Escola Politècnica Superior d'Enginyeria de Vilanova i la Geltrú

UNIVERSITAT POLITÈCNICA DE CATALUNYA

EPS – PROJECT

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Title:
Theoretical investigation on photovoltaic technologies and the possibility of applying them to vehicles in general

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Abstract

"Theoretical investigation on photovoltaic technologies and the possibility of applying them to vehicles in general"

A good use on solar energy is the key to save on fuel consumption on vehicles. Therefore, the purpose of this project is to study the implementation of new technologies for solar car roof-tops, together with the analysis of determinant materials for their construction within the automotive sector, focusing on an efficient, economical and environmental friendly vision. The major outcome of the project relates to the deepening on the materials most commonly used to manufacture solar panels for regular use and the "thin films", with emphasis on manufacturing methods, technical characteristics and a brief history of each.

In order to establish a criterion for choosing an optimal technology for this project, complete analyses on different aspects are studied for each material. In general this means the efficiency in different situations, retail prices, production costs, market shares, availability, working conditions. Furthermore also intrinsic aspects of each material such as resistance, degradation, flexibility, thickness of the cells, transparency, estimated lifetime or potential recycling have to be observed.

Secondly, most important techniques used for implementation today, and some possible techniques applicable in a not very distant future are studied. The results of these studies will be revealed and an economic study of the most suitable solutions will be included in the Business Case. Also, graphics made with a 3D modelling program showing the implementation of the solar roof-top on a vehicle from the SEAT Company, are shown.

Key words:

solar energy, photovoltaic technology, photovoltaic materials, solar application in vehicles

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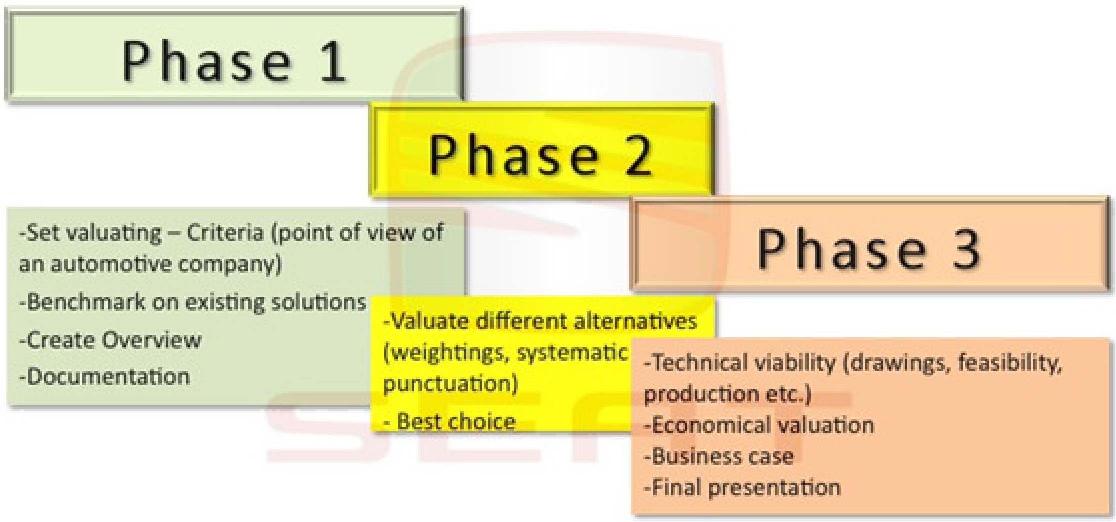
Introduction

This project has been done as an assignment during the 'European Project Semester 2010' at the Universitat Politècnica de Catalunya. The project was developed in collaboration with the automotive company Seat, the university and the students. The content of the project was applying photovoltaic technology on cars.

Title: Theoretical investigation on photovoltaic technologies and the possibility of applying them to vehicles in general.

Main aim: Valuate different photovoltaic techniques in order to find the most suitable sustainable solution for car applications to reach a minimum of 100 Watts.



The project consists of three different phases. The first phase consists mainly out of information gathering. The first step is to look at criteria that are important for Seat, besides that it is also important to look at the customer prospective. For all the materials, each criterion had to be explored. These founding were sorted in an overview and documented.

In the second phase we started with the valuating of the materials and compared al the criteria. After that we made a best choice matrix, were we included all the criteria and their weight factors. This matrix helped us choosing the best materials for further research.

In the third and final phase of our project, three different materials were selected for further research. The first part exists out of calculations on solar radiation in space, solar radiation on earth, photovoltaic cell efficiency and weather conditions. After this a part about technical viability shows how we would like to apply the solar panel upon the car including assembling material. We concluded the report by doing a business case on the profitability of photovoltaic applications on cars. In the business case the customer and company will both be examined.

Chapter 1 The project

1.1 Motivation

Every hour the Earth receives more energy from the sun then the world uses in a whole year. However, only 0.01 % of the total global energy demand is produced from solar energy [1]. With the current environmental problems the development of renewable sources becomes more important. Also the automotive industry invests a lot in the reduction of waste and saving fuels. One way of doing this is applying other energy sources on cars, like solar panels.

The electrical devices (e.g. radio, ventilation, light) in cars nowadays obtain the required energy from a battery. For recharging is commonly the engine using fossil fuels utilized. A solar panel could provide electricity for devices that are not responsible for safety (e.g. brake-force-control, steering). With higher performance it would be possible the help recharging the battery and therefore save fuel.

[1] [http://www.solarbuzz.com/FastFactsIndustry.htm]

1.2 Problem

Currently Seat has implemented a solar car-roof-top in the Seat Exeo. This solution can reach 37 watts and is used to power the ventilation system. As soon as the car is parked the ventilation system can be switched on and the air in the car will be circulated. Especially in countries where there is a lot of sun, cars can reach a high temperature when standing in the sun for a few hours. Besides the comfort the ventilation system offers, it is also energy saving. This is because the car does not have to be entirely cooled down on the regular ventilation system.

Besides the benefits of the solar panel there are also a few negative aspects. The price of the solar panel that Seat can offer to their customers is €1.250 (*www.seat.de*), compared to a normal sunshine roof of €830. The module is an additional part for circulating the air while the car is parked in the sun. The sunshine roof with the integrated solar cells can save a small amount of energy in fact the inner temperature is lower when passengers enter and consequently the air conditioning system has less work. The money saved by using less fuel is not enough to have a return on investment of the solar glass roof.

For the future Seat wants to apply solar panels with more power for less money on their cars. Therefore they want to do research to find the best suitable solution. Because the investigation takes a lot of time, and to have different views on this subject Seat decided to get external advises. Together with the Escola Politecnica Superior d’Enginyeria de Vilanova i la Geltru (EPS/EVG) they made an assignment for students to do an investigation.

1.3 Solution

After presenting the main schemes of the problem, now it only remains to present the way we will work on the project. At first, we face the inconvenience of time and resources to use. We have thought possible divisions of the time within the project and it has been agreed as the best option to make three partitions per time / work and at the same time, subdivisions as agreed to the tasks will be made in groups of two. Having also, previously established roles for each individual team member, each component of the group will be autonomous but integrated in the overall functions.

The division of the time and work will be given by the following three phases (into which later this document will delve), but later subdivided into some more:

- Assessment of photovoltaic materials and establishing alternatives.
- Prototyping, calculations, etc.
- Business case and case studies.

Each phase will have an average of one month duration. During the various reports to the supervisors of the university and the company, Gantt charts will be generated to subdivide in an effective way, the tasks to be performed.

Another task that will be always in development will be the creation and maintenance of a wiki for the project on which we will upload all the documents created by the members, as well as the presentations and documents related to meetings occurred within the context of the project.

We now discuss in more detail each of the phases that we have mentioned above:

1. **Assessment of photovoltaic materials and establishing alternatives**

Since the project will use the technologies available for today's PV systems, a comprehensive and accurate knowledge of each of the materials used will be required. These tasks will be divided among the six members and will cover the technologies of amorphous Silicon, crystalline Silicon, Cadmium Telluride, CIGS, Gallium arsenide, and Gratzel. The members of the team must perform accurate research on each material to obtain relevant data for the cases that we will study subsequently, and generate documentation for a complete manual that will include the photovoltaic crystal technology standards and thin film technologies.
To analyse each material it has been devised a template to highlight properties and data to be used for each material with the aim of assessing the viability of the implementation in the project. That is the main reason because we have included data that is more likely to be important to the vision of the vehicles company that will implement the system. This template includes sections such as: efficiency, price, market share, availability of the elements of the material, functional conditions, safety, degradation, life-time, recycling, transparency, flexibility and thickness, as well as manufacturing processes and a brief history of each material.

In order to evaluate each material in a more graphical way, we will generate tables that will show the advantages and disadvantages of each of the materials in comparison with others. These will be helpful to the decision on which are the best possible solutions.

2. Prototyping, calculations, etc.

In order to help on our decision a team of two electrical engineers will perform various calculations to determine what solution can promise better results. These calculations will focus on issues such as Incident solar radiation, maximum power or Standard Operating cell temperature.
Graphs for different latitudes will be contrasted to choose the most appropriate solution.

In the process of creating a prototype for the project we have adjusted some files, from the company, that will have to run with the CATIA V5 3D modelling program. From here, a group of two engineers will design a possible implementation in the model “LEON” of the SEAT Company.

3. Business case and case studies.

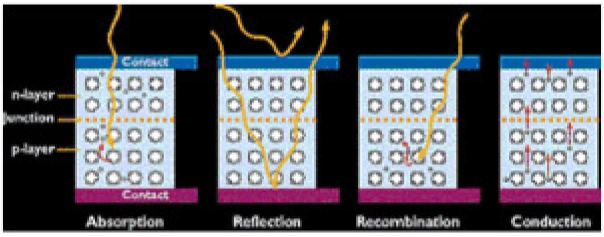
In this last phase of the project a group of two people will recreate different business cases for the automobile company SEAT. After evaluation and validation of the diverse techniques and photovoltaic materials studied, load production and financial calculations with some business marketing with its economic assessment will be reported.

Chapter 2 Photovoltaic technology
2.1 How does photovoltaic work?

Before different materials can be compared it is necessary to know the main principles of photovoltaic: how it is possible that sunlight can be converted into electricity and how does the process works. The following explanation uses a silicon solar panel.

The role of photovoltaic is to convert sunlight into electricity. Sunlight is composed of photons of solar energy. However, these photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons hit a PV cell, beam can be reflected or absorbed. Only the absorbed photons generate electricity.

PV cells have two separates layers which are sandwiched together. The result of this combination is to induce an electric field. These layers are "p" and "n" types of semiconductors correspond to "positive" and "negative". So, when the p-type and n-type semiconductors are sandwiched together, the excess electrons in the n-type material flow to the p-type, and the holes thereby vacated during this process flow to the n-type. Through this electron and hole flow will create an electric field at the surface where they meet ("junction"). The result of this field will make the electrons to jump from the semiconductor out toward the surface and make them available for the electrical circuit. At this same time, the holes move in the opposite direction, toward the positive surface, where they await incoming electrons.



Graphic 2.1.1 How does photovoltaic work [http://inventors.about.com/library/inventors/blsolar3.htm]

First Generation
First-generation characterized by single junction. The material which are part of this generation, have the largest area of applicability, with a high-quality. Also, this technology involves high energy and labour inputs which prevent any significant progress in reducing production costs. The advantage is payback period and efficiency.

Second Generation
Second-generation is characterized by thin film. Some manufacturing techniques used for these materials part of this generation, reduce high temperature processing. Production costs will be dominated by constituent material requirements, whether this is a silicon substrate or a glass cover. However, the most successful second-generation materials have been cadmium telluride, copper indium gallium selenide, amorphous silicon and micromorphous silicon. These materials promise a good efficiency and cheaper production costs.

Third Generation
The Third-generation is a complement for second generation. These materials aim is to enhance poor electrical performance of second-generation while maintaining low production costs. Current research is to have an efficiency of 30–60% while retaining low cost materials and manufacturing techniques. [4]

2.1.1 Characteristic Equation of the Photovoltaic Cell

For ideal cells, the schematic electrical, will be represented by a current source connected in parallel with a rectifying diode, and non-ideal components are shown by the dotted line.

The PV cell or module is usually represented by the single exponential model or the double exponential model. The single exponential circuit model is shown in Figure 2.1.1. Although this model is widely used and accepted in the simulation and testing of photovoltaic modules the double exponential model is more accurate and more difficult to solve and the parameters also vary with temperature and irradiance. Models that use constant parameters have been proposed but these models are inaccurate as they do not take a temperature variation into account. [1]

Recently, a lot of researchers have developed single exponential models that neglect the shunt resistance. Other researchers have developed models that take account of temperature and irradiance based on datasheet information.

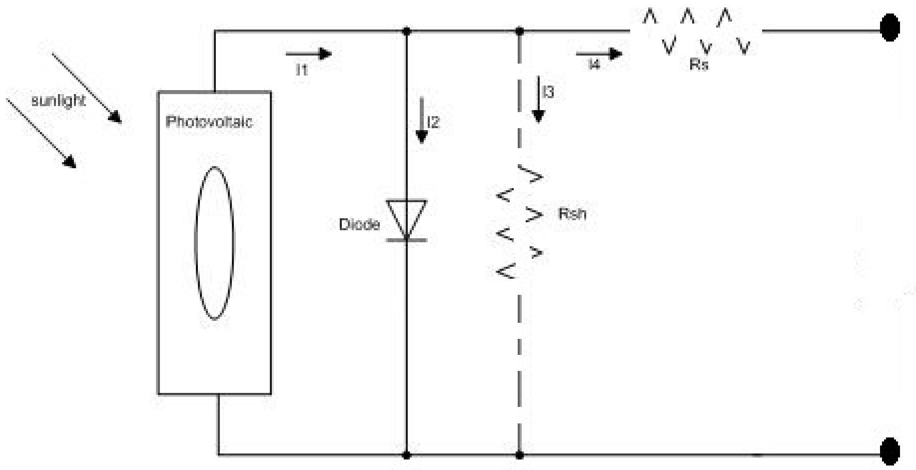


Figure 2.1.1 The single exponential model of photovoltaic cell

1. First Kirchhoff theorem:

$I_1=I_2+I_s$ (1)

$I_s=I_3+I_4$ (2)

From (1) and (2) result: $I_1=I_2+I_3+I_4$;

2. Second Kirchhoff theorem:

$U_{ph}=U_d+I_3*R_{SH}+I_4*(R_S+R_L)$ (3)

- I_1- current from photovoltaic cells;
- I_2- current thru diode;
- I_3- current thru R_{SH};
- I_4- current thru R_S and R_L;
- R_{SH}- shunts resistance;
- R_s- series resistance

Also:

$R_s=R_{cp}+R_{bp}+R_{cn}+R_{bn}$ (4)

R_{cp} is the metal contact to p-type semi-conductor resistance

R_{bp}-is the bulk p-type resistance

R_{cn}-is the contact to n-type semi-conductor resistance

R_{bn}- is the bulk n-type resistance

The equation for current/voltage (I-V characteristic described by the Shockley solar cell equation) will be:

$$I = I_{ph} - I_0\left(e^{\frac{V_C \cdot q}{k \cdot T_C}} - 1\right) \tag{5*}$$

If we include in equation and shunt resistance and series resistance, the equation will have next form:

$$I = I_{ph} - I_0\left(e^{\left[\frac{q(V+IR_S)}{AkT}\right]} - 1\right) - \frac{V+IR_S}{R_{sh}} \tag{6*}$$

$$I_0 = A \cdot T^3 e^{\frac{E_g}{kT}} \tag{7*}$$

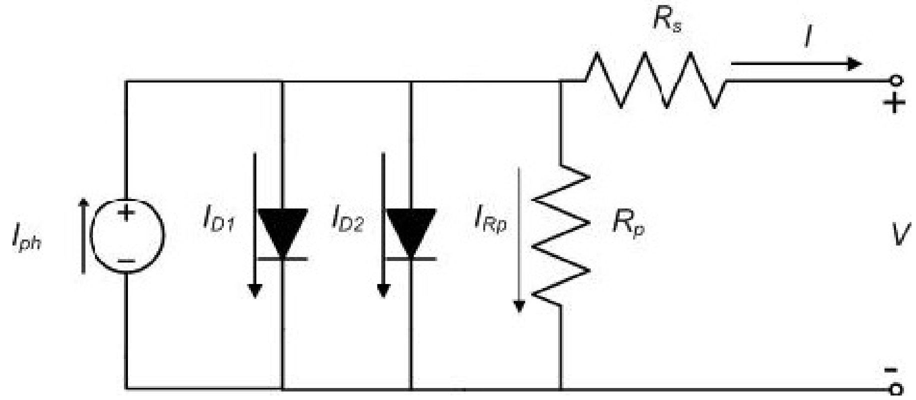


Figure 2.1.2 The double exponential model of photovoltaic cell [1]

$$I = I_{ph} - I_{s1}\left(e^{\frac{q(V+IR_S)}{kT}} - 1\right) - I_{s2}\left(e^{\frac{q(V+IR_S)}{AkT}} - 1\right) - \frac{V+IR_S}{R_{sh}} \tag{8*}$$

Where:

- I_{ph} - the photo-generated current (I_{sc})
- I_{s1} - saturation current due to diffusion
- I_{s2} - is the saturation current due to recombination in the space charge layer
- I_{sh} - current owing in the shunt resistance
- R_s - cell series resistance
- R_{sh} - the cell (shunt) resistance
- A - the diode quality factor
- ***k*** (1.38*10^{-23}[j/K])is the Boltzmann constant;
- ***T*** is the absolute temperature;
- ***V*** is the voltage at the terminals of the cell

- ***q*** (1.6*10^{-19} [coul]) is the electron charge, and Vis the voltage at the terminals of the cell;
- ***I_o*** is the diode saturation current serving as a reminder that a solar cell in the dark is simply a semiconductor current rectifier, or diode;
- ***A*** is a non-ideality factor and usually is 1
- ***E_g*** band gap

When the shunt resistance rise to a high value R_{sh}=∞, the equation for this cell will be:

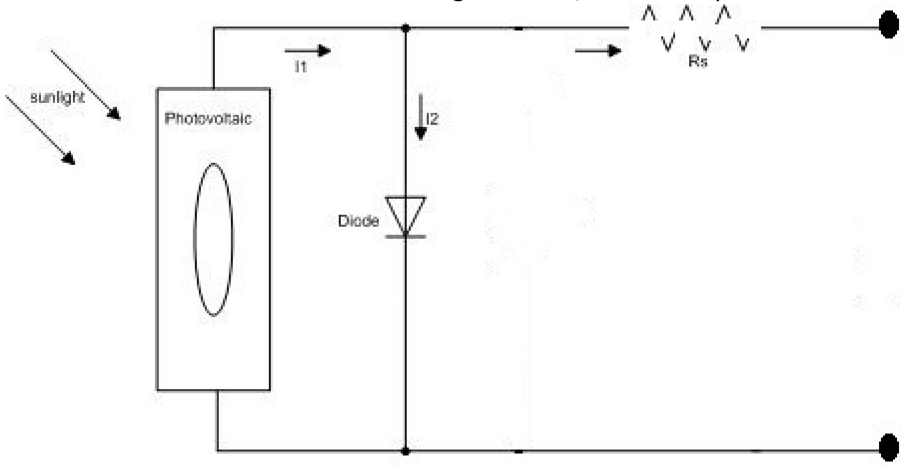
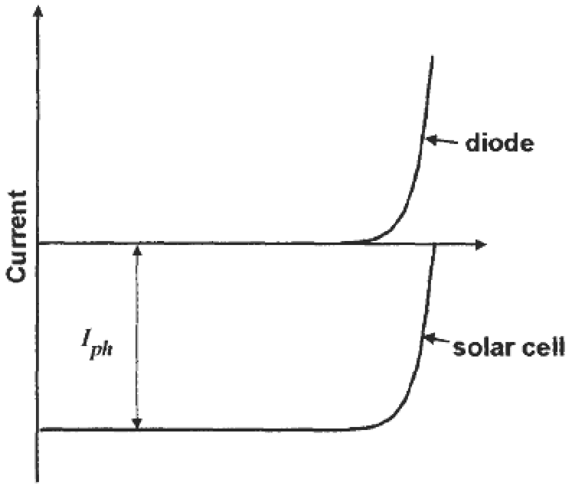


Figure 2.1.3 The single exponential model without shunt resistance

$$I = I_{ph} - I_0\left(e^{\frac{(V+IR_S)q}{kT}} - 1\right)$$
(9*)

In next figure is the difference between characteristic of diode and photovoltaic cell shown.



Graphic 2.1.1 Difference between diode behavior and solar cell [2]

From Graphic 2.1.1, we can see the current dependence of the light. And when there is no light present to generate any current, the photovoltaic cell behaves like a diode. However if the intensity of the light increases the current will increase as well.

The photogenerated current ***I_{ph}*** is closely related to the photon flux incident on the cell and its dependence on the wavelength of light is frequently discussed in terms of the quantum efficiency or spectral response

$$V_{oc} = \frac{k \cdot T}{q}\ln\left(1 + \frac{I_{ph}}{I_0}\right)$$
(10*)

The power is $P=U \cdot I$, the maximum power P_w is at the voltage V_m and current I_m and it is:

$V_{oc}I_{sc} \cdot FF = V_mI_m = P_{max}$

(11*)

Convenient to define the fill factor *FF* by:

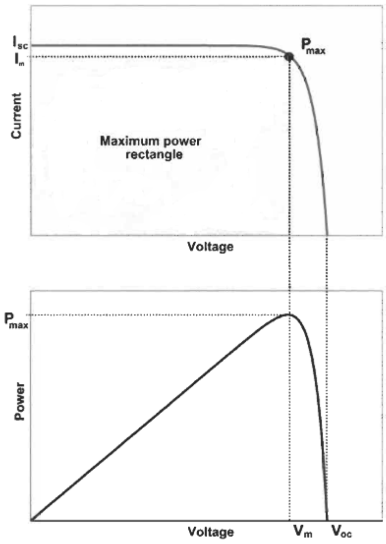
(12*)

An example for this can be for:
I_m=-2.5mA; V_m=0.3V; I_{sc}=-3mA; V_{oc}=0.5V

The fill factor *FF* of a solar cell with the ideal characteristic (1) will be furnished by the subscript 0. It cannot be determined analytically but it can be shown that FF_o depends only on the ratio . FF_0 will have next form:

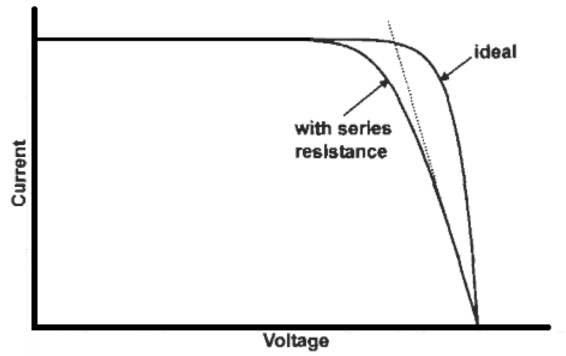
(13*)

The solar cell characteristics in practice are shown in next figure:

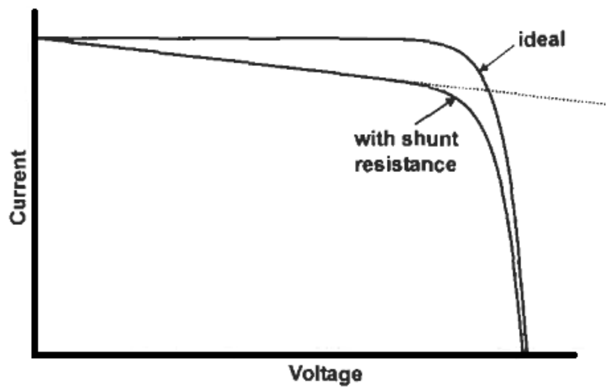


Graphic 2.2.2 The I-V characteristic of an ideal solar cell (a) and the power produced by the cell (b) [2]

For real characteristics, in electrical circuit will appear a resistance, shunt resistance or series resistance, and these two can modify the I – V characteristic. So if we have a series resistance, the maximum power will decrease because the current will decrease more quickly, but voltage will be the same like an ideal model. Also a shunt resistance will decrease the maximum power because the voltage, for this time, will decrease more quickly and the current will be the same like an ideal model.



Graphic 2.1.3 The effect of series resistance on the I-V characteristic of the solar cell [2]



Graphic 2.1.4 The effect of and parallel resistance on the I-V characteristic of the solar cell [2]

From this will result the FF, which is another important parameter of the PV characteristics. It is a term that describes how the curve fills the rectangle that is defined by (V_{oc}) and (I_{sc}). It gives an indication of the quality of a cell's semiconductor junction and measures of how well a solar cell is able to collect the carriers generated by light.

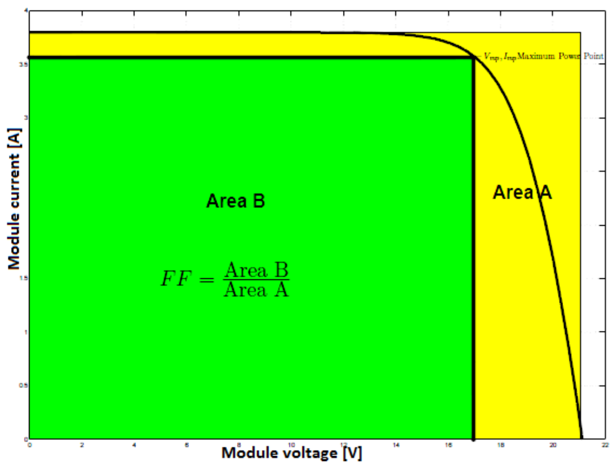


Figure 2.1.4 photovoltaic characteristic, fulfill [1]

From here we can have a conclusion which is: FF will never be over 1 (FF<1) and ranges from material to material. The effect of the series resistance on the fill factor can be allowed for by writing:

$$FF = FF_0(1 - r_s) \quad (14^*)$$

Where $r_s = R_s \cdot \frac{I_{sc}}{V_{oc}}$

- I_{sc}-It is the current in the circuit when the load is zero in the circuit. It can be achieved by connecting the positive and negative terminals by copper wire.
- V_{oc} -Open circuit voltage is obtained by setting I=0
-

The solar cell power conversion efficiency can be given as:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{max} \cdot V_{max}}{\text{Incident solar radiation} * \text{Area of solar cell}} = \frac{V_{oc} \cdot I_{sc} \cdot FF}{I(t) \cdot A_c}$$
(15*)

2.1.2 Photovoltaic panels

Have an advantage, and this is, it not have to be only sunlight (natural light), the new cells work and if are illuminated with artificial light. PV cells contain a junction between two different materials across which there is a built in electric field. The absorption of photons of energy greater than the bandgap energy of the semiconductor promotes electrons from the valence band to the conduction band, creating hole-electron pairs throughout the illuminated part of the semiconductor.

In a series connection the same current flows through all the cells and the voltage at the module terminals is the sum of the individual voltages of each cell. It is therefore, very critical for the cells to be well matched in the series string so that all cells operate at the maximum power points. When modules are connected in parallel the current will be the sum of the individual cell currents and the output voltage is equal to that of a single cell.

The best structure is made in array with photovoltaic cells which are in parallel or in series to provide enough electrical power for a given application.

The equivalent voltage for *n* modules in series will be:

for I>0

$$V_{series} = \sum_{j=1}^{n} V_j = V_1 + V_2 + \ldots + V_n \qquad (16)$$

$$I_{series} = I_1 = I_2 = \ldots = I_n \qquad (17)$$

for I=0

$$V_{series\ OC} = \sum_{j=1}^{n} V_j = V_{OC1} + V_{OC2} + \ldots + V_{OCn} \qquad (18)$$

The equivalent current for *m* modules in parallel will be:

$$I_{parallel} = \sum_{i=1}^{m} I_i = I_1 + I_2 + \ldots + I_m \qquad (19)$$

$$V_{parallel} = V_1 = V_2 = \ldots = V_m \qquad (20)$$

To have a good performance, is better to not have any part shaded, otherwise, if cells which are components imbedded in array can be damaged. So, that's why for cells protect must be used bypass diode.

The PV array in the dark behaves as a diode under forward bias and, when directly connected to a battery, will provide a discharge path for the battery. These reverse currents are traditionally avoided by the use of blocking (or string) diodes (as shown in next figure). Blocking diodes also play a role in preventing excess currents in parallel connected strings.

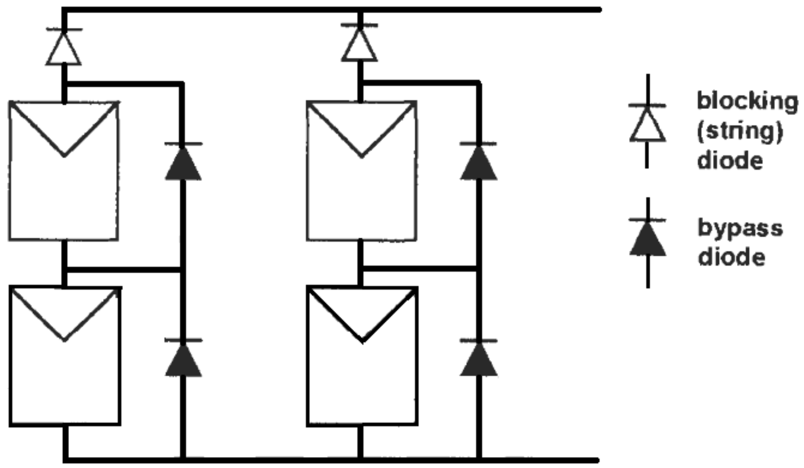


Figure 2.1.5 An array consisting of two strings, each with a blocking diode

Each module is furnished with a bypass diode. In practice, it recommended that bypass diode are used for every series connection of 10-15 cells [2]

2.1.3 Photovoltaic system

The photovoltaic systems are composed of interconnected components designed to accomplish specific goals ranging from powering a small device to feeding electricity into the main distribution grid. To obtain more than 100W for charging batteries, cells must be connected to have more efficiency and a maximum power with a high current.

A photovoltaic panel is a system configured by one or more cells. The output signal of these panels is nonlinear because it will vary with the solar irradiation or with the temperature. This power variation has a negative impact over the final end devices. In Figure 2.1.6 a basic electronic system using photovoltaic panels is shown.

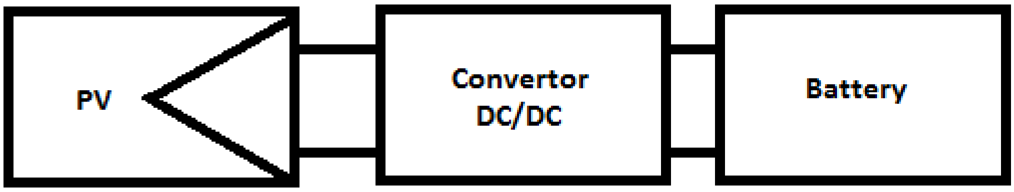


Figure 2.1.6 Electric system with photovoltaic panels

Photovoltaic panels can be connected directly to batteries or with a convertor DC/DC, as shown in Figure 2.1.6. The role of this convertor is to make a linear wave of output signal.

There are two types of storage batteries for solar power storage, acid and alkaline. Alkaline batteries are made with nickel and cadmium or nickel and iron. The main difference is that nickel and cadmium batteries have a faster discharge rate. However, nickel batteries are bad for the environment while the nickel and iron ones are not. Nickel and iron batteries are slower to reply when a load is applied and have to be broken in before reaching their maximum charging capacity. These types of batteries will not freeze, so there are no problems when operating in cold climates.

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[*] – [1], [2], [3], [4].

2.2 History

The history of photovoltaic has now advanced to the point to be a serious alternative for producing energy. The exploring of the photovoltaic-effect and the theoretical declaration took more than 100 years followed by the first inventions for space application.

The term photovoltaic's derives from the Greek word "phos" meaning light and the word "volt". Photovoltaic is a science, which examines light-electricity conversion, respectively, photon energy-electric current conversion. In other words it stands for light-current conversion. The first time that this photovoltaic phenomenon was discoverer was in 1838, and it was only until 1877 before the first solar cell construction was made. In 1904 Albert Einstein made a theoretical work describing the photovoltaic effect, which was rewarded with the Nobel Prize in 1921.

The development on photovoltaic was increasing rapidly because it became an important energy supplier for space technologies. In 1958 the first satellite powered by solar cells *Vanguard I* was launched, followed by *Explorer III*, *Vanguard II* and *Sputnik III*.

The first solar module was produced in 1963 by Sharp Corporation from silicon solar cells. The biggest photovoltaic system at the time, the 242W module field was set up in Japan. A year later, in 1964, Americans applied a 470 W photovoltaic field in the Nimbus space project.

The first sun-powered car was produced in 1955. In 1983 a Solar Trek vehicle with photovoltaic system of 1 kW drove 4,000 km in twenty days of Australia Race. The maximum speed was 72 km/h and the average speed was 24 km/h. The same year the vehicle surpassed the distance of 4,000 km between Long Beach, California, and Daytona Beach, Florida, in 18 days.

In 1983, the world production of photovoltaic modules exceeded 21.3 MW peak power, with product worth of US$ 250 million. In 1985, researches of University of New South Wales in Australia have constructed a solar cell with more than 20 % efficiency. In 2009 the worldwide photovoltaic installations had a capacity of 7.3 GW and at the University of Delaware efficiencies of 42% where achieved by means of concentration of light.

2.3 State-of-Art of solar application in vehicles

The upcoming green thinking causes research in renewable energies of almost every large automotive company. In the foreseeable future the world is running out of fossil fuels. The raising demands on these resources make it happen to think about alternatives to replace them as solitary car powering source. Different solutions for cars are in development with varying degree of success.

2.3.1 Electric hybrid vehicles (HEVs)

Nowadays an internal combustion engine powers cars. The electric hybrid car combines this with an electric propulsion system. A big advantage is that it is possible to make use of diverse efficiency improving technologies, as there are regenerative systems that can convert kinetic energy back into electrical energy while braking. Unfavourable sections in the torque range can be avoided through electric only or electric supported moving of the cars. In idle state the combustion engine can be deactivated. Even though normal cars can make use of a start-stop-system with a powerful electrical motor the restart is fast and comfortable. All of them combined can save about 15% fuel compared to normal engines regarding the New European Driving Cycle (NEDC).

There are three types of hybridization:

Full hybrid

The feature of a full hybrid is, that the engine or battery only can move the car but also a combination out of them as shown in *Fig.2.3.1*. Distinctive for this type is that beside a powerful electric motor a large, high capacity and therefore heavy battery pack is necessary for battery only-operation.

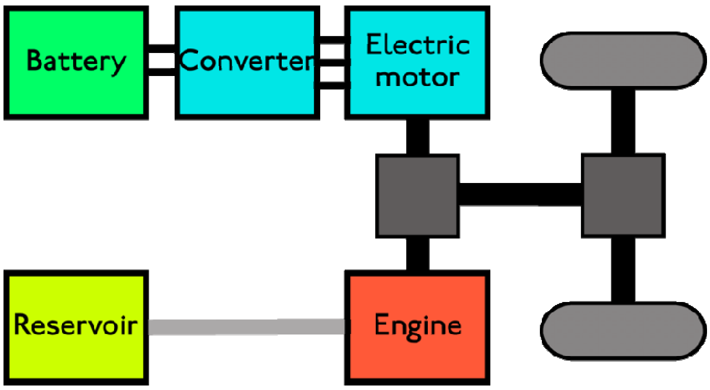

Figure 2.3.1 Scheme of a full-hybrid [1]

Current full hybrids are sold by VW (e.g. Touareg), Ford (e.g. Escape, Fusion), Toyota (e.g. Prius), Mercedes (e.g. ML) and other

Mild hybrid

When the electrical motor does not have enough power to drive the car solely the vehicle is called mild hybrid. The difference to a full hybrid is the smaller and weaker motor/generator what consequently downsize and lighten the battery.

Essentially an oversized starter motor is used to recapture the kinetic energy while braking and help to restart a turned off combustion engine quickly and cleanly.

Honda, Chevrolet, Toyota, Mercedes and other big automotive companies produce current mild hybrid.

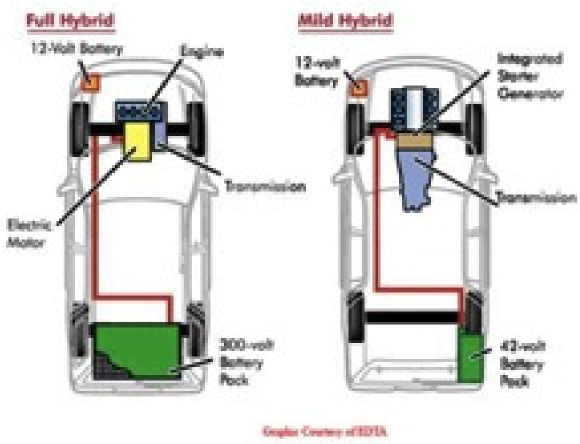

Figure 2.3.2 Scheme of a full-hybrid compared to a mild hybrid [2]

Power assist hybrid

Primarily powered by an internal combustion engine a torque-boosting electrical motor gives extra performance next to the benefits of helping to restart the main device after idle.

Plug-in hybrid

The plug-in hybrid electric vehicle (PHEV) is a normal hybrid with the possibility to fully recharge the batteries by connecting the car to an external electric power source. The PHEV combines the advantages of a hybrid and an electric-only car with extended all-electric range while eliminating the range anxiety.

Modern hybrids

The first mass produced hybrid vehicle was the Toyota Prius in 1997 directly followed by the Honda Insight. An Audi-hybrid with electrical driven rear wheels based on the A4-B5 was also introduced 1997 in Europe but due to the low demand and the high price not established.

Honda entered the market 2002 with the 7th generation Civic and Ford launched 2005 the first SUV. The early investment of Toyota and Honda in the hybrid technology now pays back with an increasing demand on fuel saving cars while European car manufacturers currently finalize their first models.

The hybrid technology commercialization shows the resonance regarding fuel saving cars. A list of the latest hybrid cars can be found on. [3]

Figure 2.3.3 Hybrid cars - Audi Duo, Mercedes S400 and Toyota Prius [3]

Conclusion

The commercialization shows that the hybrid vehicle technology is an opportunity to meet the rising demand on fossil fuels but also that this can just be a step on the way to a fossil fuel free car powered by alternative energy sources.

2.3.2 Fuel Cell Vehicles (FCVs)

A fuel cell vehicle is a car, which contains fuel cells to produce the energy to move on-board. The created electricity powers an electric motor using oxygen from the air and hydrogen or a reformed hydrocarbon.

In September 2009 the automotive companies Daimler, Ford, GM, Opel, Honda, Toyota, Kia, Renault, Hyundai and Nissan signed cooperation for a collaborative development and market launch of electrical vehicles with fuel cells. A technical collaboration was not concerted. [4]

The technology has two main issues, the efficiency and a supplier network for the essential hydrogen.

For a successful introduction in the market petrol stations have to be close-meshed over a certain terrain. With Germany as starting market the participating companies try to build an infrastructure until 2015 where a considerable number of FCVs will be offered on the market. Alongside a system for other geographical regions just like USA, Japan and Korea will be elaborated.

The other problem is the hydrogen efficiency itself. The way it is produced causes a high-energy loss. Energy is necessary to isolate hydrogen from natural compounds, to compress or liquefy the gas for storage, to transport the stored gas to the user and furthermore to convert it into electricity. The power-plant-to-wheel efficiency of high-pressure gas storage is about 22% compared to 17% while stored as liquid. [5]

2.3.3 Electrical vehicles (EVs)

Electric vehicles are powered by one or more electric motors. While normal cars and HEVs utilize fossil fuels an EV can receive their energy from a wide range of sources, as there are fossil fuels but also nuclear power or renewable sources. The energy can be stored in batteries, flywheels, super-capacitors or fuel cells.

This drive technology has a lot advantages compared to other systems. 90% efficiency commonly achieved over the full range of speed and power output. Unlike internal combustion engines an electrical motor does not need a gearbox. Also the power can be obtained through direct connection like cables and wireless transfer such as inductive charging. Another key advantage of electric and hybrid vehicles is the possibility to recover breaking energy as electricity.

Some disadvantages of this technology are challenging the companies. The limited range attributed to the low energy density of batteries compared to an internal combustion engine, the recharging time compared to refuel a tank and the weight and cooling problems batteries bring with.

If the quiet and smooth operation of the electrical device is an advantage or a disadvantage can be decided regarding the requirements. [6]

A list of 10 cars in the market 2007 can be found on *green.autoblogblog*. [7] For 2008 *alternativefuels.about* [8] provides a similar list. A well-known commercial solution presented 2006 is the Roadster of Tesla Motors. More than 100000 US$ has to be paid to own a sportive car accelerates from 0 to 60mph in 3.9 seconds and can reach an electronically limited top speed of 125mph. The battery is fully charged after 3.5 hours and has a range of about 236miles.

Figure 2.3.4 Picture of a Dodge Zeo [9]

2.3.4 Solar energy as source for power cars

While the shortage of fossil fuels in the closer future makes the companies researching for solutions to replace them, solar power as a renewable energy source becomes more popular. However, solar technology is not ready to substitute the internal combustion engine as primarily power source due to the fact that some properties makes the handling more uncomfortable and the energy density of the provided electricity is insufficient.

There are pros and cons of solar powered cars. The reason why most of the solar racers carry just one person is the fact that it is still difficult to gather enough power to move a car with the limited area. Therefore the vehicle has to be as lightweight as possible. Furthermore on buildings, open spaces and in the space itself, modules can be exposed to the sun while the conditions during a ride can change every second what causes a lack of efficiency. When it is cloudy or the car drives through a tunnel this solution is unpractical. To store enough energy for wider range large batteries are needed what causes in heavier ones as well.

All these facts make clear that solar-only powered cars are not possible in the near future. As recently as there is an answer for some issues this technology can become more practical. Some results of research already ended up in cars and make the first step for a further fuel saving.

Solar panel supported solutions in the market

SEAT Exeo

In the same way as other automotive companies, SEAT has a solar sunshine roof that helps to circulate the air with a power of 37W. When parking in the sun, this additional part can provide energy to cool down the inner room. The price for this panel is 1.250€. [10]

Figure 2.3.5 SEAT EXEO solar sunshine roof

Zhejiang's 001 Group

In October 2008 a Chinese company presented the first solar only powered car at the 29th Zhejiang International Bicycles and Electric-powered Cars Exhibition for about 5.560US$.

The expected range after 30 hours charging in the sun is 150kilometers. The car is just a demonstration for the possibility of using solar power only. As noticeable the flat panel is mounted to the roof of a small urban car taking just practical aspects into account. [11]

Figure 2.3.6 Zhejiang's 001 Group

Venturi Eclectic

The Venturi Eclectic is another interesting solution running on solar power. Advertised as an autonomous energy vehicle, the Eclectic can also use wind power to rotate a force wheel on top of the car.

The small 22hp electric motor with a torque of 50Nm obtains the power from NIMH-batteries which were charged by the 2.5 solar roof, wind power or via plug-in. The four-seater weighs just 350kg and is since 2007 in production for a price of €24.000. [12]

Figure 2.3.7 Venturi Eclectic

Astrolab venturi solar commuter

Astrolabe developed a 2-seat car in cooperation with the battery supplier Venturi. The futuristic designed vehicle has an overall range of 110km. With daily solar power only charge it reaches about 18km. Compound made the entire car weights 280kg from which 110kg are occupied solely by the batteries. It is possible to charge them in 5 h with a 16A charger or by 3.6m^2 solar panels with 21% efficiency. [13]

Figure 2.3.8 Solar commuter by Astrolab

Toyota Prius 2nd and 3rd Generation

Since the second generation Prius Toyota offers as additional equipment two solar panels. The supplier Solatec provides the panel with a performance of 30W for customers, which are willing to pay 2195$ extra. The 0,6mm flexible panels have 18V, are rooftop mounted and recharge directly the batteries.

The latest generation of the Toyota can be ordered since October 2009 with a solar roof. For 1150€ the air circulation can cool down the passenger room while the car is parking in the sun. [14]

Figure 2.3.9 Toyota Prius with the solar roof system of Solar Electrical Vehicles [15]

<u>Toyota Prius, Highlander Hybrid, Ford Escape Hybrid</u>

Solar Electrical Vehicles a Californian company, specialized on adding a convex solar roof to hybrid cars like the Toyota Prius, Highlander Hybrid and the Ford Escape Hybrid has solar modules rated at 200-300 watts. This power is used to recharge a supplemental battery and helps to power the Prius up to 20 miles per day in the electric only mode. The system costs $2000-$4000 and the payback time is said to be 2-3 years.
To enlarge the range further higher-capacity batteries are needed to implement. Currently *Solar Electrical Vehicles* experiment to replace the 212-watt solution with a 320-watt module.

Fisker Karma

The Fisker Karma is a hybrid car with a 209 HP 2.0Liter 4-cylinder internal combustion engine and two electric motors performing approximately 200PS. The vehicle achieve 80km in electric only mode. The market introduction (87900 US$) is planned for summer 2010 [18].

The company promotes the car with the world's largest continuous formed glass solar roof panel on a car orderable ex-factory. The module consists of 4 electrical separated zones with each 20 cells. 0.5kWh/day and a performance of 130W should be in posse. Three solar power-modes give the opportunity to use of the energy in the most efficient way. It can be chosen among Automatic-, Charging- and Climate-Mode. [19]

Figure 2.3.10 Fisker Karma solar roof[20]

<u>Companies selling solar roofs</u>

Systaic - http://www.systaic.de/systaic-en.html

Solar Electrical Vehicles - http://www.solarelectricalvehicles.com/

Sunrise solar - http://www.sunrisesolarcorp.com/

2.3.5 Concepts for the future

Phylla electric car

The Phylla a zero-emission car from Italy was unveiled and driven at the Turin Environmental Park. [21]

- Weight: 750kg (with 150kg battery weight)
- Range: 145km on li-ion or 220km on li-polymer
- Speed: 0-50km/h in 6 seconds, 130km/h maximum
- Frame: Split-frame, aluminium chassis
- Capacity: 2 persons, 584 litre luggage or 4 persons, 142 litres luggage
- Power source: plug-in or solar

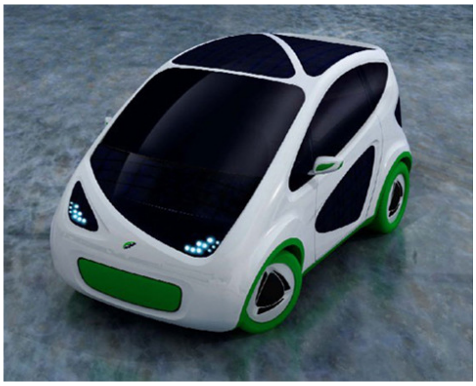

Figure 2.3.11 *The FIAT Phylla*

Other concepts:

Figure 2.3.12 *SEAT BIRSA* 2-seated solar powered sports cars and *Volvos* solar powered car for 2015 Dakar Rally

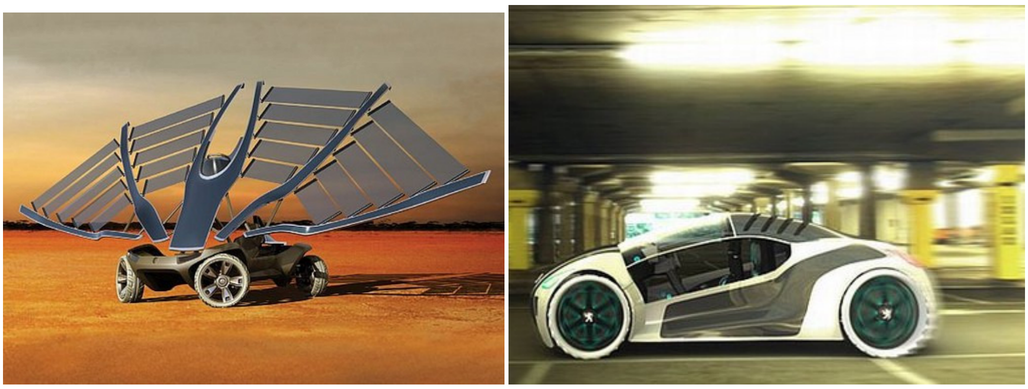

Figure 2.3.13 *Helios* solar-powered car can also power your house and *Peugeot* OMNI


Figure 2.3.14 *EVE* generates electricity from friction and solar panels and solar powered hauling *Felidae*

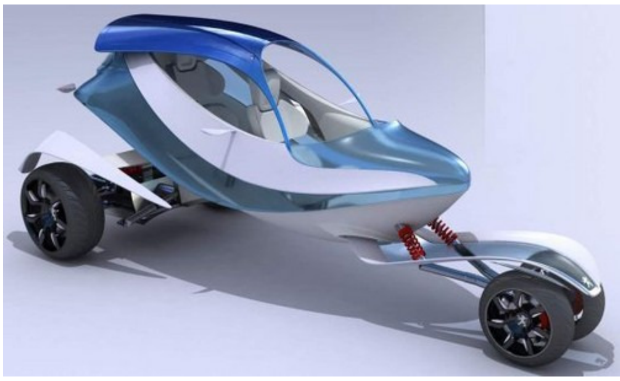


Figure 2.3.15 *Peugeot SHOO* and *VW* shows a cubic VAN running on solar-power

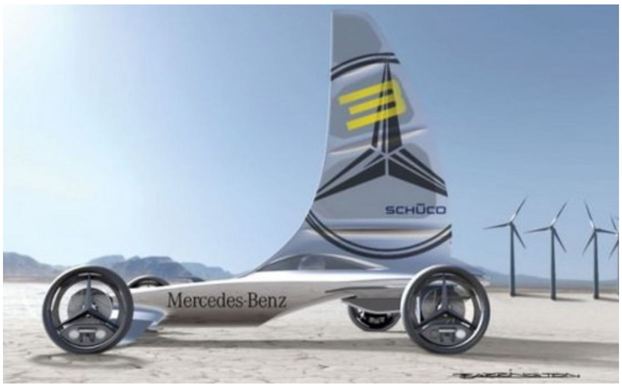

Figure 2.3.16 *Formula ZERO* – Mercedes' vision of the motorsport

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Chapter 3 Criteria explanation

As explained before, there are different kinds of materials used in solar panels. All of these materials have their own characteristics, which includes positive and negative aspects. The goal of the project is to find the best material for car usages. To determine which material suits best, aspects that are important has to be defined. This will be done by formulating criteria. In this chapter all 11 criteria will be shown and explained.

3.1 Efficiency: Efficiency is a parameter which says how much watts can be obtained on a square meter of a solar panel from the sun in 1000W/m^2 light intensity, which is presented in a percentage. Generally speaking, this parameter shows us how much sun power, which reaches the solar panel, is converted into electricity. This is one of the most important parameters; because it determines how much of material we need and how big surface we need to get the required value of current. Because a solution for using in cars is determined, the coverable surface is limited and therefore this criterion is highly valued.

3.2 Price: The price describes the monetary value of a material, production and sale of one unit of solar panel. This criterion is also quite important because Seat customers have to pay extra in order to have a solar panel on the roof and there is a maximum amount of money they are willing to spend. The value of one module needs to be affordable for each customer and if possible even have a return on investment in a reachable period. The price is listed in $/W or €/W.

3.3 Quote selling in market: The supplier market-information says how much suppliers and producers are in the market. More opportunities end up in better possibilities to negotiate about the price and conditions.

3.4 Availability of material: The availability of the material means how much of this material there is in the earth’s crust. It is necessary to know for development and investment if you invest in a technology which is not running out of sources in the future. If a material is rare it can have a bad influence on the price on the materials, which lead to a more expensive solar panel.

3.5 Functional conditions: The functional conditions of a solar panel consist out of two different performances. The first one is about the performance of the solar panel under different temperatures. The second one consists on the ability to convert diffused light into electricity.

A solar cells performance is depended on the temperature it has. The significant problem is that most solar cells lose performance at high temperatures. The power output of a solar panel decreases with the increase of the panel’s temperature. The listed power of a solar cell is the power measured under ideal laboratory conditions, which prescribes a temperature of 25 °C. However, on a typical hot summer day, it is not uncommon for a solar cell to reach a temperature of 75 °C. The efficiency of some cheap solar cells can decrease more than 0.5% for every 1 °C above 25 °C. This means that on a hot summer day, the efficiency of a solar cell could drop as much as 25%.

Another factor that determines the performance of a photovoltaic array is diffused sunlight. Climate conditions have a significant effect on the amount of solar energy received by a photovoltaic array and, in turn, its performance. Most modern modules are about 10% efficient in converting sunlight. Further research is being conducted to raise this efficiency to 20%

3.6 Safety: Safety is a criterion which says if a material is toxic, dangerous for humans or for the environment. This cannot be the case during normal usages, production, recycling or in extreme conditions like accidents. Therefore materials which are toxic or dangerous for humans when burst, burn or brake cannot be installed in a car. Another point is that some materials can be toxic for environment while producing or recycling. So far the regulations on this topic or not yet really strict, but in future it might occur that some kind of materials are not allowed to be used anymore, in terms of safety environmental protection.

3.7 Degradation: When a solar panel is sold, it is important that the lifetime is just as long or longer then the lifetime of a car. The current average lifetime of a car is about 10 years, but with improving technologies and the increasing interests in sustainability it is likely to increase in the future. Besides the total lifetime of a panel, the degradation it has during his lifetime is also important to know. Degradation means the decrease of efficiency per year in percentages. Most manufactures offer a guarantee of a certain amount of years with a power output more than 80 %

Solar panels require minimal general maintenance; however this varies depending on the climate you live in. While the panels are the main component of a solar energy system, other parts may need to be replaced. Fortunately the other materials are much lower in cost and easier to attain. These components, such as batteries, may only need to be replaced once every five to ten years.

3.8 Recycling: Because the resources of some materials are becoming rare and in order to prevent the environment from emissions, nowadays the governments put the accent on recycling. By recycling companies protect the environment, save money (because if the materials are rare, the price will increase) and save materials which will disappear if are not recovered.

3.9 Transparency: Transparency is a criterion which improves the possibility of applying photovoltaic on cars in different methods. A transparent solar panel can be applied on cars in some additional ways like a panoramic roof or in the windows and offers other opportunities for the design.

3.10 Flexibility: For a good usage it needs to be flexible, unbreakable or rigid. This is sometimes a problem for manufacturers because it is very hard to produce. If a material is not flexible, it can be very hard to implement it on a car without have any problems or take the design into account.

3.11 Thickness: Another point which is important for the design of a car is the thickness of the panel. For a good shape and the aerodynamics the panel cannot be too thick. And in general if a material is less thick, the flexibility will increase and with this the weight will decrease.

3.12 Advantages / disadvantages: At the end of each material a short summarize is given on the pros and cons of this material. Only the characteristics that stand out will be repeated.

Chapter 4 Evaluation

Now that the criteria were defined, an intensive research on the materials is necessary in order to find a suitable solution. For every material the same information is collected. Every material is rated in the same way and required information is taken from articles, papers, research institutes and other sources. In fact the data, which is acquirable online, contains state-of-the-art developments and latest information. Sources were compared to have secure information in order to have a document, which is up to date. In *Appendix A* the total research is given, all the information about the materials can be found here. In this chapter the most important properties, sorted under each criterion, are shown.

4.1 Efficiency

<u>Amorphous Silicon</u>
Efficiency of amorphous Silicon is 10% in laboratory and ranges between 6.6 and 7.1% in common production. A combination of a-Si and μc-Si has up to 9%.

<u>Crystalline Silicon</u>
Mono-crystalline Silicon is available with 14% in laboratory and 12% in production. Poly-crystalline Silicon reaches up to 20% and is sold with about 16% in modules. A combination out of mono-crystalline and amorphous Silicon is available with 17.4% under standard test conditions (SANYO HIT).

<u>Gallium Arsenide</u>
Gallium Arsenide has the highest efficiency of all materials with 28% in laboratory. While GaAs normally is just sold in Multijunction compounds, a commercial single-junction can have up to 25%.

<u>CIGS/CIS</u>
CIGS/CIS counts to the thin film technology with the best perspective for the future in performance and price. In laboratory is an efficiency of 19.9% already possible. CIGS on non-flexible glass substrate can have commercially 14% and flexible substrates like metal sheets or plastic are currently most of the time still in development while an efficiency of about 10 to 12% is expected.

<u>Cadmium Tellurium</u>
CdTe has already achieved efficiencies of 16.5% in laboratory and the sold modules with this material have and standard test conditions about 12.5%.

<u>Gratzel</u>
Gratzel can be implemented in glass or plastic. The glass-covered cells achieve an efficiency of 12.2% while a plastic covered array has just between 6 and 7 %.

4.2 Price

The price is taken from a page which compares current photovoltaic module offers to give an overview about the power-output and a price per Watt in Euro. While the prices are changing every day, the data is acquired at the 24th and 25th of May 2010. [1]

Amorphous Silicons
Amorphous Silicon is nowadays sold for about 1.36€/Watt (Nexpower - NH-100AX)

Crystalline Silicon
Mono-crystalline Silicon modules were sold for 1.37€/Watt (Chinalight CLS 270-P). Polycrystalline Silicon is available for 1.73 €/Watt (Solon P220/6+)

Gallium Arsenide
Gallium Arsenide is used only in specific applications and information about prices is just ranged and very rare. The SP-X array of "Spacequest" is available for 650$/Watt. Other sources give a range of 20-100$ per Watt.

CIGS/CIS
It was 2009 expected to reduce the cost of CIGS/CIS in 2010 to 1.4$/Watt. Currently a panel is available for around 2.12€/Watt (Avancis Powermax 100FB)

Cadmium Tellurium
CdTe panels are sold for 2.08€/Watt (Firstsolar FS275).

Gratzel
Peccell Technology offers glass-covered modules for 1$/Watt. 3G Solar provides Print-screen cells for 1.4$/Watt.

4.3 Quote Selling in the market

The six materials have a different sharing in the market nowadays. While the most common material is Silicon in mono- and polycrystalline execution thin film technologies raise in the share because of the perspective of low price.

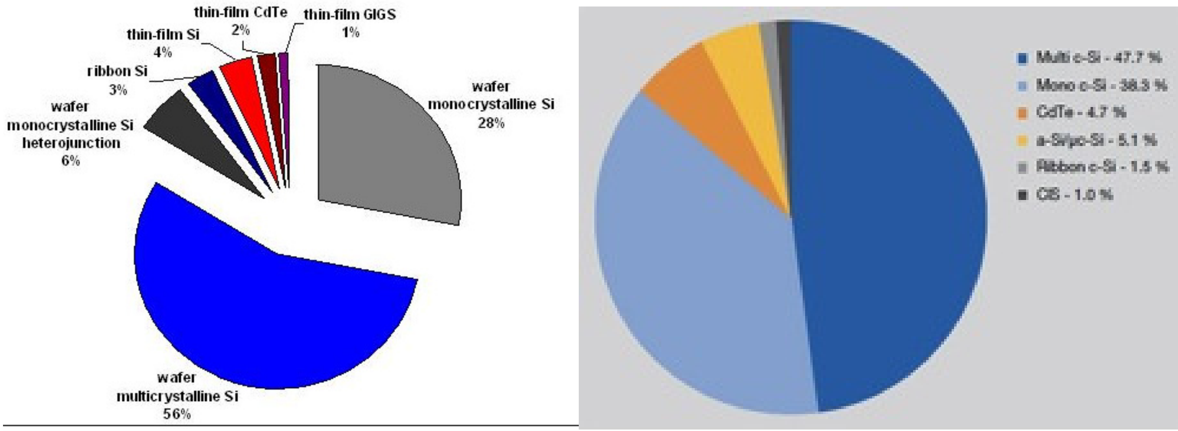


Figure 4.1 Market share of PV-materials 2005 [2] and 2008 [3]

The figure 4.1 shows the worldwide market share in 2005 compared to 2008. The crystalline Silicon is by far the most used material on solar cells. Polycrystalline wafer cover around 56% in 2005 and decrease to around 48% in 2008. Mono-crystalline had an amount of 28% in 2005 raising up to around 38%. Amorphous Silicon (4% - 2005; 5.1% - 2008) that counts next to Cadmium Tellurium (2% - 2005; 4,7% - 2008) and CIGS (1% - 2005; 1% - 2008) to the thin film materials got additional market shares in the last years. While the material costs and the energy used to produce the arrays are high parts of the total wafer price, technologies with less use of material and energy become more and more interesting. Gallium Arsenide is not in the Graph because of its very rarely use in space applications so far. Comparing the amount of produced solar panels in one year, this technology nowadays plays no role. GRATZEL cells need to be more stable and to have and improved efficiency. While this technique is still in development it also counts not in the market share so far.

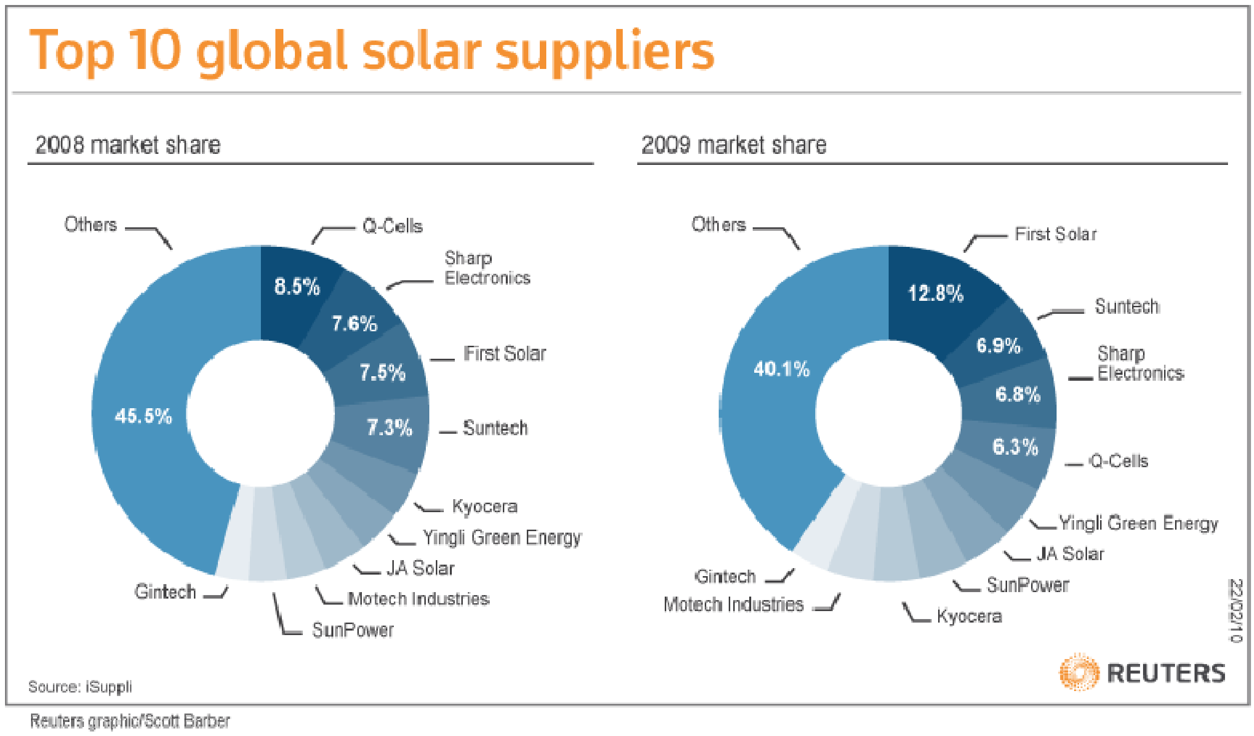


Figure 4.2 The Top 10 Solar-cell-suppliers in 2008 and in 2009 [4]

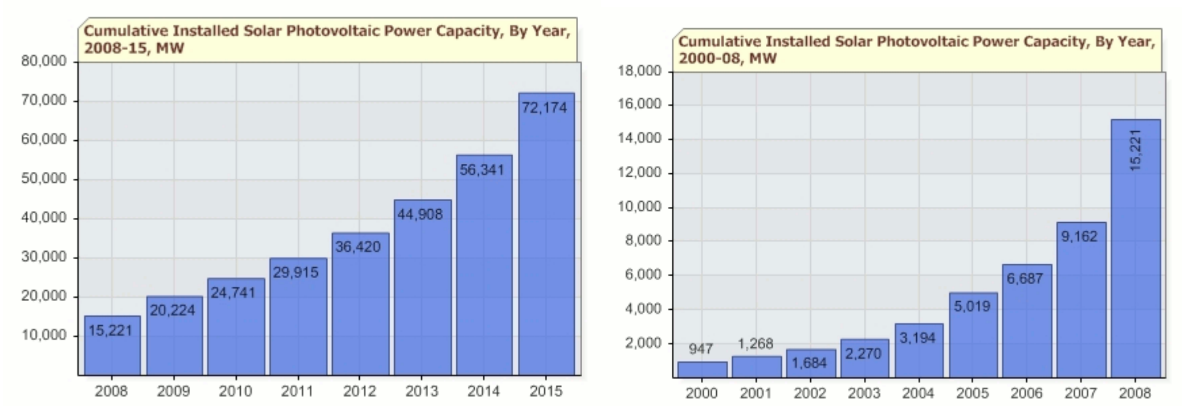


Figure 4.3 Market growth from 2000 to 2008 and expected growth from 2008 to 2015. [5]

Figure 4.2 gives an imagination about who supplies solar cells in 2008 and 2009. While the market and therefore the demand is growing every year what is shown in Figure 4.3, the expansion of the production capacity is an important factor to consolidate or extend the position of a company in the market.

4.4 Availability of the material

Silicon
Silicon is the 2nd most abundant element in the earth crust with about 28%.

Gallium
With an abundance of 19 parts per million by weight, the earth crust contains 11,35*10^21 kg Gallium.

Arsenide
With an abundance of 1.8 parts per million by weight, the earth crust contains 1,08*10^21 kg Arsenide.

Copper
With an abundance of 60 parts per million by weight, the earth crust contains 35,84*10^21 kg Arsenide.

Cadmium
With an abundance of 150 parts per million by weight, the earth crust contains 89,61*10^21 kg Arsenide.

Tellurium
With an abundance of 1 part per billion by weight, the earth crust contains 5,97*10^16 kg Tellurium.

Indium
With an abundance of 49 parts per billion by weight, the earth crust contains 26,27*10^17 kg Indium.

4.5 Functional Conditions

Amorphous Silicon
Amorphous Silicon cells work well under almost every condition including cloudy skyes and high very hot surrounding. The ability to capture diffused light make these panels competitive in the overall power output. Caused by the very low temperature coefficient, the cell loses less efficiency if the temperature is rising.

Crystalline Silicon
Crystalline Silicon has no specific functional conditions, which are outstanding compared to others. The efficiency decreases with increasing temperature. The reduction is about 0.5%/°C

Gallium Arsenide
Gallium Arsenide is highly resistant against the radiation influence that makes it predestined for the use in space applications. Furthermore the wide light capture bandwidth makes it loosing less efficiency in diffused light-conditions and with high temperature.

CIGS/CIS
CIGS/CIS is also loosing less efficiency compared to silicon within diffused light and with high temperature.

Cadmium Tellurium
Cadmium Tellurium has caused by its low temperature coefficient of -0.25%/°C as well as GaAs and CIGS less loss of efficiency under high temperatures.

Gratzel
Dye solar cells work in-between 20° and 60°C. To produce sunlight, there is no direct solar radiation necessary what makes this technology able to capture light much better during cloudy days. The angle of incidence of the sun is with 70° on both sides considerably larger than with other cell materials.

4.6 Safety

An issue, which has to be taken into account while using these technologies, is the fact that in terms of fragmentation the panel can be dangerous because of breaking materials.

Amorphous Silicon
Amorphous Silicon is completely harmless.

Crystalline Silicon
Crystalline Silicon is completely harmless.

Gallium Arsenide
Gallium Arsenide is completely harmless.

CIGS/CIS
CIGS/CIS is completely harmless.

Cadmium Tellurium
The big issue of using Cadmium Tellurium is in fact the toxicity of Cadmium for the human body in vaporized phase. To vaporize the solid Cadmium in solar cells, a temperature around 1050°C is necessary. In every other application where physically a contact is possible, law forbids Cadmium.

Gratzel
The safety of GRATZEL-cells has to be individually considered. Glass covered cells have a dye that potentially can cause harm because of the organic solvents used as the electrolyte solution. Plastic covered cells have no safety issues except the toxic gas, which arise while burning.

4.7 Degradation

Amorphous Silicon
Some companies give a guarantee on 90% efficiency over the first decade and 80% over 25years. [GS-Solar 43S]

Crystalline Silicon
Some companies give a guarantee on 90% efficiency over the first 12 and 80% over 25years. [Viessmann Vitovolt 220]

Gallium Arsenide
Gallium Arsenide is used in space because of its high resistance against radiation. The lifetime is often tested and is said to be over 30 years.

CIGS/CIS
Companies give a warranty of 25years to 80% of rated power. (Shurejo Energy SE-Series)

Cadmium Tellurium

Some companies give a guarantee on 90% efficiency over the first 12 and 80% over 25years. [FirstSolar FS 275]

Gratzel

This is next to the efficiency the big concern dye-solar-cells have. Lifetimes of cells are now between 10 years (SOLARONIX – printed on metal sheet) and 12 years (Panasonic Electric Works).

4.8 Recycling

Amorphous Silicon

Amorphous Silicon can be recycled through standard glass recovery/recycling.

Crystalline Silicon

Crystalline Silicon can be recycled through standard glass recovery/recycling.

Gallium Arsenide

Referring to the contact person of Azurspace, GaAs at all is recyclable.

CIGS/CIS

CIGS/CIS can be recycled to 99.5%.

Cadmium Tellurium

90% of the glass and 95% of the semiconductor can be recycled.

Gratzel

The organic dye photo sensitizers adsorbed on the electrode can be removed or detached by washing the electrode with alkali solutions or combustion, allowing recycling photo electrodes for DSSCs.

4.9 Transparency

Amorphous Silicon

Amorphous Silicon can be produced in a way to be semi-transparent.

Crystalline Silicon

Crystalline silicon is not transparent at all.

Gallium Arsenide

Gallium Arsenide is not transparent.

CIGS/CIS

CIGS/CIS is not transparent.

Cadmium Tellurium

CdTe is not transparent.

Gratzel

Gratzel is highly transparent.

4.10 Flexibility

Amorphous Silicon
Amorphous Silicon can be produced flexible and panels are available that can be curved to the bend in a roof.

Crystalline Silicon
Crystalline Silicon cannot be produced flexible.

Gallium Arsenide
In combination with for example Germanium-substrate in a triple junction cell, GaAs is flexible. Brittle substrates certainly do not allow flexibility

CIGS/CIS
CIGS/CIS can be produced flexible if flexible materials replace the glass substrate.

Cadmium Tellurium
CdTe can be flexible on metal sheets or polymer foils.

Gratzel
Gratzel is glass covered not flexible. Produced with plastic, flexibility is possible.

4.11 Thickness

Amorphous Silicon
In the latest achievement the cells are less than 2µm.

Crystalline Silicon
The wafers of crystalline Silicon have a thickness of 125micrometers after recent improvements of cutting.

Gallium Arsenide
The cell without substrate is about 10µm (Azurspace)

CIGS/CIS
The thickness of CIGS/CIS is between 1µm and 2.5µm

Cadmium Tellurium
The semiconductor thickness is around 1µm.

Gratzel
The efficiency of the cell increases linearly with thickness increases up to 15µm.

References:

[1] http://www.pro-umwelt.de/pvliste.php?orderby=Preis&sort=0

[2] http://www.energyresearch.nl/typo3temp/pics/927cdd1882.jpg

[3] http://www.delo.de/cont/screen/bilder/delo_news/2009_09_cn_solar_market-shares.jpg

[4] http://graphics.thomsonreuters.com/0210/GLB_SLRSP0210.gif

[5] http://www.greenchipstocks.com/report/investing-in-next-generation-solar-power-technologies

Chapter 5 Rating

Finally to smaller the circle of possibilities we rated the different materials in certain aspects. The criteria should reflect the interests of an automotive company why they would apply a technology and what is the most important fact for the decision related to it.

		a-Si		Crystalline Silicon				GaAs		CIGS		CdTe		GRATZEL			
				mono. Si		poly. Si								Glass		Plastic	
Efficiency	5	8%	1	16%	3	14%	3	30%	5	14%	3	12,5%	2	12%	2	7%	1
Price	5	1,5-3$/Watt	3	1,2-2,0$/Watt	4	1,2-2,0$/Watt	4	100$/Watt	1	1,5-2,5$/Watt	3	1$/Watt	5	4$/Watt	2	1$/Watt	5
Safety	5	++	5	++	5	++	5	++	5	(Cd: -) (TCO:++	5	-	2	-	2	++	5
Supplier-market	3	++	5	++	5	++	5	-	2	++	5	+	4	-	2	-	2
Availability	3	++	5	++	5	++	5	0	3	-	2	-	2	++	5	++	5
Funct. cond. / Resistancy	4	+	4	0	3	0	3	+	4	+	4	++	5	+	4	+	4
Lifetime / Degradation	2	25+years	5	25+years	5	25+years	5	30+years	5	25+years	5	25+years	5	12years	3	2+years	1
Recycling	4	+	4	++	5	++	5	0	3	0	3	+	4	+	4	-	2
Transparency	1	0	3	--	1	--	1	-	2	-	2	--	1	++	5	++	5
Flexibility	4	+	4	--	1	--	1	0	3	+	4	0	3	--	1	++	5
Thickness / Weight	1	+	4	--	1	--	1	+	4	++	5	++	5	0	3	+	4
			140		138		138		130		144		127		110		128

- Table 5.1 (Rating Matrix)

- **The criteria**: In the left side of the table each criteria is written. Next to them, different numbers counting from 1 to 5 indicate the importance of each criterion.
- **The materials**: The materials are in the head of the table. Under each material their characteristics are shown. Because some criteria cannot be expressed in units they are ranked. This ranking goes from [**--** / - / 0 / + / ++] with (--) as the lowest and (++) as the highest score.
- **The score**: In the vertical rows next to the characteristics, the score each material has on a certain criterion is given. This score is based on comparison with the other material and ranked from 1 to 5. For each criterion the material with the worst performance gets a 1 and with the best performance a 5.
- **The result**: The bottom of the table display's the total result for each material. The importance of each criterion is multiplied by the score. After that everything is summed up giving the result for each material.

As shown in table 5.1, CIGS was rewarded with the most point, 144 in total, followed by amorphous Silicon with 140 and crystalline Silicon with 138 points.

5.1 Summarise

The three materials with the highest score have to be more precise determined. The further evaluation has to be made between CIGS, amorphous and crystalline silicon. The materials were so far assessed by quantitative and qualitative criteria. The importance of a single criterion plays a key role in the rating matrix in graphic 5.1. The ranking is based on the gathered information. Regarding the main aim to reach 100W the efficiency criterion is not significant for a decision referring to the available surface. Further choice has to take many more essentially less important points into account as there are: price, recycling, safety, efficiency and other criteria, which are especially important for SEAT, the customers and the environment.

Silicon solar cells are currently the most popular type of solar material. There are different types of silicon that are used for the making of PV cells. Silicon is expensive to process as for mass production. The highest price has to be paid for mon 1ocrystalline silicon, followed by polycrystalline silicon, and concluded by amorphous thin-film silicon. Amorphous silicon is attractive because the production of electricity is cheaper than conventional silicon solar cells. Nevertheless amorphous silicon produces less electricity per square meter then conventional silicon solar cells, which means that a bigger surface has to be used in order to achieve the same power.

The costs of CIGS solar cells are currently higher then amorphous silicon solar cells but further prospects show great cost decline, which would make CIGS the cheapest solar material. The problem with these materials is that they are less efficient in converting the sun's rays to electricity. Amorphous is not inefficient but a significant part of the output power is left unprotected against the sun. CIGS is a quite new technology and therefore needs a lot more research and development.

Next to the price and efficiency other material characteristics made play a decision playing roll in choosing the final material. In the following chapters the consequences of all these positive and negative characteristics will be evaluated. In order to find out which material suites the best the materials have to be further explored.

Two different technologies will be explored for further research. The first one is the SANYO HIT panel, which is a combination of different kinds of Silicon. This panel makes use of the different aspects; it has the efficiency of crystalline silicon and wide light adsorption range of amorphous silicon. The second technology is CIGS. These two technologies will be compared and weighted against each other.

In table 5.1 the costs of these three material are shown:

	Crystalline Silicon % 16	Amorphous Silicon %8	CIGS %14
Cost of Solar Cell Material	0.4	0.11	0.13
Cost of Solar Labor	0.4	0.07	0.08
Cost of Module Material	0.25	0.37	0.17
Cost of Module Labor	0.5	0.07	0.08
Indirect Material	0.2	0.16	0.05
Energy Cost	0.3	0.06	0.04
Equipment Amortization	0.4	0.15	0.12
Manufacturing Overhead	0.1	0.1	0.06
Total Manufacturing Cost	2.55	1.09	0.73
Corporate Overhead(%30)	0.77	0.4	0.22
Total Cost	3.22	1.42	0.95
%50 profit margin	1.66	0.71	0.47
Selling Price	4.99	2.13	1.42

Table 5.1: The Cost of Material [1]

Technology	Commercial Efficiency	Advantages	Disadvantages
a-Si	8%	• Mature manufacturing technology	• Low efficiency
CIGS	14%	• High efficiency • Glass or flexible substrates	• Costly traditional processes
Crystalline Silcon	16%	• Recycling • High efficiency	• Non flexible • Thickness

Table 5.2 Advantages and disadvantages of these technologies.

Table 5.2 shows advantages and disadvantaged of the 3 materials used as single junction. Combined in a multijunction array as for example SANYOs HIT-panel , the properties can complement each other.

Chapter 6 Theoretical testing of Photovoltaic panels

Introduction

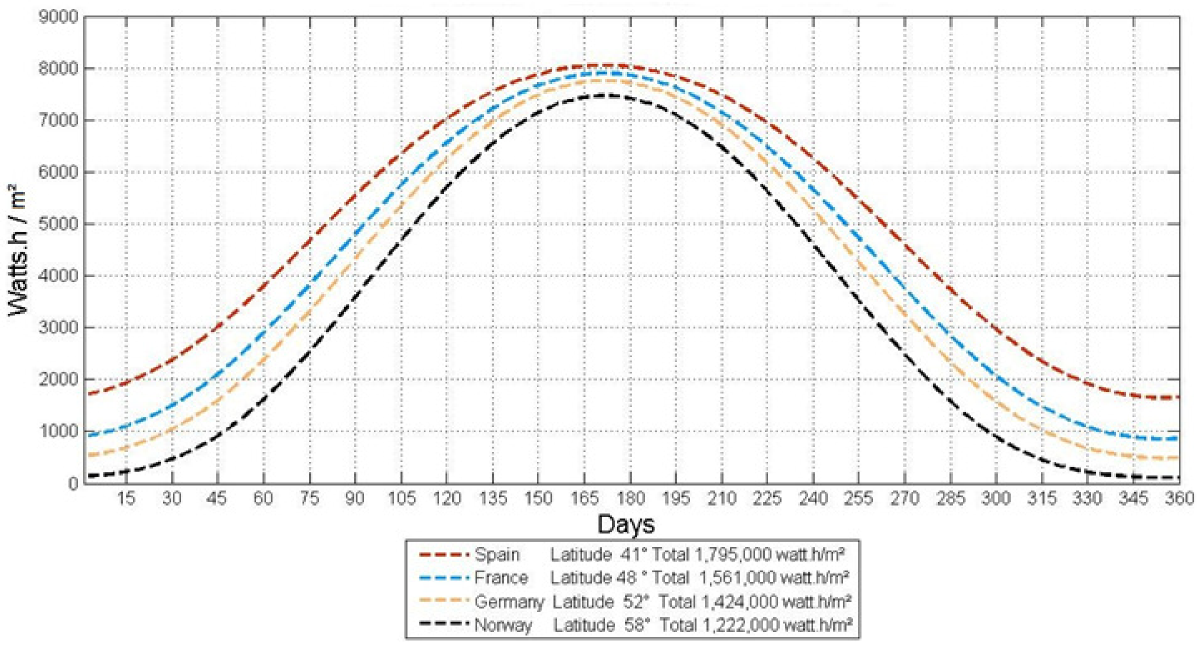
The aim of the calculation part is to inform about solar panel to assess the applicability under various conditions for four countries, which are: Spain, France, Germany, and Norway. Solar panels are photovoltaic devices able to produce power from sunlight. The most important criteria is the solar radiation for calculate the power we can get from the sun.

The about power generated by solar panels is transmitted to car's devices like air condition, radio etc. or a battery for storage. The calculation is based on a horizontal application on a car roof for the limited surface of 1,7m^2.

The amount of sunlight received by any surface on earth will depend on several factors including; geographical location, temperature, weather, etc. Also, some data from companies will help us to determine real energy.

6.1 Solar radiation

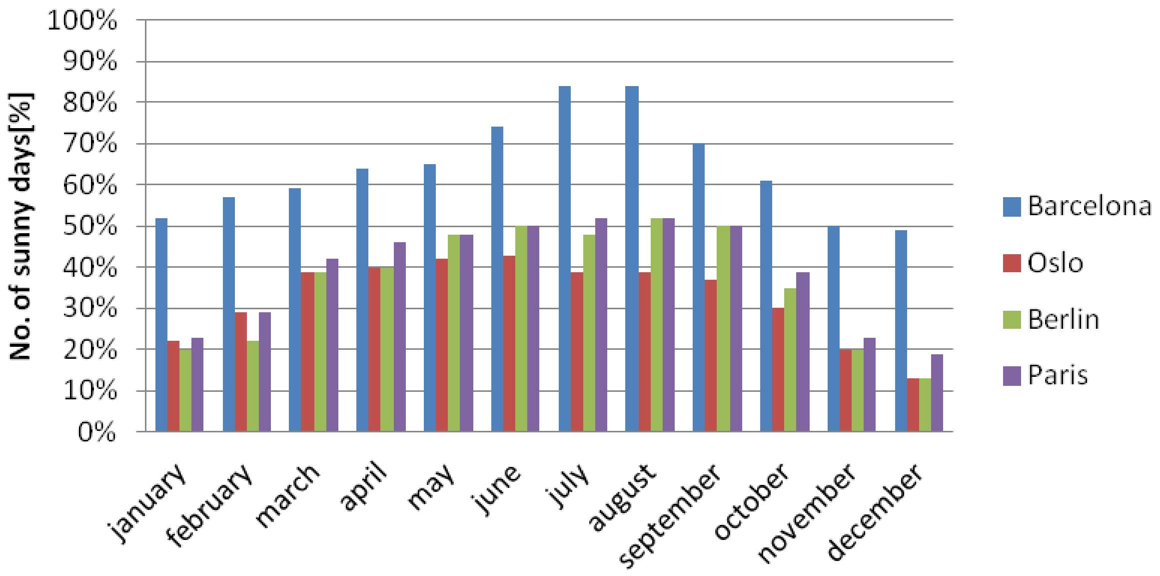
The extraterrestrial solar irradiation is 1367 W/m^2. Some factors can minimize this value. Therefore, is said that the surface of the earth receives about ***1000 W***/m^2 from the sun. In Graphic 1 the lattitude factor makes a difference of power received between the different chosen countries. In addition, the total amount of sunlight received by any surface on earth will depend on some factors like: geographical location, time of the day, season, local landscape and local weather. [1]



Graphic 6.1 Total amount of energy for Spain (Barcelona), France (Paris), Germany (Berlin), Norway (Oslo) [2]

The best condition to produce electrical power is under sunny weather, as under scattered or diffused light the solar panel will produce in some cases the half. However, PV systems can generate energy even though the sun is not direct on their surfaces.

In Graphic 6.2 the amount of yearly sunny days per each chosen country was transformed to a percentage. As the information taken from web sites shows only the number of sunny hours, an average result is needed to determinate other coefficients. The data included in table 6.1 has an average amount related to (*http://www.climatetemp.info/europe.html, Europe weather database)* web site.



Graphic 6.2 Number of sunny days in chosen countries [%] [3]

With shorter daylight hours in winter, solar panels produce commensurate less power. If the modules become covered with snow, solar radiation will be stopped. Another problem is how to capture the solar radiation effectively. Developers are working to improve the performance of Photovoltaic Cells, and as different technologies used in the manufacture of photovoltaic cells are improving in different areas, it is likely that the performance under lower light levels will improve significantly in a near future.

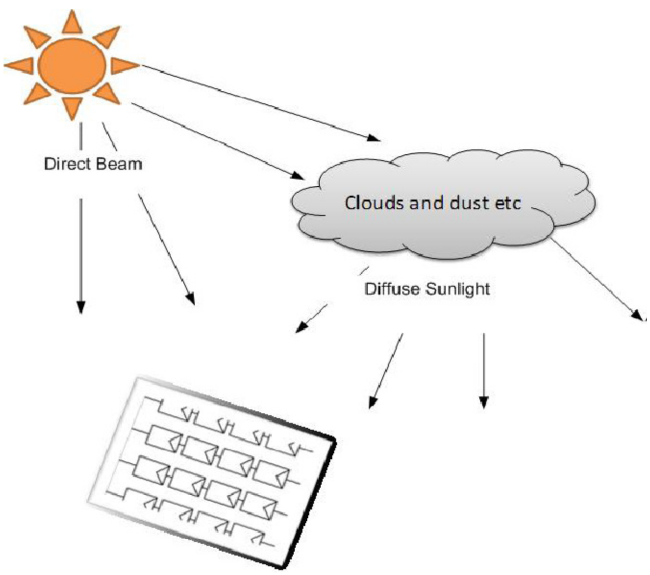


Figure 6.2 Types of radiation [1]

Beam radiation is the solar radiation propagating along the line joining the receiving surface and the Sun. It is also referred to as direct radiation.

Diffuse radiation is the solar radiation scattered by aerosols, dust and molecules. It does not have any unique direction. [4]

On cloudy days solar panels will still do their job but not at full intensiveness as they would on bright, sunny days. During those days it is possible to use power that was stored in batteries on brighter days if there is extra voltage that wasn't used by the car. Solar chargers can still work on cloudy days, but it just takes them much longer to charge up. They're definitely most useful to have if you live in an area where it's sunny a lot of the time. The current output of the solar panel is based commonly on the available sun rays. The batteries found in the vehicle stores excess solar power, so this power can be used when solar power is not available on demand like on cloudy days and in nighttime. [5]

Severe clouds will interrupt the power production. The level of covering clouds is the principal factor that determines the energy yield on the ground. Insolation on a clear day can be up to 10 times higher than on a cloudy day. Shown in table 6.1, divided the total amount of solar irradiation per clear sky and cloudy sky rates for each chosen country on 1.7 m^2 surface area.

Having a total amount of solar radiation per month and knowing how many days are cloudy and how many days are sunny, cloudy days will have a coefficient equal to 0,5 of the total amount of electrical power. This can only be made transforming the solar radiation in electric power with solar panel efficiency. [Reference: Table 6.2].

Barcelona, Spain	**Total amount of solar irradiation [Wh/m^2]**		**Total amount of electric energy for 1.7 m^2 [Wh/month]**	
	Clear sky	***With clouds***	***CIGS***	***HIT***
January	30.936	14.278	8.301	13.374
February	53.769	20.282	13.597	21.905
March	85.456	29.693	21.141	34.061
April	125.564	35.315	29.538	47.588
May	151.266	40.726	35.250	56.790
June	183.700	32.272	39.653	63.884
July	203.230	19.356	40.866	65.841
August	180.101	17.153	36.217	58.349
September	118.157	25.320	26.343	42.441
October	70.904	22.667	17.180	27.678
November	39.456	19.729	10.866	17.507
December	26.200	13.635	7.315	11.783

Table 6.1. Total amount of energy independent of temperature but dependent of solar radiation for 1.7 m^2 in Spain

6.2 Standard test condition

Standard test conditions are regular conditions that show the performance comparison made between photovoltaic cells and panels/modules. The main input data used in the planning process is the solar radiation. The total daily irradiation [Wh/m^2] is computed by the integration of the irradiance values [W/m^2] calculated at regular time intervals over the day. The solar power industry has agreed a set of standard test conditions to rate the output power of PV solar panels. In fact, it has chosen the landmark of 1000 W/m^2 as the standard illumination level for measuring and quoting a solar panel's power output.

The electrical power produced by a panel when it is emblazed by 1 kW/m^2 of solar radiation is called the "maximum output power" of the panel. Peak power is the maximum sustained power output of the panel, assuming a level of insolation of one kilowatt per square meter. PV modules are rated by their total power output. The peak power is the amount of power output a PV module produces at Standard test conditions (STC) of a module operating temperature of 25 degrees Celsius in full sunshine (irradiance) of 1000 watts per square meter. This is a clear summer day with sun approximately overhead and the cells faced directly towards the sun. [6]

The results of this test are provided on the manufacturer's datasheet. Measurements are performed under these standard conditions and the electrical characteristics obtained characterize the module accurately under these conditions. The conditions are specified as follows:

- Incident solar radiation (I_t= 1000W/m^2)
- Cell temperature for performance rating (T=25°C)
- Light spectral distribution with an air mass (AM=1.5)

Companies provide, also, performance data under Nominal Operating Cell Temperature. However, to determine temperature of cell/panel we gone follow next equation:

$$T_{cell} = T_{ambient} + \frac{NOCT - 20}{800} \cdot I_t$$

I_t- Incident solar radiation (W/m^2)
NOCT (Nominal Operating Cell Temperature) for these parameters:

- Irradiance on cell surface is 800 W/m^2
- The ambient temperature is 20 °C.

$T_{ambient}$-is ambient temperature (°C)
NOCT is a parameter provided in datasheet by companies which sell photovoltaic cells/panels. [10]

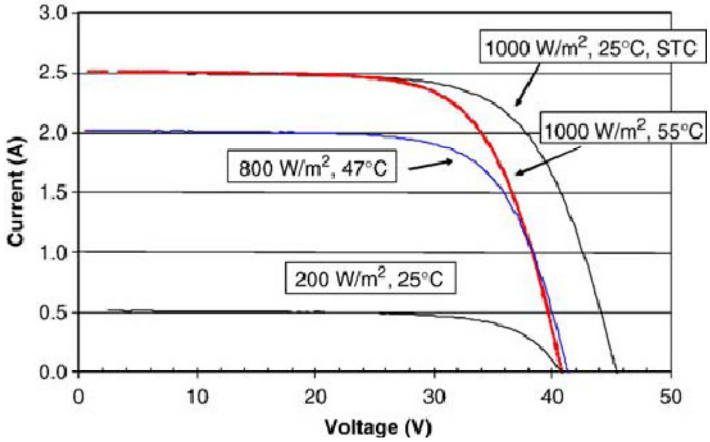
Wp means peak Watts. In other words, a 100Wp panel will produce a maximum of 100W in peak conditions (1kW/m^2 solar irradiation)

W/m^2: It calculates values of selected components (beam, diffuse and reflected) of solar irradiance.

Wh/m^2: The values of daily sum of solar irradiation [Wh/m^2] and duration of the beam irradiation [minutes] are computed as integration of irradiance values that are calculated in a selected time step from sunrise to sunset.

6.3 Impact weather conditions

Ideal it works, for high efficiency, at luminous intensity: 1000 W/m^2 panel area, the temperature of photovoltaic cell must be constantly (25°C) and light spectrum for AM 1,5 global.

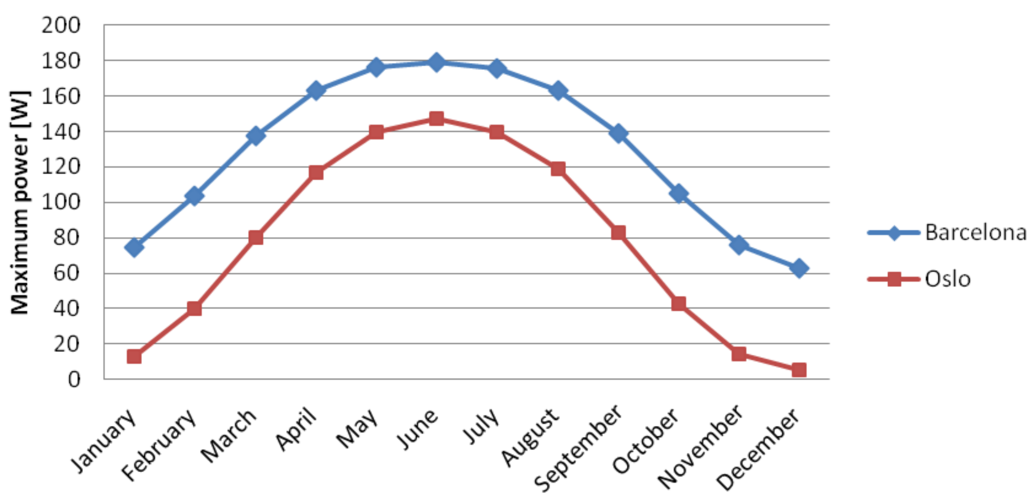


Graphic 6.3 Characteristics of a typical Würth Solar module at realistic illumination/temperature conditions [7]

Graphic 6.3 shows that the module has a lower open-circuit voltage at higher temperatures, but the current remain at the same level and the curve maintains a good shape. The curve measured at 200 W/m^2 and 25 °C in Graphic 6.3 represents cloudy sky at lower temperatures. At one-fifth of the irradiance, the module still produces one-fifth of the current. It is quite clear that irradiance has a major effect on the short circuit current and indeed the relationship between irradiance and the short circuit current is a linear one. Due to the lower temperature, the open-circuit voltage is at the same 40 V as for a sunny day. The curve at 800 W/m^2 and 47 °C gives reasonable intermediate results. This relationship is clearly depicted in this figure where the current is plotted as a function of voltage for 4 different temperatures. [7]

6.3.1 Power variation with irradiance

Graphic 6.4 show the worst case and the best case to determine the best choice for appliance. In this case the efficiency for CIGS is 10, 8 % and for HIT is 17, 4 %. Information about other countries and materials is in the *Appendix* of Table B-1.



Graphic 6.4 Maximum power for CIGS in worst and best case

To show the effect of irradiance on the performance of a module the temperature is kept fixed at 25 °C and the values of irradiance are changed to different values.

“The table 6.2 below demonstrates the percent of sun energy available to be absorbed by solar cells during different daytime weather conditions. The pictures are examples of some of the types of skies for selected weather conditions noted in the Table 6.2.”[8]

Clear and sunny	Misty	Partly cloudy	Mostly cloudy	Overcast	Severely overcast
≈ 90 to 115	≈85 to 100	≈60 to 120*	≈30 to 100	≈20 to 60	≈10 to 40
A		**B**	**C**		**D**
	* Reflection off nearby clouds can enhance module performance				

Table 6.2 Typical percentage of sunlight [8]

A B C D

Figure 6.3 Types of clouds [8]

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{max} \cdot V_{max}}{\text{Incident solar radiation} * \text{Area of solar cell}} = \frac{V_{oc} \cdot I_{sc} \cdot FF}{I(t) \cdot A_c} \quad [1]$$

η is panel efficiency

η=10,8 % for CIGS

η=17,4 % for HIT

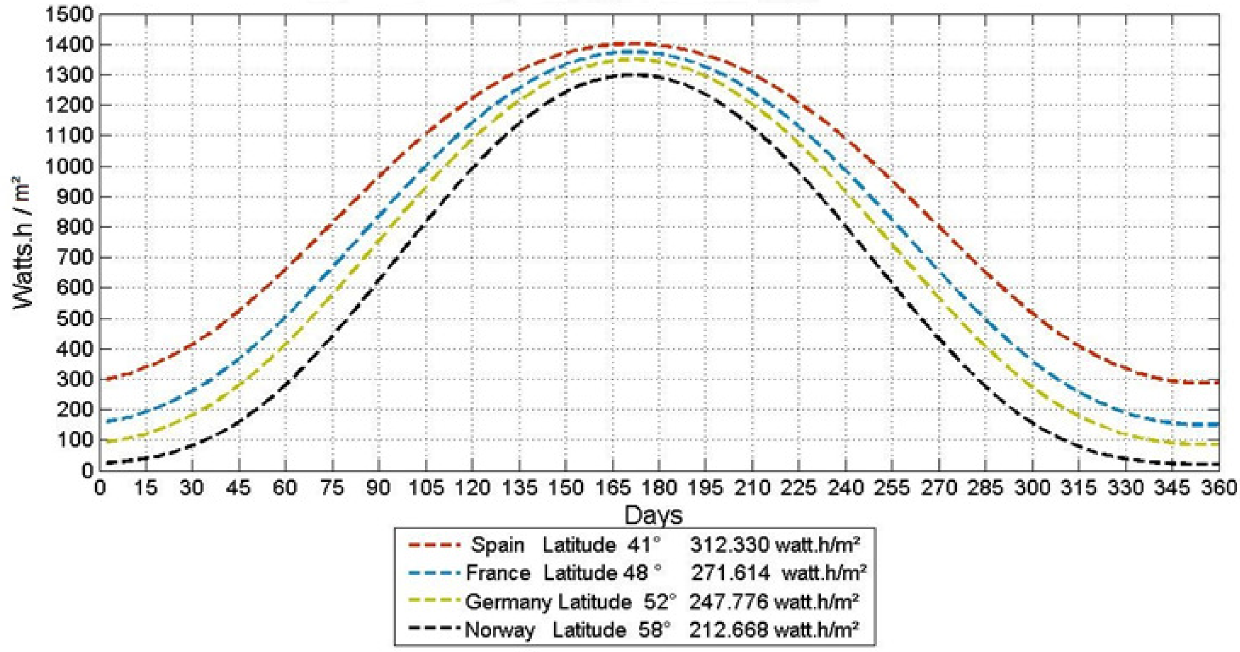
Pmax is maximum power

I(t) is solar irradiation [W/m^2], and this depend of latitude which is located each country.

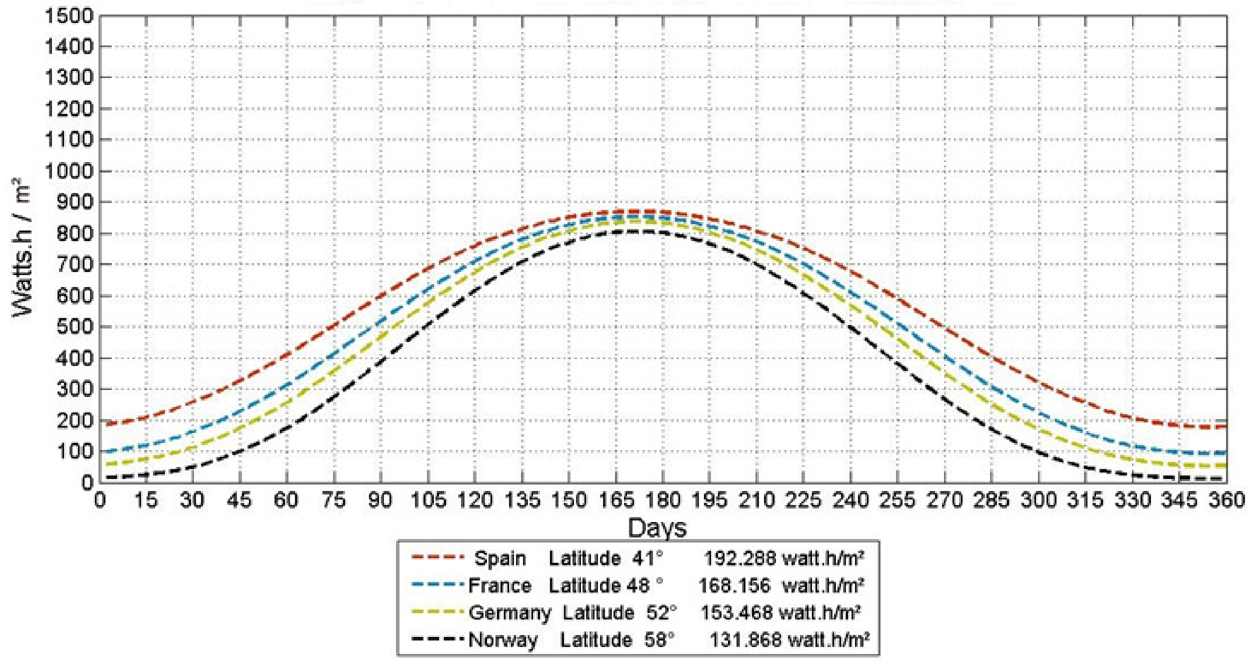
Ac=1,7 m^2

Solar irradiation and total amount of solar irradiation was calculated with RadCalc function from Matlab. The other numbers was calculated using adequate equations.

Graphic 6.5 belong to the HIT panel and Graphic 6.6 belongs to CIGS. Both, show total amount of produced power for each chosen country.



Graphic 6.5 Total amount of electric energy per year, for HIT [2]



Graphic 6.6 Total amount of electric energy per year, for CIGS [2]

In table 6.3, the obtained data of peak power for both modules (CIGS and HIT) for 1.7 m^2 area and the total amount of average solar irradiation [Wh/m^2] per months, calculated with Matlab. In addition, total amount of solar irradiation is a measure of the rate of total incoming solar energy (both direct and diffuse) on a horizontal plane at the Earth's surface.

Barcelona, Spain						
	Maximum power [W/1,7 m^2]		Solar irradiation [W/m^2]	Total amount of solar irradiation [Wh/m^2]	Total amount of electric energy [Wh/1,7 m^2]	
	CIGS	***HIT***			***CIGS***	***HIT***
January	74,24	119,63	404,43*	59.493*	10.923	17.598
February	103,43	166,63	563,36	94.332	17.320	27.904
March	137,56	221,65	749,29	144.842	26.593	42.845
April	163,27	263,06	889,29	196.194	36.021	58.035
May	176,12	283,76	959,29	232.718	42.728	68.838
June	179,27	288,83	976,43	248.244	45.577	73.430
July	175,73	283,12	957,14	241.941	44.421	72.131
August	163,27	263,06	889,29	214.407	39.365	63.430
September	138,75	223,53	755,71	168.797	30.991	49.931
October	105,23	169,541	573,14	116.237	21.342	34.383
November	75,70	121,96	412,28	78.913	14.489	23.639
December	62,49	100,67	340,36	53.470	9.818	15.817
			*-[2] Matlab			

Table 6.3 Ideal parameter for Spain

6.3.2 Power variation with temperature

The research shows different temperatures for the four chosen countries that will affect the power. Applying the equation (2), the result of the cell temperature is given. If the cell temperature is bigger than 25 °C, the power will decrease in a percent. Also, if the cell temperature is smaller than 25 °C, the power will increase in a percent too.

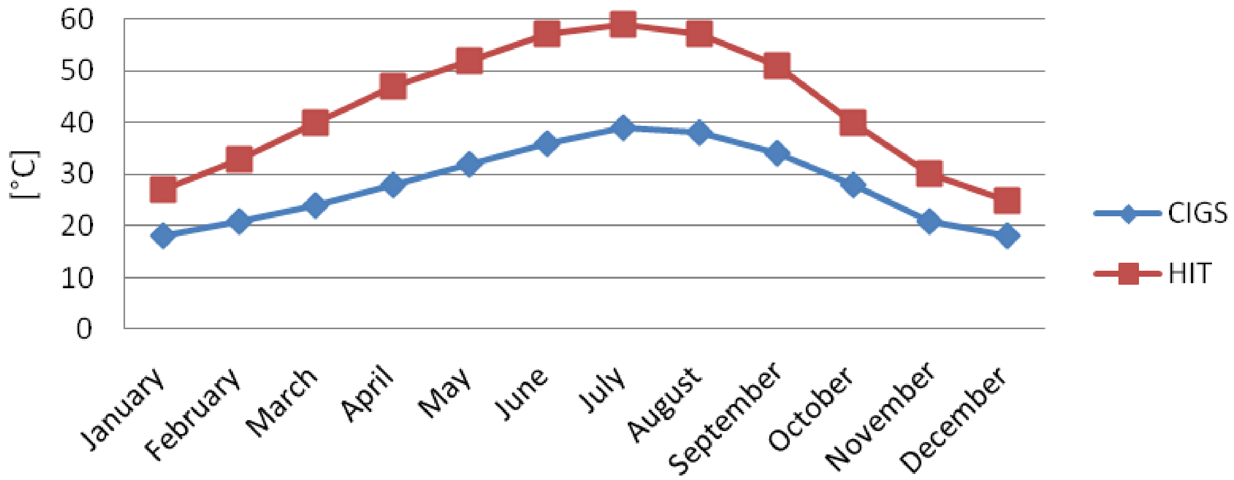
Temperature Coefficient of P_{max}, γ=-0.3 [%/°C] for HIT
Temperature Coefficient of P_{max}, γ=-0.59[%/°C] for CIGS
These temperature coefficient are taken from material datasheet provide by companies.

	T_{cell} [°C]							
	Paris		Oslo		Berlin		Barcelona	
	HIT	***CIGS***	***HIT***	***CIGS***	***HIT***	***CIGS***	***HIT***	***CIGS***
January	15	9	0,36	-1	8	4	27	18
February	22	12	6	2	16	8	33	21
March	36	19	19	9	27	15	40	24
April	42	24	29	16	38	22	47	28
May	48	29	41	24	48	30	52	32
June	52	33	47	30	52	33	57	36
July	54	35	47	31	52	34	59	39
August	50	33	42	28	42	32	57	38
September	42	28	29	20	39	26	51	34
October	31	22	17	12	25	18	40	28
November	19	13	6	4	14	10	30	21
December	14	10	1	0	7	5	25	18

Table 6.4 Temperature of panels for some countries

$$T_{cell} = T_{ambient} + \frac{NOCT-20}{800} \cdot I_t \qquad [2]$$

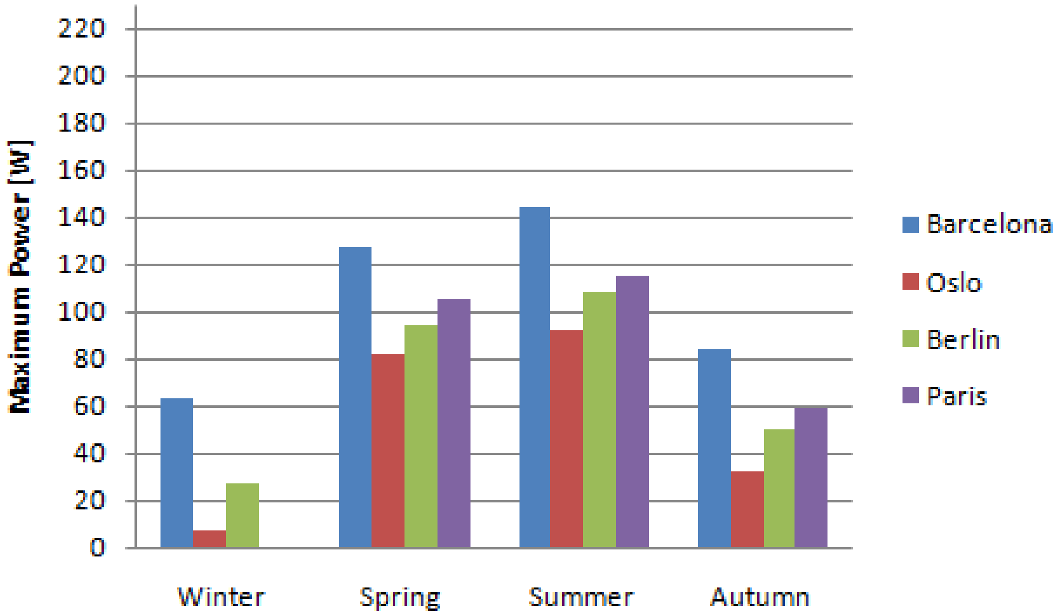
Data from Graphic 6.7 belongs to one country for the two materials. The temperature of the cell will depend on the solar irradiation and the more important NOCT. This parameter will be provided in the data sheet of the material by companies whom produce them (HIT (Heterojunction with Intrinsic Thin layer) have a NOCT coefficient of 47 [°C] and CIGS only 30 [°C]). The difference between these two materials will be considerable. $T_{ambient}$ is an average temperature for each chosen country, and I (t) is solar irradiation.



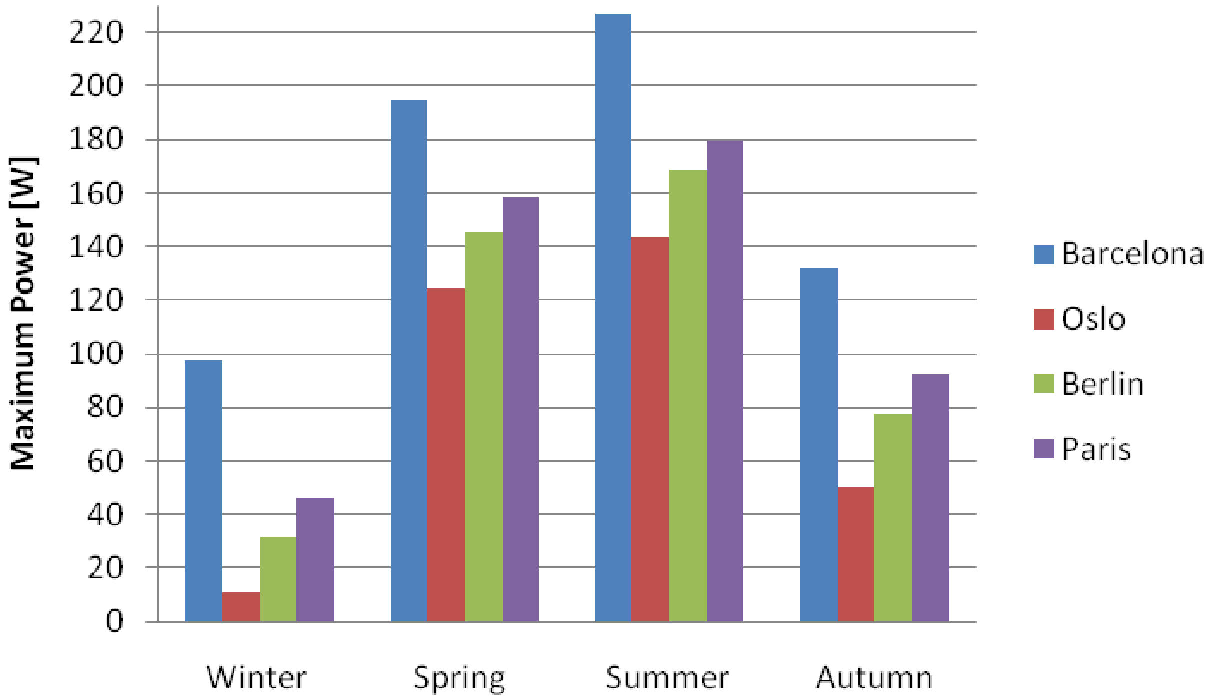
Graphic 6.7 Cell temperature per month in Barcelona

6.4.3 Variation of characteristics with temperature and solar radiation

The photovoltaic module's performance will increase significantly with solar radiation, but on the other hand the temperature can decrease it. If temperature increases, the power will have a significant reduction. This relationship is clearly depicted in Graphic 6.8 where the power is plotted as a function depending on different temperature and solar irradiation in chosen countries, and in Table 6.5 where the values are stated.



Graphic 6.8 Average of maximum power for 1.7 m^2 of CIGS per season.



Graphic 6.9 Average of maximum power for 1.7 m^2 of HIT per season.

The accessible solar radiation (Watt/m²) may vary significantly depending on local weather conditions and season. The sun is higher in the sky during summer and lower in the sky as winter approaches. The performance of the PV module depends on the temperature and on the solar irradiance. It is estimated that there will be a loss due to temperature and irradiance effects. In addition, it is possible to increase the irradiance above 100 W/1.7m^2 using some techniques to concentrate the sunlight on the cells for all months. Besides, the whole module will become hotter and extra cooling is needed.

		Maximum Power[W]			
		Barcelona	**Oslo**	**Berlin**	**Paris**
Winter	***CIGS***	63,43	7,23	27,46	30,18
	HIT	97,68	11,19	31,70	46,08
Spring	***CIGS***	126,94	82,28	94,40	105,58
	HIT	194,97	124,58	145,77	158,35
Summer	***CIGS***	144,28	92,28	108,38	114,99
	HIT	226,62	143,26	168,45	179,43
Autumn	***CIGS***	84,33	32,39	50,46	59,35
	HIT	131,87	50,26	77,59	92,12

Table 6.5 Average of power per season

6.4 Conclusion

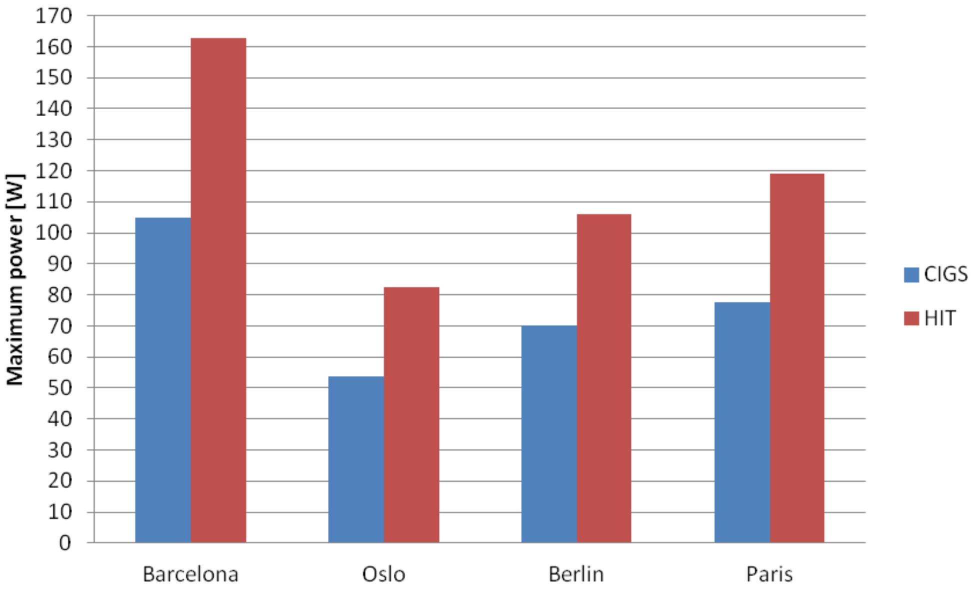
Converting sunlight into electricity on site has become an attractive investment for car companies looking to reduce utility costs. We provided the information and tools for SEAT to have a successful experience going solar, including a review of successful solar panel projects and materials.

Any future work in this field should take into account the use of solar cells and which one provides more power under all types of weather conditions. Since the output power of such cells is increasing, the solar car performance is expected to improve accordingly. In addition, environmental considerations are propulsating the solar electric power production in many developed countries nowadays. As a car company, SEAT should take their place in this field.

Even though is not possible to get as much power as 100 watts in all weather conditions, it doesn't mean that solar power isn't useful for an automotive use. For a future investment in different countries, the solar radiation, weather condition etc. should be taking into account.

		Barcelona	**Oslo**	**Berlin**	**Paris**
Average power per year [W]	***CIGS***	104,7467	53,54333	70,17583	77,525
	HIT	162,785	82,3225	105,8792	118,9942

Table 6.6 Average power per year



Graphic 6.10 Average power per year

Graphic 6.10 show that an average energy output of 100 Watts or more for CIGS is only obtainable in Barcelona. In other countries this value is minor. Even though the HIT technology (a material with higher efficiency than CIGS) is capable to obtain more power than 100W, the same problem will be found in the Norway (Oslo) latitudes.

References

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[2][Matlab]

[3] www.climatetemp.info/europe.html, Europe weather database

[4] Fundamentals of Photovoltaic Modules and Their Applications, N. Tiwari and Swapnil Dubey Centre for Energy Studies, Indian Institute of Technology (IIT) Delhi, New Delhi, India, 2010

[5] www.thinksolarenergy.net/121/solar-power-in-cars/solar-energy-solar-system/

[6] www.pvemployment.org/pv-basics/glossary.html

[7] CONFERENCE RECORD OF THE THIRTY-FIRST IEEE PHOTOVOLTAIC SPECIALISTS CONFERENCE-2005, CORONADO SPRINGS RESORT LAKE BUENA VISTA **[**www.ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F9889%2F31426%2F01488102.pdf%3Farnumber%3D1488102&authDecision=-203]

[8]www.globalsolar.com/en/products/portable-solar-chargers/tactical-operations

Chapter 7 Technical viability

Introduction

What is CAD?

CATIA V5 is a well-known Computer-Aided-Design program of the French company Dassault systèms. A so-called CAD system is used to help in the construction process with three-dimensional models and two-dimensional technical drawings.

What is CATIA?

CATIA was first developed for aircraft manufacturing and is nowadays established in different industries. The range-of functions CATIA brings with, includes not only the construction via drafts and drawings but also additional modules for Digital-Mock-Up-Investigation, Kinematic- and Finite-Element-Method-calculation and Numerical Control-programming. CATIA V6R2010x is latest version of this software.

Why did we choose this software?

As an often-utilized software in different parts of the industry, many automotive companies and their supplier use CATIA as standard CAD-system. The advantages are the functionality, design flexibility and the vast size of the overall package. The powerful generative-shape-design- and imagine & shape-surface are some of the advantages compared to other CAD software and they go beyond the borders of two-dimensional drafts extruded to volumes.

7.1 Technical design in CATIAV5

This part of the project was to design a prototype of Solar panel on the roof of SEAT Leon car. The company gave a detailed model of a car made in CATIA program. As we can see in the picture (Figure 7.1) the model does not contain all parts of car however, only the part off the roof is needed to edit and add our own solution.

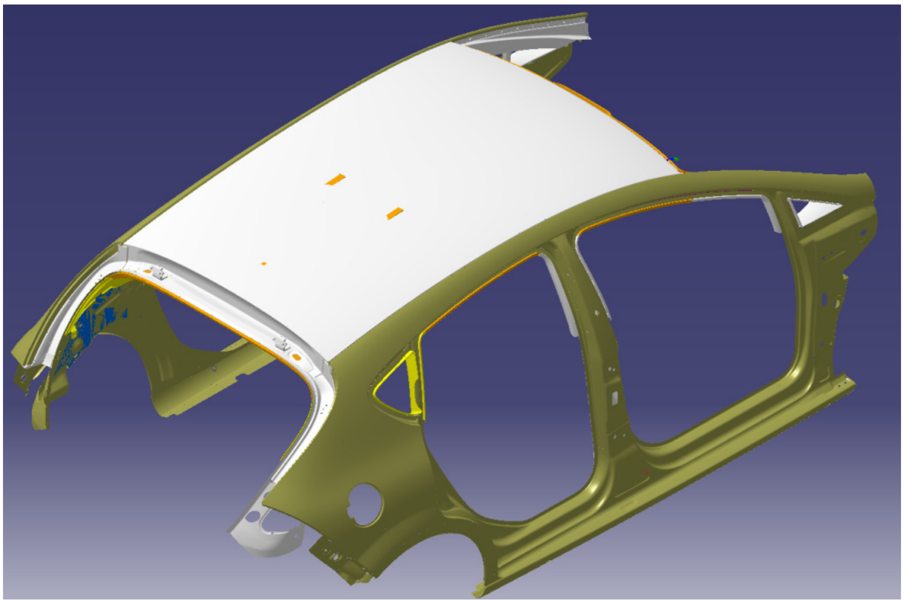


Figure 7.1 Fragment of SEAT Leon body from company.

The whole project was designed in environment "Shape" - "Generative shape design" which specializing in the editing complex surfaces. The first step was imagine how a solar panel can be applied and how should it to be placed on the roof. For this purpose the needed shapes and sizes of important elements where measured. This resulted that a roof of 1.8 m^2 on the car is available. However, because of differences between the shapes of solar cells and the shape of a roof, it is not possible to use the whole surface. Solar cells are produced in rectangular parts but the borders of a car are curved, which is visible in the picture below (figure 7.2)

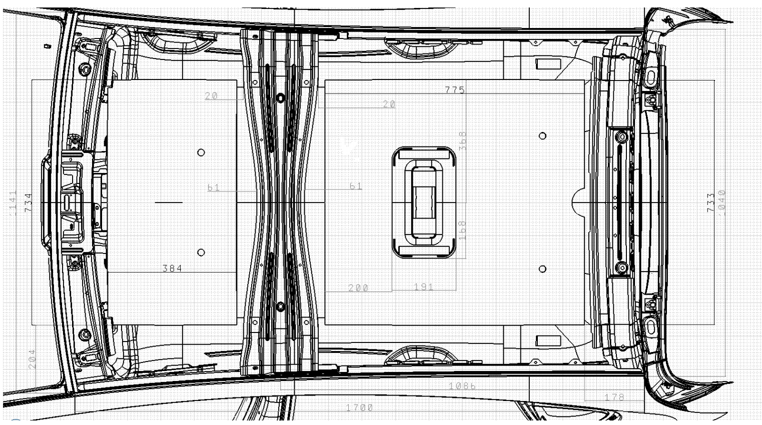


Figure 7.2 Top view sketch of car

Material which will be used for applying is CIGS, so this kind of solar cell can be produced in several sizes, depending on the requirements of the constructor. In this purpose a sketch with rectangular size 1680x990mm has been made, what let to have 20mm space between edge and side border of roof. Next the sketch was applied on the roof, which obtained the initial shape of CIGS on the car. Afterwards the first component was made which serves as insulation material protecting solar cell from vibration. Then extruded a 3mm layer and repeated this to make 0.5mm layer CIGS and 1.5mm for Plexiglas. The thickness of insulation material is sufficient for protecting the cells because of the fact that the vibration of car is not so high. Plexiglas, which protects CIGS from factors like water, snow, hits from hail and all other influences, has 1,5mm thickness. These three materials are connected by special glue which possible supplier can be Henkel Company. The total of all the above components result in a 4mm thick solar panel shown in the picture below (Figure 7.3).

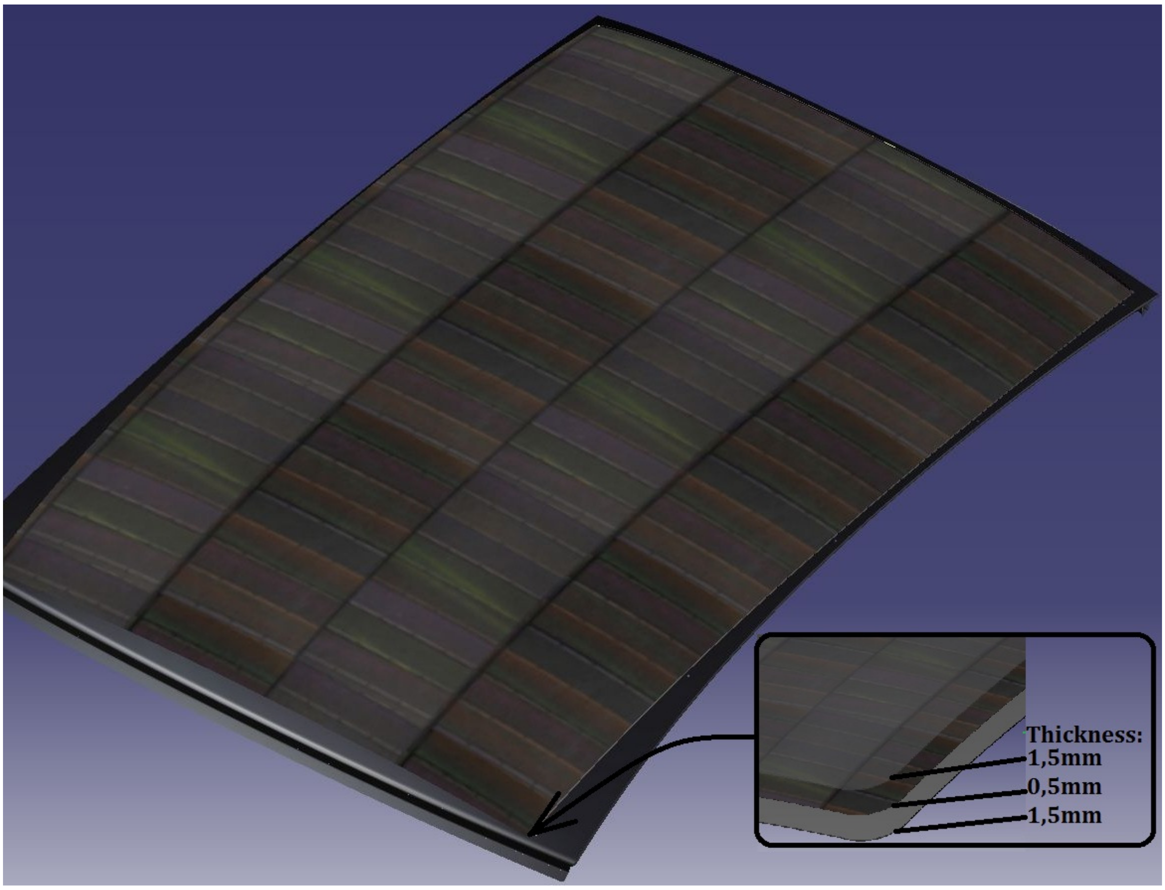


Figure 7.3 Layers of Solar panel installed on the roof of SEAT Leon.

For better secured CIGS special bars where designed which keeps the panel in three sides. The bars are made of Polyvinylchloride (PVC) and have to protect the panel against dissection and possible theft. To design this element a sketch with special profile and a model to fit CIGS to the roof was created. However in manufacturing it has a straight shape, which is show in the sketch in *Appendix 1*. This way of designing a bar produces long parts, which will be cut in shorter 1680mm elements.

Every bar is kept by 5 screws which are countersunk and recessed Allen. This is an additional solution which holds the bars to support the gluing. Screws are placed with a distance of 400mm. The dimension of the screw is M4 which is enough, because of the small amount of force needed to keep the solar panel.

In the front no bar is assembled. To protect the solar array from water, it has to be sealed in every side by special sealing silicon.

For a better look and to minimize the wind resistance of the device, some plugs were designed in the corners. Front and rear plugs are completely different as a result of the construction of above elements. Front parts connect silicon with the side bars and the rear connects two bars- side and the rear bar (Figure 7.4). They are made from the same material like the bars. They are kept by glue or a positive-fit connection with the other elements.

As last phase in the design part it is necessary to place the wires and fix their allocation. The first step was to choose where to make a hole in the roof for the wires. The best location is to place it under the rear bar in the center of the roof. From there the wiring of the panel starts. Next they are going to the right side of car and after through the roof straight to a-pillar.

At the end to give a better impression and imagination we used the command "Apply material" to give every element its own feature. The CATIA library has own definitions of materials like Plexiglas, Plastic, or Metal. However CIGS needed to define new parameters and views. At this point the total working area of is $1.7m^2$.

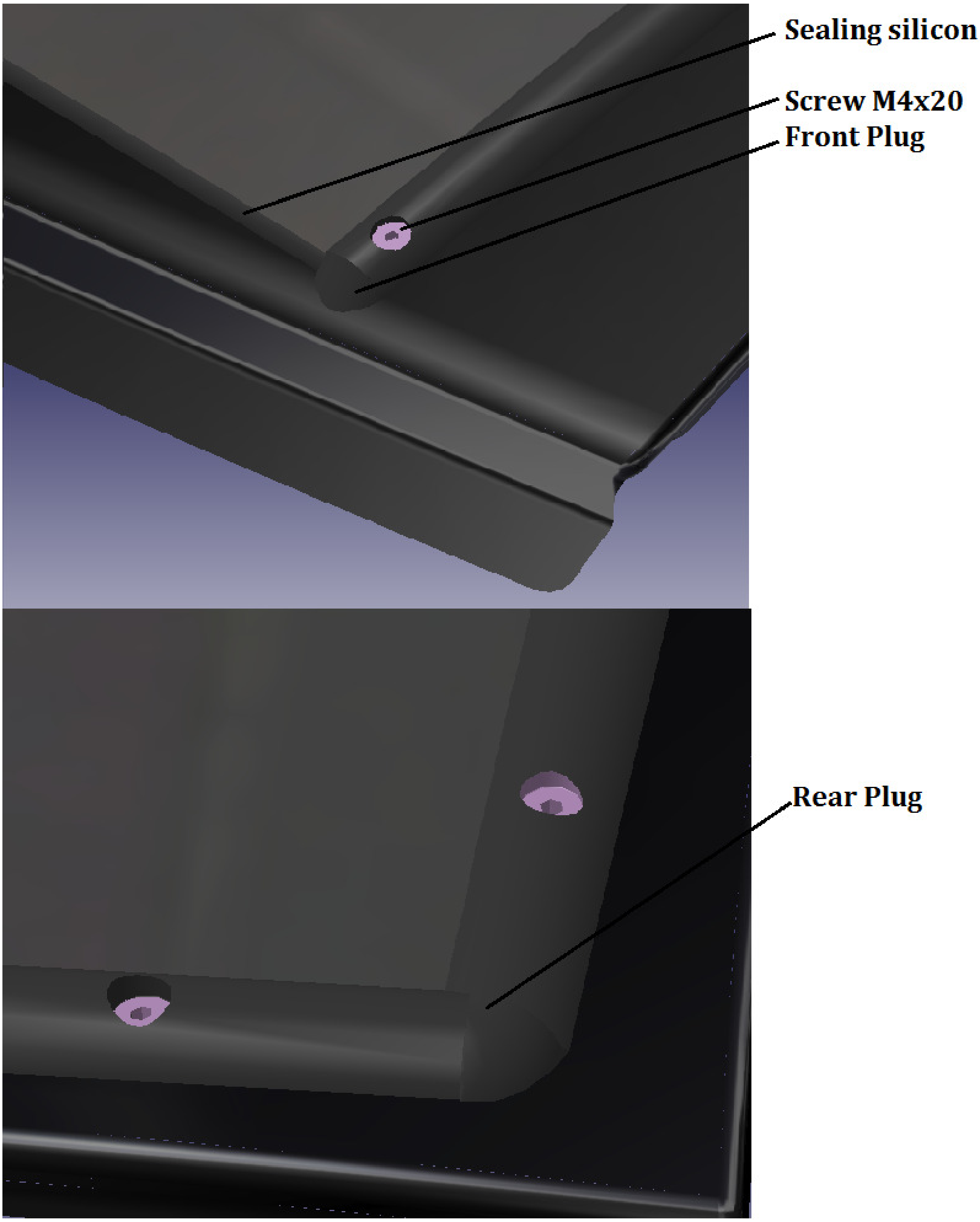


Figure 7.4 View of screws and plugs on solar panel.

Finally the assembly was added to the existing Model, SEAT Leon which final effect is shown in figure 7.5.

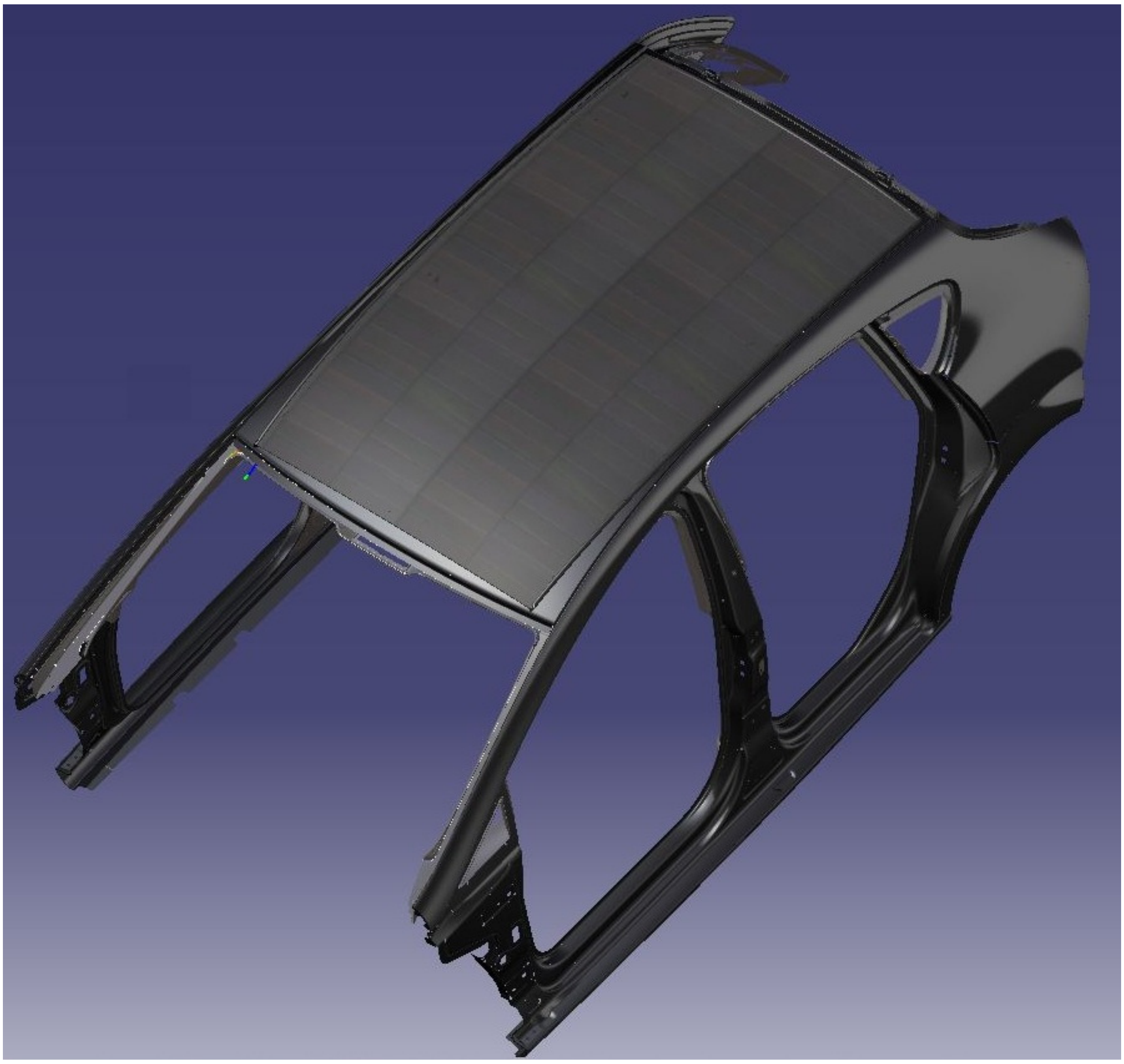


Figure 7.5 Finished model of Solar cell on SEAT Leon roof.

<u>Bill-of-materials</u>

1. Insulation material (1 unit)
2. CIGS cell (1 unit)
3. Plexiglas or glass-cover (1 unit)
4. Side bar (2 units)
5. Rear bar (2units)
6. Screw with nut and pad (14 units)
7. Front Plug (2units)
8. Rear Plug (2units)
9. Sealing silicon (1unit)
10. Electric wires (2 units)

Chapter 8 Business Case

Introduction

This business case has been made as part of a theoretical investigation on photovoltaic technologies and applying them on cars. The project has been done at the “Escola Politècnica Superior d'Enginyeria de Vilanova i la Geltrú” in collaboration with the technology centre of automotive company “SEAT” in Barcelona. The business case is a sequel to an investigation about using different materials for photovoltaic’s and continues with finding the best suitable solutions for photovoltaic appliance on cars.

The report will start with an explanation about the current product that SEAT offers to their customers. After this the goal of SEAT will be stated, this part will make clear what SEAT wants to achieve with this research. When the objectives and boundaries are explained it will continue by giving information about the technologies on which the research is based, including the reasons for choosing these technologies for future investigation. Then different calculations will be done for each material, resulting in a list of costs and benefits for SEAT and her customers. To give a good image on the calculation results, a market research has been done. In this chapter the opinion of potential customers will be compared with different characteristics of the technologies. Finally the evaluation will give a verdict about each technology.

8.1 Needs

One of Seat's objectives is to be environmental conscious, in order to achieve this they want to develop cars that have minimal waste production and that use as less fossil fuel as possible. A technology they want to use for this is photovoltaic's. Photovoltaic application on cars is a quite new technology which replaces energy generated by the car engine with the energy generated from the sun. In this way the cars have to burn less fuel.

8.1.1 Current Application

SEAT Exeo

The SEAT Exeo has a solar sunshine roof which uses mini solar panels embedded in the glass to provide the car's ventilation system from energy, even when the ignition is off. When parked in the sun, this additional part can provide energy to cool down the inner room. The advantage is that with the 37 Watts the panel provides there is no drain on the car battery. Sensors automatically switch on the system when there is a difference between the inside and the outside temperature. The price for this luxury is an additional €1.250 on the purchase of the Exeo.

Figure 8.1 SEAT Exeo (http://pictures.topspeed.com/IMG/crop/200903/2009-seat-exeo-42_800x0w.jpg)

8.1.2 Issues

The problem with the current photovoltaic application is that it only generates 37 watts, which is to less to power other electric systems in the car. It is currently used for circulating the air in the car when parked, in this way the car doesn't have to be cooled much while driving, which saves a little bit energy. The price of such a solar panel is € 1.250 and with the current energy saving it has no return on investment. Therefore it currently serves as a luxury item, so that the inside of the car has a comfortable temperature.

8.1.3 Improvements

As the issue from Seat stated; the power generated by the solar panel is insufficient to replace some energy consuming devices in a car. Next to that the ratio between power and price is much to low in order to have a return on investment. Therefore Seat wants to have solar panel which has a better performance so it can provide more power. In order to define the expected outcome of this research SEAT stated demands which the solar panel has to fulfil.

For the performance a minimum of 100 Watts and 14 Volts is stated. This is the performance the panel can achieve under normal testing conditions of 1000 W/m^2 irradiance and with a cell temperature of 25C°.

Currently Seat purchases there Solar panels for €400 – 450 and sells them for €1.250 euro. Information taken from the market research of Seat tells that a customer doesn't want to pay more than €1.600 that is why the purchasing price should be around €800 – 900, because of the additional cost of implementing the panel.

The solar panel will be placed upon the roof of a SEAT Leon, therefore there is minimal amount of space available. The maximum surface available for the solar panel is 1.7 m^2.

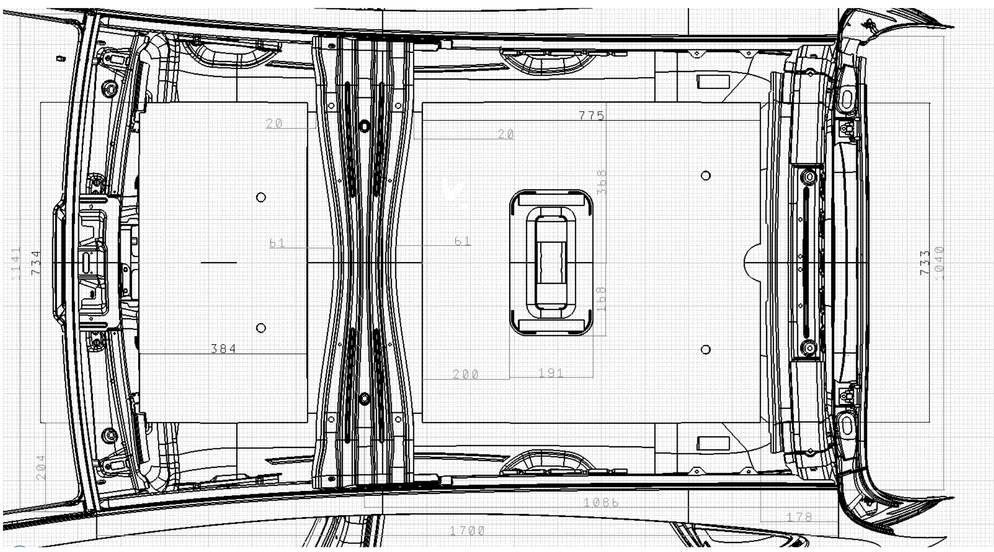


Figure 8.2 Seat Leon roof surface, top view

8.2 The Technologies

After analyzing all the different materials, two technologies remained and where chosen for further research. The first technology is named CIGS / CIS. Due to the good characteristics of this material it will be explored further on. The second material, HIT is a combination of Mono Crystalline Silicon and Amorphous Silicon. Because this technology makes use of the good characteristics of the different materials it is really interesting to explore more. In this chapter a short summarize of both materials will be given.

8.2.1 CIGS Cells

CIGS is a photovoltaic application based on Copper indium gallium di-selenide technology. One of the main features of CIGS is that it is flexible. This makes it really practical for applying it on cars. Next to that CIGS has the following suitable characteristics:

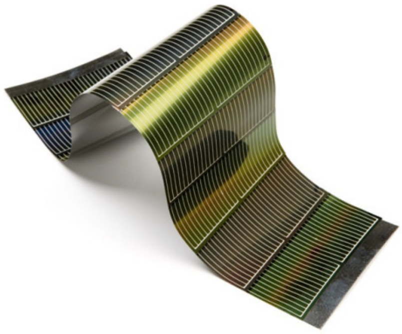


Figure 8.3 CIGS *http://www.greentechmedia.com/wp-content//uploads/2009/02/tf-global-solar.jpg*

World's best efficiency of thin film modules

CIGS cells are the most efficient of all the thin film modules. Current used panels have a nominal output of up to 95 – 110 Wp (+5Wp/-0Wp), with an efficiency of 10.8%. This power is achieved on a panel of only 7.4 mm thick.

High energy yields for good cost-efficiency

The efficiency given for the CIGS is a performance under good conditions. But especially when used on a car the circumstances will not be perfect. Therefore it is good to know that CIGS has a good performance when used in low or oblique light. Next to that CIGS has a better temperature coefficient than silicon-based modules, around -0.40%/C° above 25 C°. Finally these cells differ from layout which makes them advantageous in case of partial shading.

Solid quality

The lifetime of a car is around 10 years, so when a solar panel is attached you have to be sure it has the same or a longer lifetime. CIGS has a long-term functional stability. There is a product warranty of 5 years and a power warranty of 25 years with a power output of 80% or more. Of course this guarantee is for normal usages but manufactures are willing to subject a mutual agreement with customer on new conditions.

Properties

Efficiency:	10.8%
Temperature coefficient:	0.40%
Lifetime:	25 Years
Flexible:	Yes
Thickness:	7.4 mm
Recycling:	Yes
Transparent:	No

8.2.2 HIT Cells

HIT Cell technology consists of two different materials. The first one is Single Crystalline Silicon which has the highest performance of flat plate technologies and is the most used material in photovoltaic applications, the biggest challenges for this material is cost reduction. The second material used is Amorphous Silicon, this because of the low cost potential.
Because HIT Cells are a combination of these materials, they can make use of each other's characteristics to improve their own.

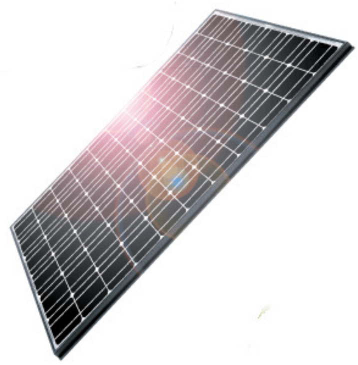


Figure 8.4 HIT solar panel (www.ge.co.id/images/hit1.png)

More capacity in limited area
HIT cells are known for their high efficiency, in commercial usages this can reach up until 17%. Therefore it is possible to install more capacity compared to other conventional photovoltaic modules. This feature is really useful for photovoltaic car application because there is a limited amount of space (1.7 m^2).

High performance at high temperatures
Another positive point of HIT solar cells is that they maintain higher efficiency than a conventional crystalline silicon solar cell. For every Celsius degree above 25 C° the efficiency degreases with -0.3%, compared to -0.5% of a conventional silicon solar cell. This means that HIT cells can deliver a greater amount of power when temperature rises.

Considerable output under diffuse and low light conditions
Because the solar panel will be applied on a car, it is important that as many sunlight as possible is captured while driving. Besides direct sunlight, HIT solar cells have the ability to catch ambient and scattered sunlight. Next to this they also function well under low light conditions.

Properties

Efficiency:	17.4%
Temperature coefficient:	0.30%
Lifetime:	20 Years
Flexible:	No
Thickness:	35 mm
Recycling:	Yes
Transparent:	No

8.3 Evaluate the costs

Now that the technologies and their characteristics are known, this chapter will continue by doing different kind of calculations. First an overview is created on the general numbers that will be used for the calculations. After this it will take a look at what the customer cost and benefits are, in the view of CO_2 - and money saving. The same will be done for SEAT; when will the solar panel investment become profitable and which other effects does it have on the company. When all these calculations have been done they will be compared with the results of a market research. Finally the gathered information will be collected and a final conclusion will be given. The calculations make use the following numbers:

Car:	SEAT Leon 1.6 (2006)
Average usage:	15.000 km per year [1]
Fuel:	Gasoline, Super Unleaded
Emission:	180 CO_2 g / km [2]
Consumption:	37.2 MPG = 6.35 litres / km [2]
Gasoline prices:	Super Unleaded (24th of May) [4]
Savings:	8.9 kWh* = 1 liter of fuel less [3]
	Gasoline: 2.3 kg CO2 / liter [8]

* Lost of energy because of the engine efficiency (50-62%) and the alternator (55-60%).
50 % * 0.55 = 27.5%. If 27.5% = 8.9 kWh then 100% is 32.36 kWh. [11]

To calculate the savings, we first needed to know how much a normal car usages. Therefore a calculating on the average use of a SEAT Leon 1.6 has been done, because this is the car were the solar panel will be applied on. The calculation includes an average use of 15.000 km a year, with 50% usages within the city for short distances, and 50% usages outside the city for long distant drives. Further; driving style, maintenance, tire pressure, usages of air-conditioning and open windows are taken into account and have been calculated as an average. For the calculation an online program provided by the Belgium government was used [5]. The calculation method is given in *Appendix 8.1*. [8]

Average Use of SEAT Leon 1.6 STYLANCE (2006)			
	Per Year	**Per Kilometer**	**Per 100 kilometers**
CO_2 emission (kg CO_2)	3.433	0,229	22,89
Fuel usage (liters)	1.493	0,1	9,95
Fuel costs (euro's)	2.165	0,144	14,43

Table 8.1 Average use of SEAT Leon 1.6 (http://www.energivores.be/tips_car_intro.aspx?lang=NL&mod=2)

As given in table 1 the total amount of fuel usages is about 1.500 liters per year producing about 3.400 kg CO_2. These numbers we will use for further calculations.

8.3.1 Customer Costs and Benefits

There are three main benefits a customer has from the solar panel. The first benefit is the one which the current application focuses on, the comfort. The automatically cooling of the car when the inside temperature rises is a function that is also possible with the new solar system. Next to this, customers which are environmental conscious have the opportunity to reduce their CO_2 output. Finally the customer will save on the amount fuel used, which results in saving money. The amount of these savings will be calculated in this chapter.

In the calculation chapter the amount of kWh a year has been calculated for the cities Barcelona, Oslo, Paris and Berlin. These numbers we need to calculated our savings. To turn the kWh into saved liters we use the fact that 8.9 kWh saves 1 liter of fuel. After this the money that a customer saves per years is given, this is calculated with the fuel price of every country.

		Average kWh/year	Saved liters*	Gasoline price (€)	Saved money** (€)
CIGS 10.8%	Barcelona	275,205	30,92	1,22	37,72
	Oslo	162,833	18,30	1,45	26,53
	Paris	212,282	23,85	1,45	34,59
	Berlin	193,092	21,70	1,50	32,54

HIT 17.4 %	Barcelona	427,920	48,08	1,22	58,66
	Oslo	250,318	28,13	1,45	40,78
	Paris	329,868	37,06	1,45	53,74
	Berlin	299,142	33,61	1,50	50,42

*** Saved liters formula**: Average kWh a year / kWh necessary to save 1 liter of fuel (8.9 kWh)
**** Saved money formula**: Saved liters gasoline price

Table 8.2 Saved fuel and money when applying a HIT or CIGS solar panel on a car.

Fuels savings: In liters of fuel we can calculate the same. You save minimal 18.30 and maximal 30.92 liters with CIGS and for HIT between 28.13 and 48.08 liters. When the average amount is 1.493 liters the percentages you save are, CIGS: 1.2% - 2.1% and HIT 1.9% - 3.2%.

Money savings: Now that we know how much money we save on gas every year we can calculate the amount of money we save during the lifetime of a car. As an average we take 10 years. For CIGS this means between: €265 – €377 and for HIT: €407 – €586. Because of the instability of the fuel prices the average percentage of price increase is not included in this calculation. Notable is that the prices will probably rise in the future, making the savings even higher. When the solar panel wants to have a return on investment the selling price should be lower than these amounts, which is currently not the case.

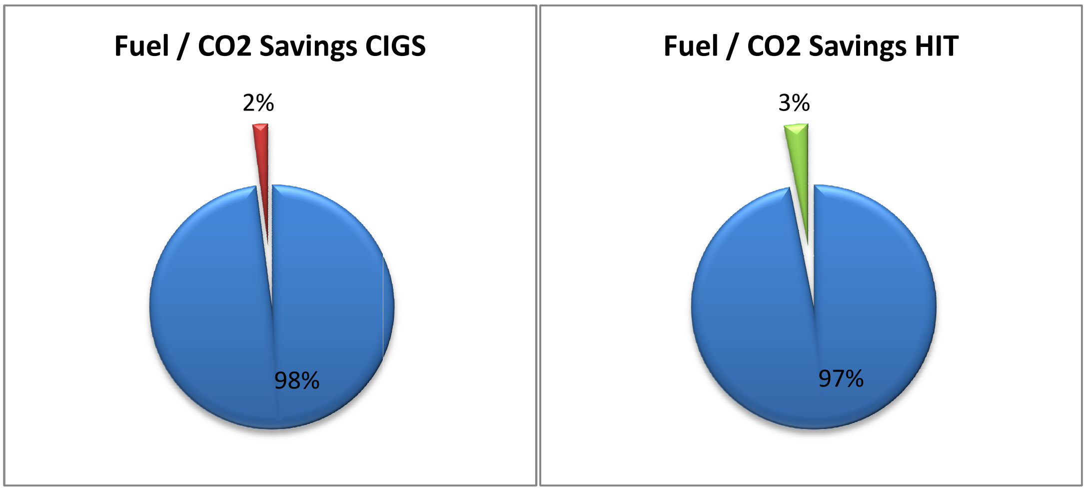
CO_2 savings: Because the amount of fuel a solar panel saves, the emission of CO2 declines as well. In table 3 all the data about CO2 saving is given.

		Saved liters*	Saved CO_2 in kg*	Saved CO_2 g / km**
CIGS 10.8%	Barcelona	30,92	71,12	4,74
	Oslo	18,30	42,08	2,81
	Paris	23,85	54,86	3,66
	Berlin	21,70	49,90	3,33
HIT 17.4 %	Barcelona	48,08	110,59	7,37
	Oslo	28,13	64,69	4,31
	Paris	37,06	85,25	5,68
	Berlin	33,61	77,31	5,15

* **Saved CO_2 in kg formula**: Saved liters * Amount of CO_2 per liter (2.3 Kg)
** **Saved CO_2 in g /km formula:** Saved CO_2 in gram / 15.000 km

Table 8.3 CO2 savings by applying a HIT or CIGS solar panel on a car

As table 1 showed, the average amount of CO2 is 3.433 kg per year. For every city a calculation how much percentage of the total amount we can save, has been made. The amount saved by the usages of a solar panel is for CIGS minimal 42.08 and maximal 71.12, and for HIT 64.69 and 110.59 kg/CO_2. When you look at the average amount of CO_2 a car produces (3433 kg) the percentage you save is with CIGS around 1.23% - 2.1% and with HIT 1.88% - 3.22%.



Graphic 8.1 Percentage Fuel and CO_2 savings from the total amount produced per year.

8.3.2 Company Costs and Benefits

For SEAT the main reason for developing solar application's on cars is to gain a competitive advantage and sell more cars. Next to that they also want to make a profit on the solar panels they sold. Therefore a calculation has been made about the profit and breakeven point of the solar panels. The breakeven point is the moment that the total turnover covers the costs that have been made. The following numbers are based on estimation and we have taken a worst case scenario to give an idea of the future investments. In the calculation we take the price of a HIT solar panel (€900), this because it is the only accurate known price we have on these technologies.

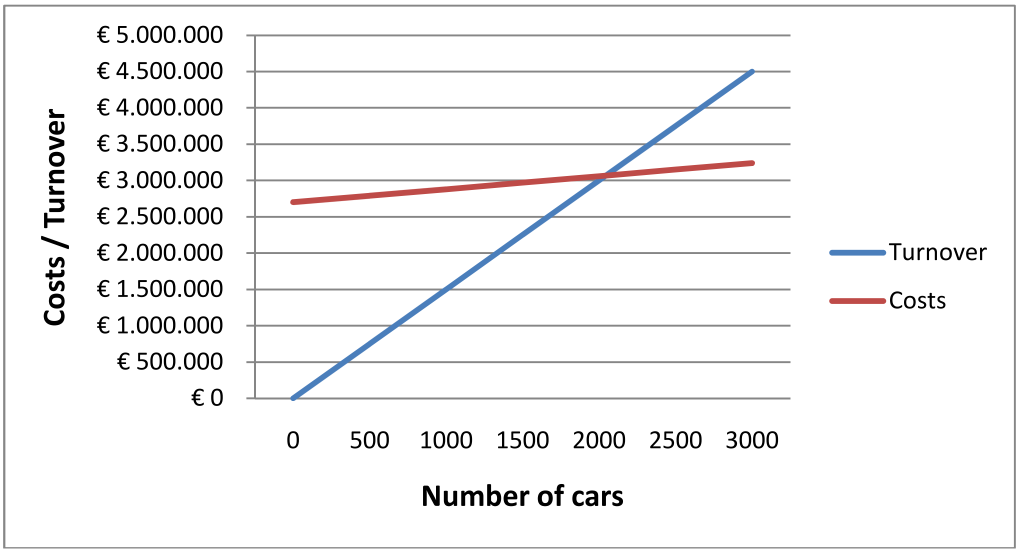
Breakeven point

To calculate the breakeven point, the following formula will be used:

- Breakeven point = Total fixed cost / (Selling price – Variable costs)

The fixed costs exist out of the total purchase price of 3000 solar panels, no matter how much cars you sell this number will be the same. In this calculation the fixed costs do not include factors like transport cost, storage costs etc. this because these numbers are unknown to us. The variable costs exist out of the applying costs. As soon as a car is sold the panel has to be attached which includes fabrication cost, material cost etc. For this calculation we used an estimation of 20% of the product price.

Total fixed costs: 3000 solar panels of € 900[7] each = €2.700.000
Variable costs (included applying costs): 20% of the product costs price (€900) = €180
Selling price: €1500
HIT Breakeven point: 2700000 / (1500 – 180) = 2045,455 = 2046 cars.
This means that 2046 cars have to be sold in order to cover the costs.



Graphic 8.2 Break-even point

Profit

Graphic 8.2 shows the cost line as the turnover line, the point where they cross is the breakeven point. After this the differents between the turnover and the cost become bigger, this different is the total amount of profit and can be calculated as follows:

Total turnover – Total costs
= (Number of cars sold * Selling price) – (Number of cars sold * (Purchasing price + applying costs))
= (3000 * 1500) – (3000 * (900 + 180))
=€1.260.000 profit

CO_2 emission legislation

As said before, there is a big pressure from governments to reduce CO_2 emissions. Because countries set targets on reducing their total emissions, different rules are set for industries. Also for the car

industry the European Commission made a proposal to reduce the average CO_2 emissions of new passenger cars.
The objective is to reduce the average CO_2 emissions from new passenger cars in the EU from around 160 grams per kilometre to 130 grams per kilometre in 2012. And every company that does not fulfil these rules has to pay a fine.

The law goes as follows [9]:
Each year from 2012 onwards a manufacturer's average specific emissions of CO_2 can't exceed its specific emissions target in that year or it will receive an excess emissions premium.
The excess emissions premium will be calculated using the following formula: Excess emissions*number of new passenger cars* excess emissions premium.

'Excess emissions' means the positive number of grams per kilometer by which the manufacturer's average specific emissions exceeded its specific emissions target in the calendar year rounded to the nearest three decimal places.
'Number of new passenger cars' means the number of new passenger cars for which it is the manufacturer and which were registered in that year.

The excess emissions premium shall be:
(a) In relation to excess emissions in the calendar year 2012, 20 euro's;
(b) In relation to excess emissions in the calendar year 2013, 35 euro's;
(c) In relation to excess emissions in the calendar year 2014, 60 euro's; and
(d) In relation to excess emissions in the calendar year 2015 and subsequent calendar years, €95

For Seat this means that they have to decrease the amount of CO2 which their new cars produce. For our calculation we compare the amount of CO2 we can save with a solar panel with the amount of money this might save for SEAT.

- CIGS 2.81 and 4.74 CO_2 grams/km which means that SEAT can save between €180.000(2012) and €1.425.000(from 2015) a year.
- HIT: 4.31 and 7.37 CO_2 grams/km which means that SEAT can save between €1.425.000 and €1.995.000 a year.

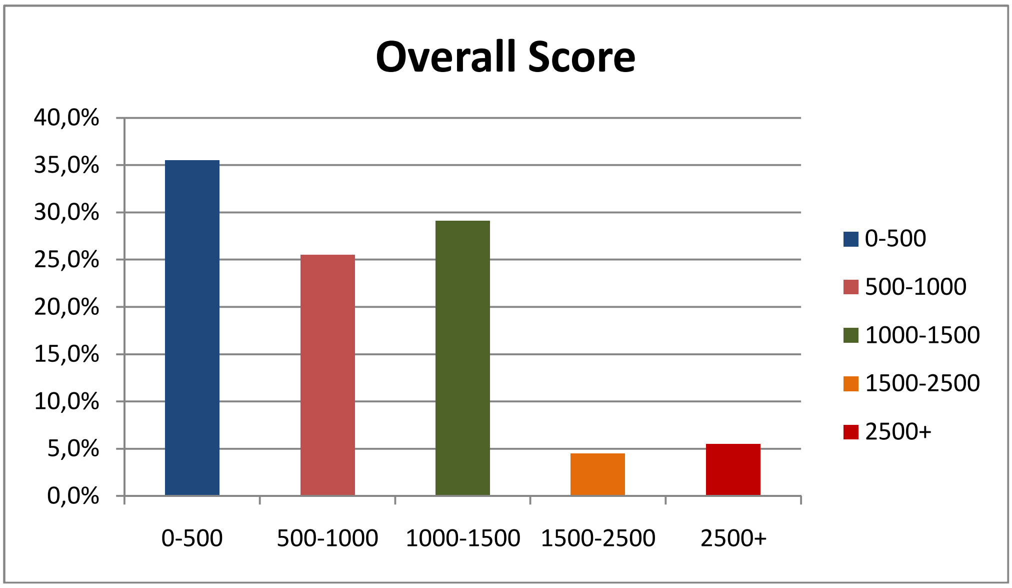
Year	Penalty	1 gram	2 grams	3 grams	4 grams	5 grams	6 grams	7 grams
2012	€ 20	€ 60.000	€ 120.000	€ 180.000	€ 240.000	€ 300.000	€ 360.000	€ 420.000
2013	€ 35	€ 105.000	€ 210.000	€ 315.000	€ 525.000	€ 525.000	€ 630.000	€ 735.000
2014	€ 60	€ 180.000	€ 360.000	€ 540.000	€ 720.000	€ 900.000	€ 1.080.000	€ 1.260.000
2015	€ 95	€ 285.000	€ 570.000	€ 855.000	€ 1.140.000	€ 1.425.000	€ 1.710.000	€ 1.995.000
2016	€ 95	€ 285.000	€ 570.000	€ 855.000	€ 1.140.000	€ 1.425.000	€ 1.710.000	€ 1.995.000
2017	€ 95	€ 285.000	€ 570.000	€ 855.000	€ 1.140.000	€ 1.425.000	€ 1.710.000	€ 1.995.000

Table 8.4 EU regulations (http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007PC0856:EN:NOT)

8.4 Market research

For our research a questionnaire was made, on what amount of money people would spend on a solar panel. The questionnaire has been done so that a comparison of the solutions with the opinion of the market can be done. By doing research in the market we get more information; about what the people know and expect from solar technology applied on cars. In total 110 people of 18 and 60 years old from 8 different countries cooperated with the research. The countries where: Spain, Germany, Poland, Romania, The Netherlands, France, UK, and USA. In this chapter the outcome of the research and the relation it has to SEAT will be discussed. For the complete questionnaire see *Appendix D2.*

The outcome of the research was as follows; (see graphic 8.3)
35,5% doesn't want to pay more then €500
25,5% between €500-1000,
29,1%, between €1000-1500,
4,5% between €1500-2500
5,5% don't mind paying more then €2500+

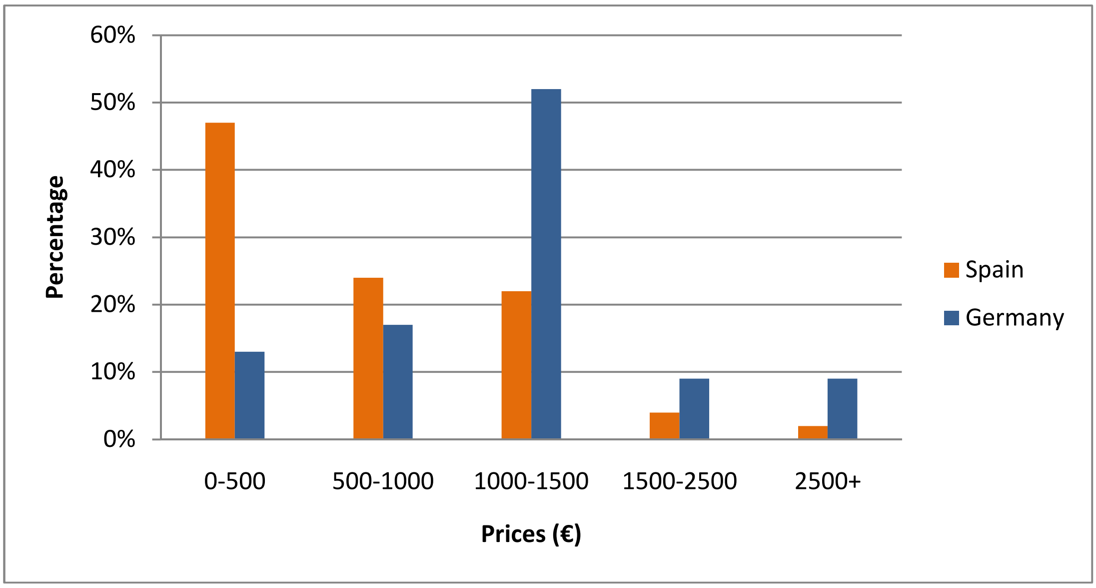


Graphic 8.3 Overal result questionairre

There are some remarkable points in the graphic. First of all says more then 35% that they don't wont to pay anything, or less then €500. Another intersting thing is that almost 30% of the people said they would pay between €1000 – 1500, compared to the group of €500 – 1000 (25,5%). Clear is that 90% of all the people between €0 - 1500 choose. This means that to reach this group of people and to have an commercial interesting product, the solar panel should have a selling price below €1.500

Countries

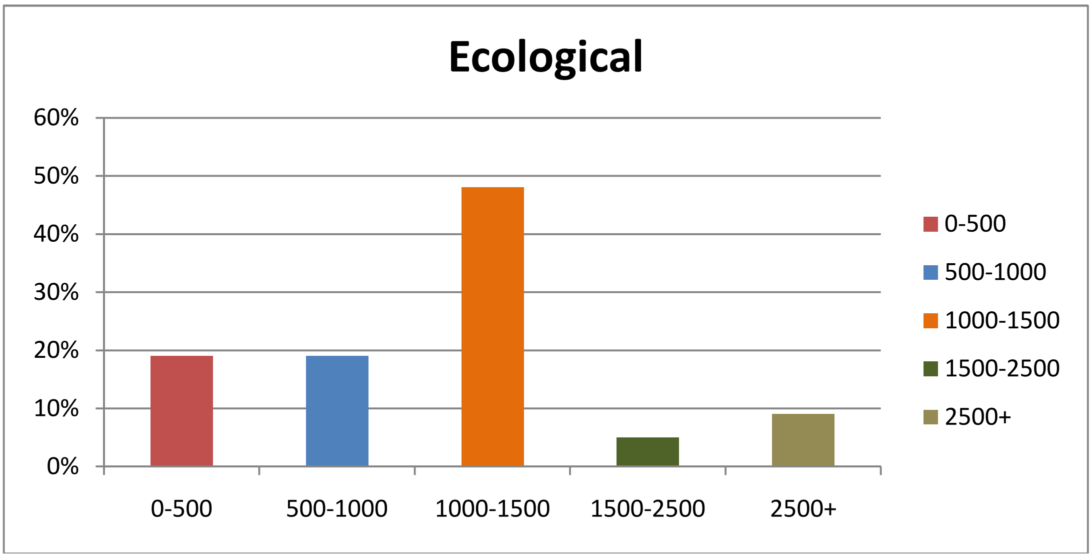
After looking at the overall picture of our results, we looked for notable difference between the countries and the amount of money they would spend. The biggest difference is between Spain (45 questionairres) and Germany (23 questionairres). Whereas in Spain the most people don't want to spend more then €500, more then half of the people in Germany would spend between €1000 – 1500 for a solar apllication on there rooftop



Graphic 8.4 Difference between Spain & Germany

Ecological

In the questionnaire people were also asked what they think is important when purchasing a car. The options of which they could choose from where: Design, Performance, Ecological, Safety, Practical use, Comfort, Price and Brand image (maximum 3). From the 110 people, 21 said that ecological was one of the criteria they take into account when buying a car. And half of them would pay around €1000-1500 euro's for an application which makes their car more ecological.



Graphic 8.5 Ecological people's spending

8.5 Evaluation

Now that the calculations and the market research have been done a comparison can be made. As said before, the estimate cost price of a HIT solar panel is around €900, including additional costs and a profit margin SEAT will sell the panels for a price around €1.500. From all the different technologies this is probably the most expensive one. When we look at the questionnaire, it shows that the most people want to pay nothing or maximum €1.500. So with the current price we will reach a small amount of the people. With CIGS it might be possible to achieve almost the same results (in further prospective) but for a lower price and therefore a much larger amount of people can be reached.

HIT: HIT solar cells have proven to be a really good technology, and are globally used for many applications. Especially the efficiency and price ratio is really good. However there is no current product which they can apply on cars. Because the only company that produces these cells makes them on glass substrate and therefore it is not possible to construct it on a car. Therefore our advice for SEAT is to contact the manufacturer SANYO (http://sanyo.com/solar/) and discuss the possibilities on production of HIT cells on a flexible material.

CIGS: Although CIGS has less efficiency then solar applications like HIT cells, it is the best of all the thin film technologies. Thin film is a really suitable for using on cars, especially because of the flexibility and the thickness. Next to that there is a lot of investigation in this material to make it more efficient. Different companies announced higher efficient panels in 2012 and on. The company that provides the flexible form of the panels with the highest efficient is Global Solar (http://www.globalsolar.com). When contacting this company they said that they would be pleased to send more information about the current developments but only confidential. After this they provided a form that had to be signed, which we gave to SEAT. In this way SEAT will get in contact with the company and will know more about the possibilities for them.

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Chapter 9 Project conclusion

The project was about the analysing of different photovoltaic technologies regarding the requirements on the cells and panels to be applied on a car surface. To reach 100W for supply the battery with energy was the main aim guiding the evaluation. Furthermore different criteria were chosen to respect the needs of the automotive company SEAT and their customer.

Starting with six different materials, the first evaluation showed that not every technology is suitable for an application in vehicles.

Figure 9.1 Criteria table rated with through traffic-lights

Figure 9.1 shows with a traffic-light animation which criteria can and which cannot be expected to be full-filled with the various materials. A green light tags a positive characteristic referring to the criterion. Red-signs mark problems in the linked category. The yellow colour should imply, the property is not optimal but can be improved with further development and research. Also in case of flexibility and transparency it can be produced in a way to fulfil the criteria but is not necessarily done because it has effects on other properties. While transparency, flexibility and thickness are no essentially decisive arguments not to take a technology into account, the efficiency, price and safety, as well as the supplier-market can be crucial.

It is extractable that Cadmium Tellurium not can be applied because of the safety issue. The degradation of GRATZEL is a topic that has to be solved and therefore even if some properties are very interesting it is not immediately usable. The high efficient Gallium Arsenide is ineligible because of the exorbitant cost of the cells. The irradiation-calculation made aware that with the surface of 1,7sqm every material is able to reach the 100W in summer under similar conditions to Barcelona. CIGS as well as Silicon in both types have an outstanding combination of characteristics, made them preferable for an application. While the efficiency of amorphous Silicon is even less than CIGS it was also not took into account for using in vehicles.

Crystalline Silicon is the best developed photovoltaic technology and therefore applicable in a close future. This offered WEBASTO Solar which can provide a crystalline roof top within 15month. Even if the panel is not flexible, they apply the 156mm x 156mm cells on a curved surface under one side security glass.

CIGS as photovoltaic technology of the 2^{nd} generation is going to be continuously improved to reach a higher efficiency and to use the advantages of the flexibility. A lot of companies produce CIGS nowadays on glass substrate. Suppliers, producing the cell on flexible substrates, are currently very rare but several companies research on the topic to offer them in 2012.

The Figure 9.2 should give an insight into the development stage. If the efficiency is improved, a research on application on roofs is made and more suppliers offer the CIGS as flexible panel, the functional conditions and the price can be an advantage to decide a study in this field.

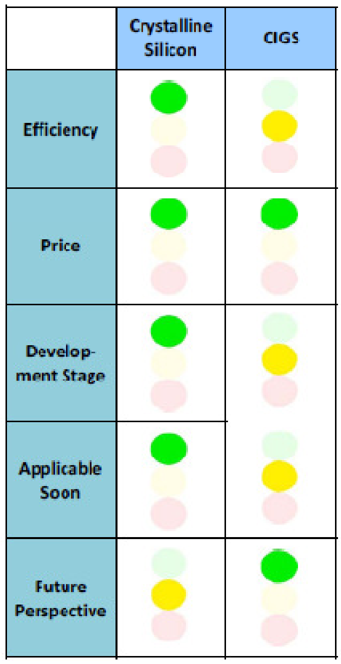

Figure 9.2 Development stage of the final technologies

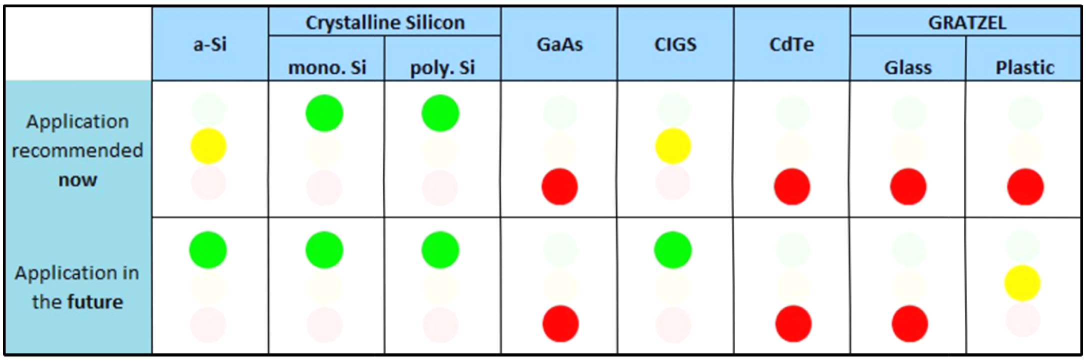

Figure 9.3 Research results for application in the closer and far future

Finally figure 9.3 show all materials and if it is recommended to use them in the current state of development regarding all criteria and gathered information. Actually the best decision might be the application of crystalline Silicon but CIGS and a-Silicon are alternatives with perspective.

Some responses on information namely the KYSOEMI-Sphelar® technology and the solution of KYOCERA and WEBASTO were too late and are still to incomplete to include in the report. The efficiency of the HIT cell in the calculation can be a guiding principle for the solution of the last two. *Appendix E-1* contains an almost complete special report to KYOSEMIs new invention with practical examples on bigger surfaces. Some further information to WEBASTO can be found in *Appendix E-2*. Contact data can be found in *Appendix E-2* as well.