

1. ENERGY AND THE ENVIRONMENT

Can a product design be made 'sustainable'? To answer this question one has to go back to the origin of Sustainable Product Design. In the drive towards Sustainable Product Design, a good balance has to be found between sustainability, functionality and the user context. To accomplish this, the designer should be aware of the environment and incorporate ongoing trends. One of these new (technology) trends is the application of Sustainable Energy technologies.

1.1 WHAT ARE THE GENERAL ENVIRONMENTAL AND SOCIAL PROBLEMS IN CONNECTION TO ENERGY CONSUMPTION?

1.1.1 ENERGY SCENARIOS/STATISTICS

World energy production rose 42% between 1980 and 2000 and will grow 150-230% by 2050. Renewable resources like solar and wind account for only 11,5% of current consumption.

The Western world consumes much more energy per capita than do developing countries. For example the electricity consumption per capita:

It can be observed almost a factor of 30 in difference in use of electricity between the high and the low-income countries.

	1999	1995	1990	1985	1980	1975	1971
World	174	165	158	144	132	114	100
Developed countries	568	540					
Developing countries	63	55	42	33	25	18	14
High Income Countries		669	610	533	483	410	356
Low Income Countries		23	17	12	10	9	7

TABLE 1 ____ ELECTRICITY CONSUMPTION PER CAPITA (WORLD RESOURCE INSTITUTE)

1.1.2 ENERGY CONSUMPTION AND CO2

CO₂ production and the amount of energy consumption per capita is the main problem in developed countries.

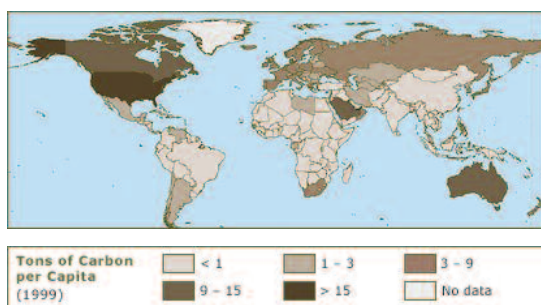


FIGURE 1 ____ TONS OF CARBON PER CAPITA. SOURCE [HTTP://EARTHTRENDS.WRI.ORG/](http://earthtrends.wri.org/)

1.1.3 ENERGY CONSUMPTION IN DEVELOPING COUNTRIES: PROBLEM FUEL WOOD

With a lack of access to fossil fuels and sustainable renewable energy resources, the people in developing countries use a serious amount of fuel wood for cooking and heating. This one of the main energy related problems in developing countries.

Fuelwood, charcoal, and other wood-derived fuels (collectively known as woodfuels) are the world's most important form of nonfossil energy. Production and

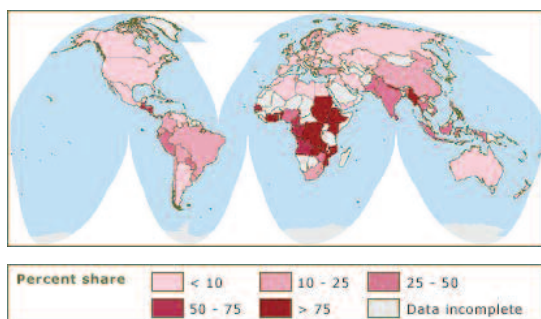


FIGURE 2 ____ THE IMPACT OF USE OF FUEL WOOD SOURCE [HTTP://EARTHTRENDS.WRI.ORG/](http://earthtrends.wri.org/)

consumption are concentrated in low-income countries, with five countries — Brazil, China, India, Indonesia, and Nigeria — accounting for about 50 percent of the total.

1.2 THE NEED FOR ENERGY AND THE RELATION TO PRODUCTS.

The world is facing a continuous increase in use of energy consuming products. Therefore, one of the hot topics now and in the future will be how to optimize the electrical power consumption of these products. At this moment electrical energy is obtained from the mains, primary and secondary or rechargeable batteries.

The exploding portable products market shows a trend in the consumer and professional market towards increasing mobility. In all these products, rechargeable energy storage media play an important role. So there is a demand to recharge these storage media anywhere at any-time, not to be limited by the availability of a mains socket. Many consumer electronics products nowadays function on low voltage DC (8-20V) instead of the 220 (or 110) V AC. This has led to an increase use of batteries and adaptors.

To cope with these trends, it is a logical step to combine the energy storage media with a recharger powered by a mobile energy converter, i.e. photovoltaic (PV) cells.



1.2.1 ENERGY USE DURING THE LIFE CYCLE

1.3 WHAT IS RENEWABLE ENERGY

Renewable Energy (RE) technologies like Biomass-Installations, Hydro-Power and Wind-Energy have their application often on a system level. Other RE technologies like Photo Voltaic (PV), Human Power (HP) and Fuel

Cells (FC) are also being applied on a product(-system) level. This paragraph will describe in short the technological aspects and the potential benefits & disadvantages of PV, FC and HP in product(-system) applications.

1.3.1 WHEN IS AN ENERGY RESOURCE SUSTAINABLE?

The application of RE technologies like PV cells, FC and HP might be a more sustainable alternative. The application of these new energy technologies into product design is moving from an experimental phase towards a discipline in Industrial Design. At this point structural knowledge regarding identifying and integrating of renewable energy technologies into products is needed for both technology developers as well as industrial designers.

- > Renewable
- > Low emission (CO₂)
- > Efficiency
- > The total life cycle

1.3.2 WHAT ARE THE NEW EMERGING SUSTAINABLE TECHNOLOGIES OF INTEREST FOR PRODUCT DEVELOPMENT?

RE technologies like:

- > Wind
- > Solar
- > Bio-mass
- > Solar: PV and heating
- > Human power
- > Fuel cells

RE systems can be distinguished into *grid-linked systems* and *stand-alone systems*. In the case of a grid-linked system there is a connection between the RE system and the local electricity network. They can therefore be used to meet part of the immediately needed electricity, or can export power to the networks at moments when the local need is low. Stand-alone systems are independent of the local electricity network. These systems are often used in areas without a local electricity distribution net or to make a product independent of the electricity project (like in the case of portable products). Within our research we focus on the *stand-alone* applications of RE systems.

1.3.3 HUMAN POWER (HP)

HP, as the name implies, uses the (physical) energy of the user to support the (electronic) function of the product. There are two ways of generating electricity by means of human interaction: thermal (only low wattage) and physical. The physical human power of the users can be transferred by piezo technologies (0-0,5 Watt), linear (0,5-5 Watt) and rotation (0,5 –50 Watt) induction into electricity. This can be done e.g. by pushing, shaking, pulling, turning a part of the product which is connected to the electricity generating technology. The amount of produced energy depends on the power, frequency and period of the movements of the user and the efficiency of the applied energy conversion technology. Often the generated energy is stored between the energy generation and use in rechargeable batteries, capacitors or mechanical storage systems like springs and fly-wheels.

To make use of the HP, an interaction between the user and the product is needed. This interaction can take place in different manners:

1> The human power is **integrated** in the normal use of the product. For example a piezo element could be integrated in the keys of a keyboard of a laptop. By using the product it will create its own needed electricity. This is the most ideal situation.

2> **En-passant** movements of the user create energy for the use of the product. For example some watches use the kinetic energy of the natural movement of the arm to charge the watch batteries.

3> **Additional movements** like turning a crank is needed to power the products. This is the case in most HP-products.

With HP technologies only a limited amount of energy can be produced up to around 50 watt. This makes the technology more suitable for low-energy consuming products. Also should be taken into consideration that the operations needed to create the HP-energy should not conflict with the normal use of the product.

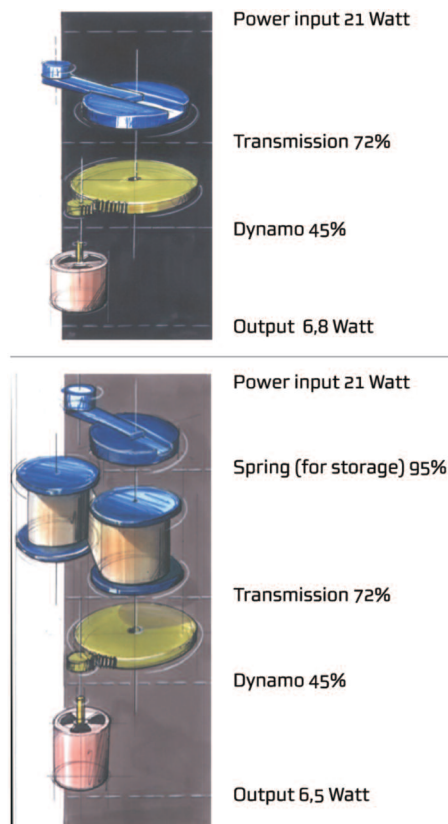


FIGURE 3 — EXAMPLES OF HUMAN POWERED ROTATION INDUCTION TECHNOLOGIES.

1.3.4 PHOTO-VOLTAIC TECHNOLOGY (PV)

Solar Power is produced by the conversion of sunlight into DC (Direct Current) electrical power using PV cells. PV cells are modular and light, have no moving parts, have no direct impact on the environment, and require only minimal maintenance. They therefore offer many potential advantages compared with more conventional power generation systems, including easy installation, long life and durability and low operating costs. PV cells were originally developed in 1970s, at the time they were expensive and quite inefficient. Since then, PV technology has been further developed to improve the efficiency and to reduce costs. During the last decade an efficiency increase of PV cells from 4% to 16% has been achieved. Nowadays, three main types of PV cells are available:

> **Monocrystalline Silicon PV** cells are made from a single, continuous crystal lattice structure. These cells are complicated and relatively expensive to manufacture, with a typical conversion efficiency of 12-15%.

> **Multicrystalline Silicon PV** cells are cast from molten silicon obtained, using many different lattices of Monocrystalline Silicon. The manufacturing process is simple and quite cheap. The average conversion efficiency is lower (11-14%) compared to Monocrystalline PV cells.

> **Amorphous Silicon PV** cells use a homogeneous layer of silicon atoms rather a crystal structure. They absorb light more efficiently than crystalline silicon and can be deposited as a thin film on a rigid or flexible structure. They are cheaper to produce than crystalline silicon cells, however, the average conversion efficiency is lower, around 6-7%.

The efficiency of amorphous silicon cells is significant lower than the efficiency of monocrystalline silicon cells (7% versus 15%). To produce the same amount of energy with amorphous silicon, twice as big a surface of PV cells is needed. This is the reason that these cells are primarily used in low power equipment like watches or as facade elements (in buildings where a big area is available). On the other hand, Amorphous Silicon has the potential to function better at lower light intensities and to be less sensitive to temperature variances. These PV cells also can produce useful quantities of power in

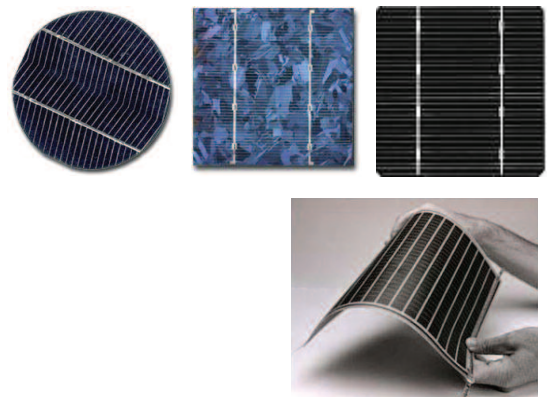


FIGURE 4 — EXAMPLES OF MONOCRYSTALLINE SILICON CELL, MULTICRYSTALLINE SILICON CELL, AMORPHOUS SILICON CELL, A PV PANEL AND FLEXIBLE PV-CELLS.

less than ideal conditions such as cloudy weather or indoors.

Photovoltaic technology continues to develop rapidly, and several alternatives to silicon are already under development. These include Gallium Arsenide (GaAs), Cadmium Telluride (CdTe) and Copper Indium Diselenide (CIS). PV cells made from these new materials could be manufactured in the near future more cheaply than Crystalline Silicon cells and are more efficient than Amorphous Silicon cells.

Each crystalline silicon PV cell generates around 0.6 V and cells are combined in series and in parallel to make modules to meet the higher power and voltage demands of typical applications. A typical module may produce 50 W of power at 24 V (DC). The output from a PV module varies depending on the amount of incident light and other factors such as temperature and the cleanliness of the cell surface. Modules are rated in terms of their peak output (peak Watts or Wp), which is the maximum power that they will produce given optimum solar input and operating conditions. The average power produced will be closer to the rated (peak) output in locations where there is a high level of incidental radiation during the year like for example in South European countries.

“Thin Film” technologies have made it possible to make PV-cells flexible (see fig 4). These Amorphous cells hold a niche position in lower than 50 W appliances and in consumer electronics. Often they exist of multi junction cells, several amorphous layers on top of each other. Each layer is sensitive to a specific part of the light spectrum and the efficiencies of these multi junction cells are higher. These cells are also suitable for different kinds of light like indoor and outdoor light.

It is difficult to estimate the general cost for all type of PV cells applications. However, considering the new technologies under development which will use less material and energy in production (dematerialization) and are becoming at the same time lighter and more efficient, the costs of energy produced by PV cells will become lower.

From this introduction to the PV technologies presently available, one can conclude that the appropriate type of PV cells to be used in design depends on the type of use (intensity) by the product-user and the contextual influences like light intensity, environment tem-

perature and indoor/outdoor light.

1.3.5 FUEL CELLS TECHNOLOGY

Over the last ten years, there has been a huge global effort to develop fuel cells. Originally driven by the prospect of improved electrical efficiency and of improving air quality in urban and indoor environments, fuel cells are now seen as an important potential option for improving the sustainability of energy consumption, reducing emissions of greenhouse gases and reducing emissions in energy use in sectors like transport or portable electronic products.

Fuel cells are electrochemical devices similar, in principle, to primary batteries, except that the fuel and oxidant (e.g. hydrogen and oxygen) are stored externally; they produce both electricity and heat directly. Individual fuel cells typically generate a DC voltage of 0.7-0.8 volts and a power output of a few tens or hundreds of watts. Cells are assembled in modules known as stacks to provide larger voltage and current. There are several types of fuel cells with their specific characteristics, in different stages of development categorised according to their electrolyte and operating temperature.

In the high temperature range (600-800° Celsius) Solid Oxide Fuel Cells (SOFC), and Molten Carbonate Fuel Cells (MCFC) have a very high efficiency (55-70%), and are mainly used for stationary electricity generation. In the low temperature range (80-200° Celsius) Proton Exchange Membrane (PEM FC) and Direct Methanol Fuel Cell (DMFC) are the most promising.

Fuel cells have a typical electric efficiency from 40% to 50% and 70% to 80% of the global efficiency of co-generation insulations or combined cycle with really good results in environmental standards: low emissions of NO_x, no emissions of SO_x, low emissions of CO₂ and low noise.

The flexibility in the type of fuel in use is an added value of this technology, being possible (depending on the type of fuel cell) to use hydrogen, natural gas, coal, ethanol, biogas and diesel. The challenge is, of course, to use a sustainable type of fuel. Because of this acceptance of different types of fuel from different non-and renewable resources, fuel cells can become the ideal solution to switch from a fossil fuel economy to a widespread

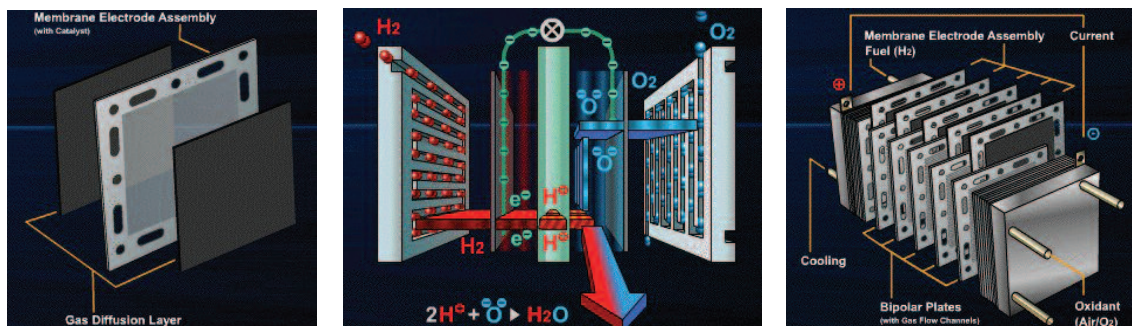


FIGURE 5 ____ A FUEL CELL, ITS WORKING PRINCIPLES AND A STACK EXISTING OF A SERIES OF PV-CELLS.

use of sustainable and renewable resources as hydrogen. Fuel cells have, to overcome the economical handicap to become more competitive than solutions that are presently available in the market.

In the last years, according to the characteristics of for example the PEM fuel cells opportunities of Fuel Cells applications with low and medium power ranges like (consumer) products have been explored. However, bigger range power uses like automotive industry have spurred interest in use of PEM FC as an alternative for the conventional combustion engine. One of the specific qualities of fuel cells is the high energy density compared to other conventional energy technologies.

1.3.6 CHARACTERISTICS OF RE TECHNOLOGIES

Each of the three described RE technologies have their own advantages and disadvantages for their application in product -systems. It depends of course on the specific application if the RE technology has an added value or not. However, in general, we can make some remarks on the characteristics of RE technologies in relation to product -systems.

1.3.7 STORAGE MEDIA

Batteries are at present the most common media for storing electrical energy. Two types can be distinguished: primary or non rechargeable and secondary or rechargeable. Commercially available rechargeable batteries are: NiCd, NiMH and Li-Ion batteries (Stibat, 2003).

Another less common medium for electrical energy

storage is the capacitor. This solution is used, for example, in calculators and endoscopic robot capsule (Norika, 2003). Capacitors exist in various sizes (from a few pF up to 1 F). In the last years special energy storing 'super' capacitors have been developed which can store up to several hundred farads.

The difference between batteries and capacitors concerns both their charge and discharge characteristics.

1. Direct transfer of energy

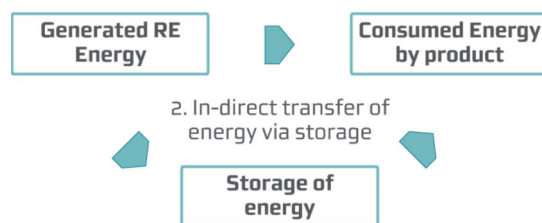


FIGURE 6 ____

1.4 CURRENT APPLICATIONS OF RENEWABLE ENERGY SYSTEMS

A serious amount of RE product-system applications have been collected in order to learn from earlier experiences and problems encountered with the application of RE.

These applications can be separated into 4 categories:

- > Existing product designs with an "added" RE source;
- > Redesign of existing products with "integrated" RE source;
- > New products based upon RE technologies and
- > New product-systems based upon RE technologies.

Potential advantages	HP	PV	FC
No or low CO ₂ , NO _x and SO _x emissions - environmental sound technology			
No or low noise			
No moving parts			
Stand alone systems (decentralized and independent generation from electricity grid)			
High power range products (> 2 KW)			
Medium power range products (100 to 2000 W)			
Low power range products (0 to 100 W)			
Wireless systems			
Minimal maintenance requirements			
Use of batteries for storage			
Can replace batteries in products			
Long life time of the working system (> 20 years)			
Use of renewable sources			
Possibility to use several types of sources (including non- and renewable)			
System affected with specific external conditions (for example specific geographical or weather conditions)			
Higher energy density than conventional rechargeable batteries			
Faster source storage (few minutes)			
Unlimited refuelling cycles			
Longer shelf life (compared with common batteries)			
Off - grid systems			
Possible to integrated with the grid system			
Convenience for the user by not replacing batteries			
Interaction between the product and the user			
Potential disadvantages			
Long pay back time			
Limited energy power output			
Conflict with the use of the product can happen			
Large area needed for large power applications			
Inverter or special DC appliances needed to convert DC in AC, when it is needed			
Possible to use as storage energy			
Need for a sustainable fuel (production and distribution) infrastructure			
Non dangers storage of sources or fuel			

TABLE 2 ____ CHARACTERISTICS OF HP, PV AND FC

Within the next paragraphs these four categories will be described and will be illustrated by product

examples. The PV applications will be described in more detail followed by HP and FC application in short. In

general the following main findings could be made on the observation of “non-successful” integration of Renewable Energy sources in products:

- > There is not always an added value for the user created by the RE technology (compared to conventional energy sources).
- > There is no match between the generated energy by the RE technology and the consumed energy by the product.
- > PV-technology is not properly integrated into the product design resulting in an unattractive product aesthetics.
- > There is no insight into the environmental impact or benefits of the PV-technology in the new function.

1.4.1 PV-POWERED PRODUCT-SYSTEMS

Of the three presented RE technologies, the PV-cells are the most applied on product(-system) level. During the last decade the amount of applications of PV-cells connected to products has rapidly increased. A wide variety of electronic products are being powered by PV-cells, like solar chargers, outdoor lightning, calculators, gadgets and ticket machines.

1> Existing product designs with an “added” PV source:

In the case of a PV-powered weight-scale (see fig. 7) the PV cells have been “pasted” to the product by adding an additional surface. The added PV-cell is not integrated in the total design of the product (neither by shape or colour) and does not create an essential added value for the user (the battery normally only has to be replaced once in 3 years).

2> Redesign of existing products with “inte-

grated” PV source:

If PV-cells replace another type of energy source in a product, it is very likely that the product design and the configuration have to be adapted and optimised for the new situation. The solar battery pack from Nokia (see fig. 7) is a product in which the solar cells, despite constraint in the size and shape of the battery pack, are integrated well by choosing transparent plastic and hi-tech styling for the surface into which the PV cells are integrated. The added value of this product–technology combination is clear. However, the problem is the balance between generated and consumed amount of energy. Although the PV cell area is small, a sufficient amount of energy can be produced in a full day of sun for the proper functioning of the mobile telephone. In reality, however, the mobile telephone will most of the time be away from sunlight. The PV-cells characteristics and positioning are not optimal for the user context and energy need.

3> New products based upon PV technologies:

Based upon the characteristics of the new RE technologies and the needs of the user new PV-powered products are being developed. For example several solar chargers (see fig. 7) take advantage of creating energy everywhere independent from batteries or the electricity grid. The design is often developed around the new function and technology in shape and colour and is an appropriate match between the energy generation and consumption.

4> New product-systems based upon PV technologies:

One can observe a rapid increase of low voltage and

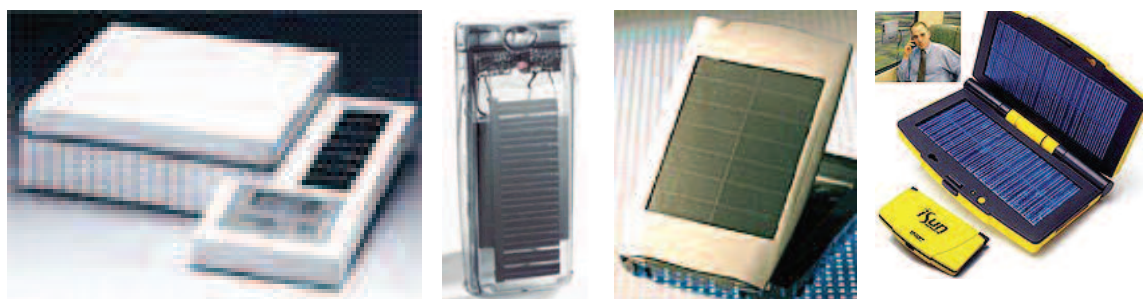


FIGURE 7 — EXAMPLES OF PV-POWERED PRODUCTS; WEIGHT SCALE, MOBILE TELEPHONE, PDA AND A SOLAR CHARGER FOR MOBILE TELEPHONES.



FIGURE 8 __ EXAMPLES OF HUMAN-POWERED PRODUCTS: TWO TORCHES AND A MOBILE CHARGER.

Direct Current (DC) appliances (like mobile telephones, Discmans etc.) in the household. In order to power these products the 220 Alternating Current (AC) has to be converted two times (with efficiency losses) to the low-voltage DC. Renewable Energy technology like PV panels produce directly low voltage DC electricity that make them more appropriate to power these kinds of appliances. One of the current solutions under research is to integrate a PV-powered low voltage DC electricity grid in houses to power these products more efficiently and to abandon the need for adaptors.

1.4.2 HUMAN POWERED PRODUCTS

Human-powered products have existed for a long time. Since the introduction of the Freeplay radio in 1996 a new interest in HP has been created and a range of HP products have been introduced into the market (see fig. 8) In the case of the first example, a Freeplay wind-up torch with a metal spring for storage of the energy, one

might question if the HP source is not creating any inconvenience because of added weight and largedimensions. In the second example, the technology has been integrated more elegantly into the product (by shaking the torch linear induction within the torch will create energy). Finally several new HP-products have been developed to charge low power products like mobile telephones.

1.4.3 FUEL CELL POWERED PRODUCTS

Since the miniaturisation and commercialisation of fuel cell technology is more recent, the amount of product examples is much more restricted. Most of the examples (see fig. 9) are still in an experimental or prototype stage. This can be seen in the first example, a PDA fuelled by a fuel cell. As can be observed easily, the fuel cell source is big in relation to the product and not integrated in the design. Within the second example, a racing cart, the fuel cell has been integrated in the design,

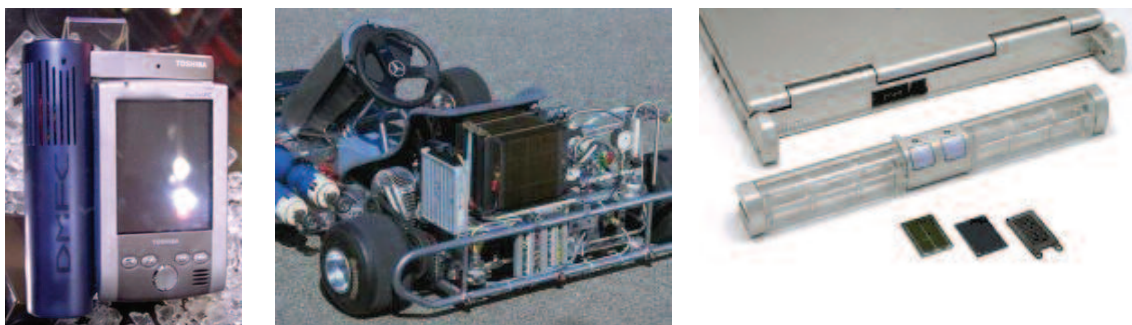


FIGURE 9 __ EXAMPLES OF FC-POWERED PRODUCTS: PDA, RACING CART AND A FC-POWERED LAPTOP.

however it does not yet match the characteristics of competing technologies like combustion engines. The last one provides the cart with more speed and acceleration power. In the case of the integrated fuel cell power unit into a laptop the fuel cell technology creates an interesting added value for the user: because of the high energy-density of the fuel cell, the user will be able to work at least the double amount of hours independent from the electricity grid.

2. SUSTAINABLE ENERGY TECHNOLOGY AND PRODUCT DEVELOPMENT

RE Technologies might be an interesting alternative. However, to be sustainable, the technology should have an added value for user (to make the products attractive, appropriate and useful) and reduce the environmental impact of the function fulfilment. There are several approaches to integrate renewable energy technologies into product systems.

Looking at the D4S Lids wheel (fig. 10) and its strategies, one can observe that as a direct continuation, RE technologies can contribute to the solution of some of the biggest impacts of the life cycle of the product, especially the ones regarding energy use during the use phase of the product. This is especially a concern related to electronic consumer products (e.g. batteries of all DC products), electric home appliances (e.g. big appliances like a refrigerator), transport and vehicles.

There are several situations than can direct the

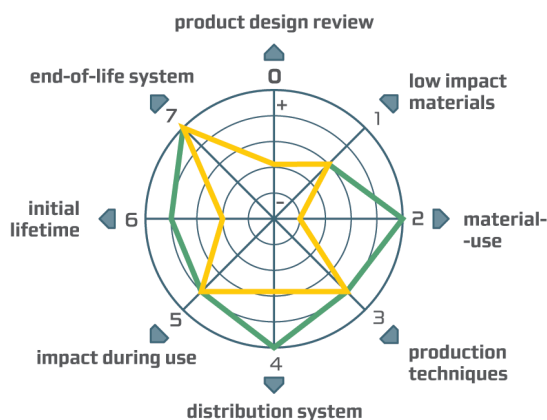


FIGURE 10___ D4S STRATEGY WHEEL (ALSO SEE CHAPTER

design process of a product towards a final product. Mainly, and not different from other types of products, electronic consumer products should be designed by taking into consideration the *external criteria* of the product aswell as the *internal criteria* of the product:

> *External criteria* as the identification of the needs of the user (functional, operative, economical, social, psycho-semantic, etc) and the potential consumer market. Here, the designer identifies his target group.

> Secondly, *Internal criteria* for the product are defined; here all decisions for the final product are fixed, mainly by the product development team or the designer. In parallel the Aesthetics, Ergonomics, Sustainable criterias are recommended as priority and technological solutions have to be found to power a specific product.

“How to find the better sustainable technology to potentialize the functionality, the correct operation and the utilization of the product ?

Different kinds of information are needed to find the answer to this question. However the main intent should be focused on energy generation and energy

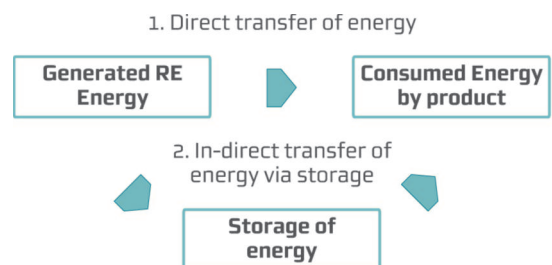


FIGURE 11 ___ OVERVIEW OF THE ENERGY FLOWS WITHIN A RE-POWERED PRODUCT-SYSTEM

consumption. The following scheme outlines this concept.

Approaching this topic, and depending on the daily practice of the target group, different methods can be applied that lead to different types of solutions. We will introduce the following three approaches:

WHAT ARE THE APPROACHES?

1> Redesign: the first approach, adding or integrating

RE technologies in existing products (to replace batteries or electricity from the main (via adaptors)). In this the focus is on how to integrate RE technology in the best possible technical way.

2> New technologies as starting point: the second approach is to create total new visions for the integration of RE technologies in product development. Here new sustainable technologies are being considered from the beginning as a starting point for product development.

3> Product System Solutions: This third approach, related to the second is how to design new product-system solutions in order to find new solutions for the energy problem within the product.

2.2 SUSTAINABLE ENERGY REDESIGN APPROACH

In the case of a redesign approach one should try to replace non-renewable energy technologies with RE technologies. The product and the function that it should fulfil is already known. An approach for integrating RE technologies in products is described below:

2.3 REDESIGN APPROACH FOR RE POWERED PRODUCT-SYSTEMS

Based upon experience with the integration of RE technologies in product-systems and by evaluating other RE-based products, a checklist for designers has been developed. This checklist is meant to support the designer to understand the energy flows and to select appropriate RE technology. This is just one way to integrate RE technologies into products. Many other approaches are suitable depending on the design context and the characteristics of the product.

The Checklist has been split up into 5 steps.

Step 1. Product, user and context identification

The starting point of the product development process.

- > What are the characteristics and the functions of the

selected product?

- > Who will be the user of the product?

- > In which context will the product be used?

Outcome: A general description of the use of the product, the user and the context.

Step 2. Energy consumption by product-user

The goal is to analyse the energy patterns in order to identify the “energy need” of the product when it is being used by the user. For some products the energy patterns are very predictable (a tooth brush will be used twice a day for 5 minutes), for other products the use might differ per person per day (like for example a PC mouse).

- > What is the maximum power used?

- > What is the frequency of use of the product indicated in amount of times per hour/day/week?

- > What is duration each time of the use of the product indicated in minutes per time?

Outcome: Energy pattern of the energy use over time by the product.

Step 3. Identifying the appropriate RE-technology

Based upon the outcome of step 2, the designer can start to identify a RE-technology that can fulfil the needed energy pattern of the product. There are no strict guidelines in this step, but the characteristics of the three technologies as described in table 1 can be used to select the most relevant RE technology. For example:

- > What are the characteristics of the RE-technology that one is looking for?

- > If the average needed energy power is more than 40 Watt than Human Power is not the appropriate technology.

- > If there is a need for a high energy-density than FC will probably be the appropriate technology.

Outcome: Selection of RE-technology

Step 4. Potential energy generation by selected RE-technology

After the RE technology has been selected it is neces-

sary to identify the potential characteristics of the technology and energy pattern that could be generated. These questions are often more specific for the selected RE Technology for example:

- > What is the maximum power output?
- > What is the pattern of the energy output?
- > For PV: What is the light intensity? What is the light source (indoor or outdoor)? What is the efficiency of the PV-cell? How are the PV-cells positioned? What area is available for the PV-cell? What are the climate conditions?
- > For HP: What is the efficiency of the system? Can the product be used while creating HP-energy? How often and for how long is the user willing to create HP energy?
- > For FC: etc.

Outcome: Energy pattern of the energy use over time by the product.

Step 5. Matching the generated and consumed energy

In order to be in balance, the generated amount of energy of energy should be at least the same or more as the consumed amount of energy. By matching the results of step 2 and 3, design decisions can be made on, for example, the needed surface of PV-cells, the needed power of the FC, the appropriate HP technology or the need for integration of storage components like batteries.

- > Is the total amount of potentially generated the same or more than the expected need for energy?
- > Is the energy being consumed at the same time as it is being generated? Is there a need for storage?
- > If there is a need for storage, what is the most relevant technology?

Outcome: Specification for the specific type of RE technology and the need for storage.

EXAMPLE OF THE INTEGRATION OF PV TECHNOLOGY

To illustrate the approach an example of the energy patterns of a toothbrush and mouse based upon PV-technology will be shown in the underneath figures.

In step 2 and 4 first a diagram has been drafted of the energy patterns (see figure 8). Next they have been

quantified and finally in step 5 they have been matched

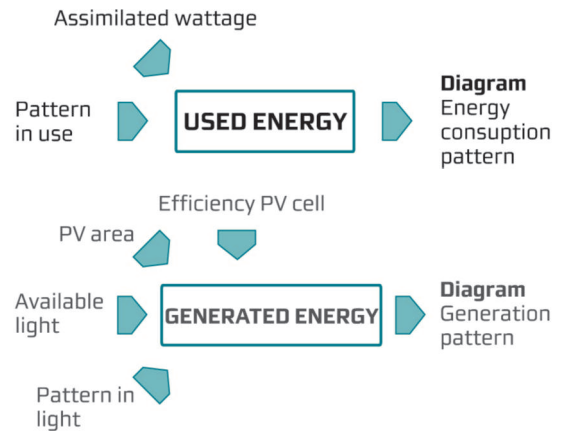


FIGURE 12 ____ DIAGRAMS OF THE ENERGY CONSUMPTION PATTERN AND THE ENERGY GENERATION OF A PV-POWERED PRODUCT

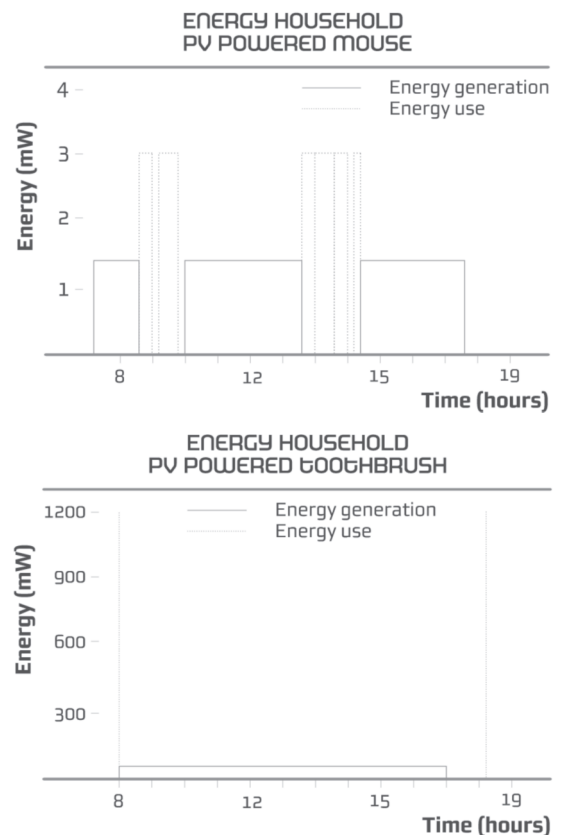


FIGURE 13 ____ QUANTIFIED GRAPHS OF THE ENERGY GENERATION AND USE OF A PV-POWERED TOOTHBRUSH AND MOUSE

(see figure 9).

2.4 NEW SUSTAINABLE TECHNOLOGIES AS STARTING POINT

New emerging sustainable energy technologies also can lead to new product systems. They can create new opportunities for new products with an added value for the user and in the meantime reduce the environmental impact.

In this case one looks for appropriate products to apply a new technology to fulfil needs that exist in society. Here the focus is to identify a need that can be fulfilled with RE. Important in this approach is to understand the state of the art of the development of the new technologies. When will they become commercially available on the market against what price. In this approach it is essential to have intensive contact with the developers of the new technologies and experts in this field.

2.5 DESIGN FOR (RADICAL) NEW SOLUTIONS WITH RE TECHNOLOGIES

Within the 2nd proposed methodology, the user is the central point for the design decisions. Within the context of this approach, the concepts for Sustainable Energy Design Solutions should match the needs of the user of the 21st century in three complementary ways:

- > First, by **creating scenarios of appropriate solutions for the user: flexible product utilization, independent power and multi-functional small systems** that fulfil needs, but of **any product, for any reason, everywhere**.
- > Secondly, an **extensive dissemination by commercialization** of these products-systems on **common places**. This will bring the user in close connection with the technology by the **proximity to the technology** and by the **personal experience of the technology**.
- > Thirdly, by designing these product-systems in such a way that they can provide **real solutions for the user** and not just *gadget* solutions for the moment. These solutions should be identified in close and/or together with different universes of users. In this way, for exam-

ple, **modular, multi-target** oriented solutions can be directed to different optimisations of the use situations.

A method is proposed here taking in consideration the Design for (radical) New Solutions. However this method is just one of many possibilities, and maybe useful to use, as a guide for others.

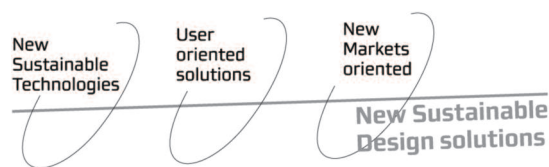


FIGURE 14

PHASE 1 – USER ORIENTED DESIGN

> Analyze the user's context (focus group) as support for the Design options and usability in an active way close to the user (comprehension of the universe of experiences of the user) by methods of empiric user research. It is important that a detailed description of the use of the product, the user and the context of use should be done.

> The methods for the empiric user research are session groups with users, Individual interviews, questionnaires and other creativity tools.

PHASE 2 – USE OF SUSTAINABLE RESOURCES AND TECHNOLOGIES

> Analyze the technological context of the resource in use. For example, in the context of the vision presented, the Photovoltaic technology will support the use of Solar Energy in the products, by understanding the technology, and finding technical ways to apply in a correct and optimized way the technology to the product. This phase leads to a list of sub-steps that correspond to the technological requirements for the integration of RE technologies in consumer Products:

a) Identifying the Energy consumption pattern by product-user

The goal is to analyse the energy patterns in order to

identify the “energy need” of the product when it is being used by the user.

b) Identifying the appropriate Sustainable Energy technology

Based upon the “energy need”, the designer can start to identify a Sustainable Energy Technology that can fulfil the needed energy pattern of the product.

c) Potential energy generation by selected Sustainable Energy technology

After the Sustainable Energy technology has been selected it is necessary to identify the potential and the characteristics of the technology and energy pattern that can be generated.

d) Matching the generated and consumed energy

In order to be in balance, the generated amount of energy of energy should be at least the same or more than the consumed amount of energy. By matching the results of “energy need” and “potential energy generation”, design decisions can be made for example, the needed surface of PV-cell.

PHASE 3 – FIND MARKETING OPPORTUNITIES FOR TECHNOLOGY-BASED SOLUTIONS

> Analyze the market opportunities according to the different type of created solutions. It is recommended that the Design of Sustainable Solutions should be focused on different user groups. In this way solutions with the same concept and different characteristics can be adapted to and appreciated by different users.

Next a comprehensive study in which three different marketing approaches using technological solutions is presented:

1> Technology oriented Marketing (design only based on technology)

Here the focus is on the technological aspects of the product; in this way the technologically superior values of the design of the product are considered.

2> Experiences oriented Marketing (design for

an experience)

In this case, the focus is on the experience that the product can stimulate in the user. The market strategy and the resulting Design Solutions dominates the creation of the experiences that a technology-based product can create.

3> Ambiences oriented Marketing (design for ambience)

Here the focus is on the creation of intelligent environments, where the technology is incorporated in the environment, not visible, but capable of answering the wishes of the user, generating high levels of comfort.

Here Design Solutions add to the technological and experience parameter; a third level that is the generated stimulation based on the user emotions, wishes and needs.

PHASE 4 – MASS DISSEMINATION OF THE USE OF RENEWABLE ENERGY RESOURCE

> This phase leads to an invisible or *Meta* moment of the approach. It is not related with the created solution itself, but with the results that a disseminated utilization of the product or solution can lead to.

3. CASES

3.1 DEVELOPING COUNTRIES CASES

This case has been taken from the web-site Intermediate Technology Consultants: <http://www.itcltd.com/solar>.

GLOWSTAR: PV-POWERED LANTERN FOR AFRICA

Solar Home Systems of 20-50 Watts are not affordable for the majority of rural people in Africa, nor in many countries in Asia and Latin America. In Kenya, for example, 80 % of rural people possess kerosene hurricane lamps and spend between \$3 and \$8 per month on kerosene plus batteries for torches and radios, and candles. Battery charging is an increasingly common service in towns. For most of these homes a small power source for lighting using modern compact fluorescent

lamps, power for a radio and possibly other electronic appliances would do much to improve living conditions if it was affordable.

CONSUMER RESEARCH WITH EXISTING MODELS

While the study demonstrated that there was a real demand for solar lanterns, customers highlighted a number of technical shortcomings with all of the products tested. Most of these shortcomings are related to the poor construction of the lanterns, the quality of light and the relatively sharp drop off in performance after a period of months of use.

The most important features were identified were as follows; Service characteristics;

- > The price of the lantern should be between \$75 and \$100 if possible
- > The lantern should provide light for up to 4 hours each evening.
- > Customers should have access to affordable and readily available spares
- > Customers expect an overall lifetime of the lantern of 6 years
- > *An indicator to show that lamp is charging,*
- > *A warning light to show that the lamp is about to switch off when the battery is low,*
- > *A power socket to allow a small radio to be connected to the unit.*

The findings of this initial survey were used to form a



design brief and as a result, the team produced a new design for a lantern which incorporates all of these features.

<http://itcltd.com/glowstar/gallery.htm>

A crucial component for any rechargeable device is the battery. The project activities have included research

into available battery technologies to identify a battery which; has the capacity to store charge sufficient for the required period of lighting, is suitably robust to withstand the heavy duty cycle required for daily charge and discharge, requires no customer maintenance (also spill and leak proof), has minimum impact to the environment if disposed of at the end of its life cycle, could be manufactured locally in the medium term in developing countries, and provides a cost effective solution. As a result a Valve Regulated Lead Acid (VRLA) battery with a gel electrolyte has been selected as the battery technology with which to prototype the lantern.

HOW DOES IT WORK?

The solar lantern kit consists of a Photo-Voltaic panel, and a lantern containing a high efficiency lamp, a rechargeable battery and a charge control circuit. The concept is a simple one – during daytime, sunlight falling onto the Photo-Voltaic Panel generates a small electrical voltage. This is used to charge the lantern battery so that the lamp can provide light during darkness. The charge control circuit housed within the lantern is the “brain” of the unit. Not only does it ensure that the battery is charged and discharged correctly so that it gives a lifetime of maintenance free service, but it can also “decide” to give the battery an extra top-up charge if the panel has gone without its full quota of sunlight for a few days. Its on-board microprocessor will even store information (which can be downloaded later after using) on how the lantern has been used. This information is extremely useful and will help the designers build



a picture of how customers use their lanterns. This information will be used to design better lanterns in future.

A similar project on a solar powered lantern in Cambodia is described in Chapter 8 (on the web).

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