chinkanan – 'where the Sun disappears'

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65 *Quechua expression: A piece of flickering Sun**
66 From: Coronel-Molina, S.M. *Quechua Phrasebook. The Language of the Andes.* Lonely Planet. October 2002, Victoria (AUS).

Quick start in 11 counts

This is a possible 11-steps scenario depicting a rational step-by-step way to get a
PV-involved project starting.

1. It starts with an idea
2.1 It needs unavoidably electricity to work.
2.2 Or, you want to explore the possibilities of photovoltaics as such. Go to 6.
3. Calculate the power requirements of your system.
4. Determine when this electricity is needed.
5. Try to think of ways to keep the power consumption as low as possible. (Unless fucking up the power to its extremes is your thing)
6. Check out the existing pv-technologies
7. Experiment with some ready available, cheap, small pv cells/panels.

8. You have found the technology you want
8.1 It is readily available
8.1.1 it fits in your budget: ready to purchase. **Go to**
8.1.2 it is too expensive: Go to 11
8.2 You want to explore and deepen the knowledge, want to explore and experiment with this pv-tech, customize it

9. Look for a nearby company or research center dealing with this tech.
9.1. In case you decide to contact a manufacturer, look for the R&D-responsible (not the marketing boy or girl!)
10. Send him/her a short and most appealing description of your project including
- your expectations of the pv-tech (if possible);
- some 'hunch' that there's a budget (if this is not clear yet, go to 11)
- project timing if possible.
- pv-system sizing: it would be helpful if you could give an idea of the amount of electricity that might be needed to power your project. (link pdf system sizing and power consumption table)

10.1. If you've managed to get your foot in, always ask for a 'guided tour' -they will probably refuse- and consequently a sample *por favor*.
10.2 In case you are convinced that this is what you want, and they are willing to make a customized solution according to your needs, ask them to help you with the testing and implementation in your system.

11. Check in any case -sufficient budget or not- if they consider sponsoring of the material.

Above all: Learn some electricity basics.
It is useful knowledge for the rest of your days.
Especially try to learn how to measure and calculate current, voltage, power and resistance.
W=VxI (power equals voltage times current (Amps)) and $R=V^2/I$

Discussion

(under development)

-
- **comparison of the expected and the achieved results**
  off-grid non-domestic installations

- **suggestions & comments on the research process and its results**

PV is a technology that has not yet diffused thoroughly into our society.
Limited knowledge about this technology by product designers and product manufacturers can be **a barrier** to its application in products.

- **suggestions for the future work based on the conclusions of the research**

Ideas further research

[Draft]

Arts:fundamentally behind in (ab)using & exploring PV
– Urgent need for more documented PV-involved arts projects and experiments. Interviews /contacts with artists documented in this research should be developed.
- More training opportunities
- More DIY experiments and resources especially for the newer and 'cleaner' technologies
· Have to start playing a role in Material improvements
=> More collaborations with science/industry (research centers / R&D) needed!

Environmental impact - limited number of research centers and people involved.
Monitoring!! measuring!!
· Environmental impact of PV and secondary batteries in various portable applications
. "At present you would need tens of tonnes of very rare and expensive materials for large scale production of solar cells to produce sizeable amounts of power.
"Some of the materials currently used may not be sustainable in 20 years time which is why we have to conduct research into alternative materials that are cheaper to buy and more sustainable.

Tech
- Integration in products and use of products will lead to more mechanical stress in solar cells than they endure in a static PV module. The lack of information about mechanical stress indicates a need for further research.
· Technical developments and costs of batteries: esp. Energy storage which could be integrated into the design concept or which may represent a separate cradle-to-cradle technology for development.
  – **Electricity from bacteria -** Microbiële Ecologie en Technologie labMET Vakgroep Biochemische en Microbiële Technologie Ugent Peter Clauwaert olv prof. Verstraete - Onderzoek naar microbiële brandstofcellen
  – Hydrogen powered by PV incl. fuel cells
- Technical developments of PV materials and low power electronics
- To what extent is it possible to depart from the Cradle-to-Cradle principle
- Hybrid PV/Wind
- Monitor control & software

Concerning the language bias this research could be translated into other languages.

> Perhaps a new revelatory experience is taking place, an experience wherein human consciousness awakens to the grandeur and sacred quality of the Earth process. Humanity has not participated in such a vision since shamanic times, but in such a renewal lies our hope for the future for ourselves and for the entire planet. ***- Thomas Berry***

General context:

Politics: where are the decision centres about what energy model will be 'choosen'?
If renewables are going to play a more predominant role in the energy production mix, what will there be a chance for Distributed Generation or will the major energy companies/states continue to exercize their global control through the creation of new Power Plants based on Renewable Energy?

If more and more individuals and local communities will provide in their own energy supply through distributed generation, what would be the possible consequences in terms of population growth, consumption, land occupation, migration, relation urban - non-urban communities, transportation, telecommunication...
Environmental: What would be the most sustainable energy mix of tomorrow?
Educational: how to increase the awareness of the interdependence of personal energy consumption and the eco-system?

- *Not applicable:*
    - *description & suggestions around the collaboration process (if applicable >NOT)*
    - *comments on the response of the public (if applicable* - NOT*)*

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Duurzame Info – www.duurzame-info.be
Ecogeek – www.ecogeek.org
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Materials Today - www.materialstoday.com
MIT Technology Review (Nanotech update) - www.technologyreview.com
The Green Guide (National Geographic) – www.nationalgeography.com
Noorderlicht (VPRO) - http://noorderlicht.vpro.nl
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Robert McMahon's Solar and heat tips - http://www.mrsolarenergy.com
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* For a complete overview of the consulted websites and the newsletters see the PhoEf overview

- **media used in the research (film, audiovisual media, photographs…)**

Online television
Nanosolar's Vice President of Engineering - July 3, 2007 -

www.kqed.org/quest/television/fullscreen?id=399

Google keyword alerts
Keywords: solar energy; photovoltaics

Audiovisual media
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Q Cells – The Production of PolyCr-Si Cells.mp4 (German, English subtitles) Juin,27, 2007 - www.qcells.com
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- **visual/sonic/tactile material generated in the research to be archived at FoAM**

PV-Tech
The power of the sun (flash)
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Intersolar movies
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List of Abbreviations:

a-Si: amorphous silicon
B2B: Business to Business sales only
BIPV: Building integrated photovoltaics
CDTE: Cadmium-telluride
CIGS: Copper Indium Gallium Selenium
CIS: Copper Indium Selenium
CuInSe2: Copper Indium Diselenium
CPV: Concentrated Photovoltaics
CSG: Cadmium-Tellurite-Sulfite
CTS: Cadmium-Tellurite-Selenium
GaAs; Gallium Arsenide
Ge: Germanium
InGaAs: Indium Gallium Arsenide
InGaP: Indium Gallium Phosphide
Si: Silicon
mc-SI: monocrystalline Silicon
pc-Si: polycrystalline Silicon
uc-Si: microcrystalline Silicon

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For specific questions feel free to contact the author at bartaku[at]yahoo.co.uk

About

FoAM vzw
FoAM is a laboratory for re-integration of human knowledge, from science to arts, from technology to culture. As a hybrid between a research center and an artistic studio, FoAM works toward transdisciplinary models of creative expression and knowledge production. Our works include mixing virtual and physical realities; raising intellectual and emotional understanding of science; creating temporary responsive environments; using environmentally and socially sustainable design and eco-technology practice. FoAM is based in Brussels with subsidiaries in Amsterdam, Berlin and soon Singapore.

FoAM vzw
Koolmijnenkaai 30-34
B-1080 Brussels
Belgium
+32 2 513 59 28
http://fo.am
http://luminousgreen.org
info@fo.am

Bartaku
Bartaku, °1996 Kobe (Jap); pseudonym for Bart Vandeput, °1970 (BE)
Lives & works frequently at 50.845N – 04.35E (BRU, BE)
MA Communication Science (University of Leuven)
Creates installation works, interventions & experiments interweaving fictional and/or nonfictional content combining different media such as threads, sounds, images and texts.
http://recuerdas.blogspot.com

Also about the author:
who
w/is an academic (the books were so heavy).
w/is a drummer (the drums were so heavy).
wandered aimlessly (being more sedentary),
from here and now.

Bartaku

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