ABSTRACT: Given the high potential of PV technology to reduce the environmental impact of electricity use of consumer products, it would be worthwhile to advance the application of PV systems in mass produced products. To date this field of application has been explored only to a limited extent. For this reason the developers of consumer products, the industrial designers, might be unaware of the possibilities of product-integrated PV systems [1][2]. Their focus on the utility of consumer products might have an added value to existing R&D of PV technology which emphasizes on increased performance and decreased production cost. In the nearby future integration of both points of view might be important to better integrate PV cells in consumer products. Therefore, in this paper, we will assess industrial product design of integrated PV technology in the context of future scenarios. In our project about 25 product designers have conceptually designed products with integrated flexible PV cells within a future scenario. By observing the resulting cases we can evaluate how the design process was established in the framework of integrated technology design, the product phase model and future scenarios. The PV-powered products that will be evaluated are an electronic book, an information bracelet, a floating platform, sports garment and a robotic monitoring device. Each product is supported by visual materials such as renderings and an explanation of the design process based on scenarios.

Keywords: PV Systems, Design and Manufacturing, Technology Transfer, Education and Training

1 INTRODUCTION

In this paper we will assess how theories about industrial design and more specifically future scenarios can be applied in order to better integrate PV systems in consumer products. We will explain the approach of industrial design engineering by cases. Each of the 5 cases comprises a product designed by a team of master students of the Studies of Industrial Design Engineering at University of Twente. In 2005 in the course ‘Create the Future’ students have developed products using future market forecasting scenarios. The aim of the project was to develop a long term view of ten years on product-integrated PV systems. Assuming the use of flexible PV cells each product design is based on a scenario of specific use. In order to fit this project in the context of industrial design engineering we will present theory about integrated technology design and the product phase model in Section 2. Next, theory of future scenarios will be presented in Section 3. In the fourth section PV-powered products designed in our project (a digital book, an information bracelet, a floating platform, sports garment and a robotic monitoring device) will be evaluated in the framework of industrial product design and future scenarios. The paper will be finished by conclusions and recommendations.

2 INDUSTRIAL PRODUCT DESIGN

2.1 Context of industrial product design

Design methods – the process of designing a product - have a large impact on the final product. Main focus is the utility of consumer products. The field of industrial design can be represented by the following topics: technology, design & styling, ergonomics and marketing [1][4]. Product designers perceive each of the four topics evenly decisive for the final success of a product. Hence, if these topics are required for a successful consumer product they should be applied to products with integrated PV cells as well.

2.2 Integrated technology design

So far, design and manufacturing of PV technology is mainly focused on improved performance of flat solar modules [3]. By integrated technology design, the product to be designed and the technology integrated in the product are considered as evenly important, see Figure 1. This approach may be necessary if a relatively new technology is implemented in existing processes of industrial product design. Possible results of integrated technology design could be new product concepts and other specifications of PV technology, for instance PV modules which can be shaped like a product surface and be easily implemented in manufacturing processes. Besides this, energy balance is a matter of concern in the case of integration of PV technology in a product. For a well-functioning product the energy production of the PV cells should fit the energy demand of the product. Therefore, integrated technology design refers to the first two phases ‘Performance’ and ‘Optimisation’ of the product phase model which we will explain next.

Figure 1: PV product design according to integrated technology design [1].

2.3 Product phase model

In the product phase model [5] the phenomena that appear during the six chronological phases of a product's life are described. In each phase a certain aspect is focal point of product development. The aspects that can be distinguished are: performance, optimisation, itemisation,
segmentation, individualisation, and awareness, see Figure 2. Each phase will be described below.

**Performance:** The product is new to the market and product development is aimed at improving performance. Styling or ergonomics are not very important. Only a few competitors are on the market; the price per unit is relative high.

**Optimisation:** Though the product is new to the market some consumer awareness exists yet. Product development is aimed at better reliability, improvement of ergonomics and safety. The number of competitors starts to grow. Product promotion happens predominantly through fairs, free publicity, and trade promotion.

**Itemisation:** In this phase the product functions well; also it is reliable and safe. Product development aims at extra features and accessories, including special editions of the product which are developed for different target groups. Prices start falling and promotion is mainly done through direct marketing, print-, TV- and radio-advertising.

**Segmentation:** In this phase the product has become a commodity. It is available in a broad product range. Styling becomes more expressive aiming at adding emotional benefits. In this phase market penetration is high and promotion and advertising are intensively channelled through the media.

**Individualisation:** Allowing the customer to influence the final product by mass customisation or co-creation can be possible if competitors’ prices are low. In this stage interactive media such as internet are used to customise the product to needs of the individual.

**Awareness:** Customers demand social or environmental friendly conduct of the company which produces a certain product. In this phase companies communicate their ethics concerning society and environment.

![Figure 2](image)

**Figure 2:** Product phase model; chronological phases matching to a product’s life

By the chronological order of the six phases it will be possible to predict the further directions of product development for an existing product in a certain stage. However if designing new products we will use another approach; future studies.

3 FUTURE SCENARIOS

3.1 Future scenarios and product design

Product design is always future oriented, but often the time horizon is limited. Therefore several techniques have been developed to stretch the time horizon beyond the common sense. These include trend-analysis, Delphi-studies, expert studies, simulation, time-series, causal modelling and scenario writing [6]. One of the most powerful of these techniques is scenario-development [7]. The advantage of scenario development over other techniques is its flexibility in the time dimensions, details and imagination and the possibility to include the results from other methods. By writing multiple scenarios, designers can also take into account the inherent uncertainty of the current developments. Though one might discern typical patterns in product development and diffusion, combined with other technical and social developments tensions may arise with unpredictable but not unthinkable outcomes [8].

3.2 Sketching the future of PV powered products

In our project future markets for product development with PV technology were assessed by using explorative, context scenario’s. This scenario technique, based on the methodology developed by the Shell Strategy Group [10], is adapted to the aims of future oriented product design and consists of five steps.

1. Analysis of industrial sector, commercial market or societal field (like agriculture, public transport, entertainment, hospital) by mapping main actors, critical factors and main drivers of future developments in a uncertainty/importance matrix.
2. Development of a two dimensional strategic space, see Figure 3, which axes represent the key long term uncertainties in the future of the field. Examples of such uncertainties are in the agricultural sector the extent by which agricultural production and consumption will really be guided by sustainable values and in the health sector the possibilities of genomics and effects of the ageing population.
3. Writing three scenarios that fit with balanced developments and extremes in the strategic space. Scenario writing includes systematic analysis of how certain typical developments will work out for the specific combination of uncertainties indicating by that scenario, as well as creative writing and imagination.
4. Developing new PV technology based products for each of the scenarios.

![Figure 3](image)

**Figure 3:** A strategic space for food production and three scenario points.

4 PV POWERED PRODUCTS

In this section we will show PV powered products resulting from our project. The products are designed for the year 2015 using flexible PV cells. During the project all participants were informed about PV technology by a PV specialist of Akzo Nobel. In the following each product will be related to a future scenario, the quality of integrated technology design and the phase of development according to the product phase model.
4.1 PV powered electronic book
In 2015 the world is full of media. Customers are overwhelmed by information available everywhere. Economy is growing steadily. In this scenario customers want to be continuously informed about recent developments and news.
A PV powered electronic book fits in this scenario. Electronic paper in this book is updated on demand by wireless internet. Given the power requirement of 250 mW each day, the available surface for PV cells and the use of other existing electronics (Li-ion battery, LED lights, WiFi and E-paper) this product concepts seems feasible, i.e. technology is integrated well in the design. Because the E-book is feasible yet in 2006 we expect it to be a commodity in 2015. That is to say it will be in the product phase ‘itemisation or segmentation’.

4.2 Information bracelet powered by PV cells
The future of transport will be strategically divided by the use of fossil fuels vs. sustainable fuels and the use of public vs. private transport, see Figure 5. In 2015 the scenario ‘Go Public’ will be common.

4.3 Floating PV platform
The floating PV platform shown in Figure 7 fits in several future scenarios for agriculture called ‘Protectionism’, ‘Quality’ and ‘Mass Production’. Each scenario leads to a certain extent of use which is predominantly based on awareness considering the environment (last product phase). However, since the product is new to the market and will probably have to be further improved, it is in the product phase performance. Though the product concept creates more available area for PV cells, the product seems not feasible during windy days. Also the use of helium gas which fills the PV platform could be a financial bottleneck. Hence, integrated technology design could be increased considerably.

4.4 PV powered virtual sports garment
Four scenarios were developed for the future of sports. Figure 8 shows the three-axial scheme in which team vs. individual sports, fun vs. health and performance are represented.
In the scenario ‘Team and fun’ the actual tendency to sport less and to invest more time in computer gaming is converted in team sporting in the virtual realm. In this way physical activity is possible while playing computer games. Virtual reality or better said augmented reality requires a computer and therefore power supply. Figure 9 shows the PV powered sports clothing which allows virtual gaming. The black area of the shirt represents the PV cells. If wearing the glasses reality becomes augmented showing parts of the virtual play ground. The product concept is from the point of integrated technology design feasible. However we expect major user centred improvements of the product as it is still in the optimization phase.
4.5 PV robotic monitoring device
Future globalisation of agriculture requires more efficient production of crops. In this scenario an optimal constitution of soil contributes to high yields. The product concept which has been developed in this scenario samples soil of arable land. It is an autonomous robotic monitoring device which probes the soil and collects samples for further analyses in a basis station. Figure 10 shows the interior of the device which consists of a connected series of alike elements. The exterior is covered with solar cells (not shown in the picture). Batteries inside the elements provide energy for probing, sampling and motion. The robotic monitoring device is both new as a concept and as a technique, which means it is in the performance phase.

4.6 Merging the findings
In Table I we show the findings of the product designs in relation to integrated technology design (ITD), product phase model (PPM) and future scenario (FS).

<table>
<thead>
<tr>
<th>Product</th>
<th>ITD</th>
<th>PPM</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-book</td>
<td>+</td>
<td>Itemisation or segmentation</td>
<td>Media</td>
</tr>
<tr>
<td>Bracelet</td>
<td>+</td>
<td>Individualisation</td>
<td>Transport</td>
</tr>
<tr>
<td>Floating PV</td>
<td>-</td>
<td>Performance</td>
<td>Agriculture</td>
</tr>
<tr>
<td>PV garment</td>
<td>+</td>
<td>Optimisation</td>
<td>Sports</td>
</tr>
<tr>
<td>PV robot</td>
<td>-</td>
<td>Performance</td>
<td>Agriculture</td>
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5 CONCLUSIONS AND RECOMMENDATIONS

Future scenarios appear to be very useful in the context of integrated technology design. New product concepts which are less predictable but not unthinkable, can be developed on the basis of future scenarios. Following the product phase model we found that new concepts and techniques start in the product phase performance.

In order to further develop the product concepts we found that activities are required in the field of marketing and in the field of prototyping of products with integrated PV systems.

Education and training of industrial designers to design products with PV technology appeared to be successful in this project.

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7 REFERENCES
