METHODS AND CONCERNS FOR DISPOSAL OF PHOTOVOLTAIC SOLAR PANELS

A Project Report

Presented to

The Faculty of the Department of General Engineering

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

In

Engineering

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December 2011

SAN JOSE STATE UNIVERSITY

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ABSTRACT

Methods and Concerns for Disposal of Photovoltaic Solar Panels

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Solar energy plays an essential role in the move towards renewable energy. By generating energy through photovoltaic (PV) solar technology and reducing carbon dioxide emissions to the environment, the solar energy industry is able to present a clean energy source to the market. However, in order to introduce an environmentally safe product to the market, companies need to study the full cycle of the product, from cradle-to-grave. The electronics industry failed to account for their product's end-of-life into consideration in the manufacturing process and created widespread toxic chemical pollution. The solar energy industry can avoid a similar mistake by not only accounting for the materials used during manufacturing, but also the transportation of PV panels, disposal, and reuse of these panels need to be considered.

This project attempts to present a safe and sustainable process for the disposal of PV solar panels. A detailed study of current PV solar panel disposal practices is discussed, as well as the feasibility of implementing recycling processes in the solar energy industry.

ACKNOWLEGDGEMENT

We wish to express our gratitude to Dr. Leonard Wesley for providing us an opportunity to complete our project on “Methods and Concerns for Disposal of Photovoltaic Solar Panels.”

Our sincere thanks to Dr. Fred Barez, our faculty advisor from San Jose State University’s Department of Mechanical Engineering, for guidance and encouragement in carrying out this project.

We would also like to thank Mr. Francois Rongere, Energy Efficiency Segment Supervisor at Pacific Gas & Electric, for providing additional feedback and support during this process.

In addition, we would also like to express our gratitude to Dr. Amip Shah, Senior Research Scientist at Hewlett-Packard Labs, and Mr. Markus Beck, Chief Technologist at First Solar, for rendering their help regarding their company’s current processes.

Last but not least, we would like to take this opportunity to express a sense of gratitude to our families for their support, strength, and help.

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1.0 Introduction

With increasing awareness of sustainability and the demand for renewable energy sources, the solar industry plays an essential role in providing such a solution. Solar energy presents the opportunity to generate clean electricity, which can lead to a sustainable life style. However, if the solar industry is to truly present a sustainable solution, the photovoltaic solar panels end-of-life phase must be addressed.

Established manufacturing processes in the electronics industry are creating alarming amounts of hazardous wastes at the end of their product's lifecycle. While only concentration on the manufacturing stage of their product, companies lack concern for the proper disposal of their products and the effects that it has on the environment. Electronic Waste (E-Waste) involves the improper disposal of cell phones, computers, printers and other electronic waste that are filling landfills with hazardous and toxic materials. The solar energy technology industry should take interest in avoiding the same route by accounting for their product's entire lifecycle.

However since the manufacturing process for solar panels follow the same rules and regulations as the electronics industry, it technically can be considered environmentally friendly. If the solar industry is to provide a sustainable solution, it could learn from the mistakes of the electronics industry to change their approach in which they manufacture their product (Mulvaney, 2009).

This study presents a safe and sustainable process for the disposal of the major components of PV solar panels. This is done by incorporating existing recycling and waste management processes in order to implement a sustainable method of reducing waste, leading to a safe and sustainable solar energy industry.

1.1 Solar Panel Components

The typical crystalline silicon PV module consists of four main components: the front cover, encapsulate, solar cells, and the back cover as shown in Figure 1. The front cover is primarily made of glass, in some instances the front cover can be made of a polymer film. The encapsulant acts as an adhesive and connects the front and back covers to the solar cells. Typically this is made of ethylene-vinyl acetate (EVA), but polyvinyl butyral (PVB) can also be used. The solar cells in a silicon based PV module are either made from mono-crystalline or poly-crystalline technology. The back cover is tedlar film which is made from polyvinyl fluoride, providing a durable, weather-resistance back sheet for PV modules (Pern, 2009).

"The outer glass cover constitutes the largest share of the total mass of a finished crystalline photovoltaic module (approximately 65%), followed by the aluminum frame (~20%), the ethylene vinyl acetate encapsulant (~7.5%), the polyvinyl fluoride substrate (~2.5%), and the junction box (1%). The solar cells themselves only represent about four percent (4%) of the mass of a finished module" (Knut Sander, 2007).

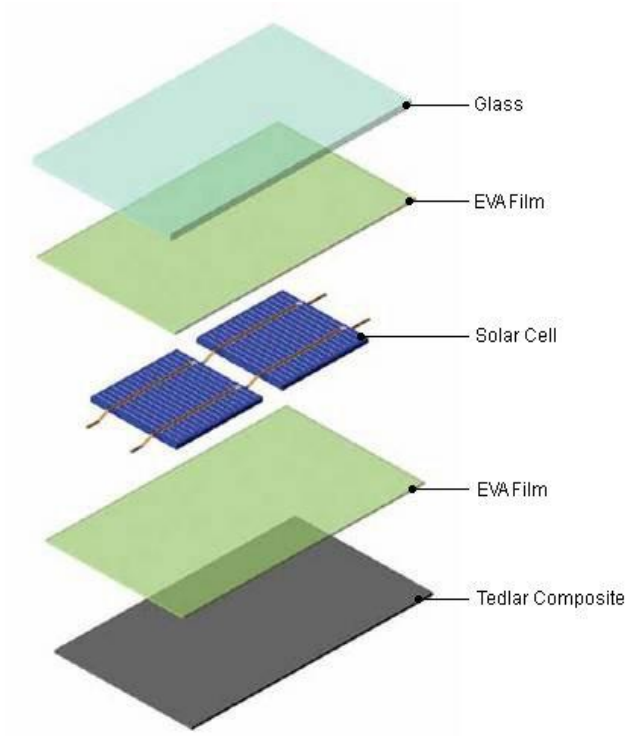


Figure 1.Encapsulation of a standard silicon PV module (Pern, 2009)

1.2 Concerns for the Disposal of Solar Panels

Safe disposal of solar panels suggests the decommissioning of solar panels in such a way that no harmful materials are released to the environment. As mentioned in section 1.1, solar panels are made up various components and each component has different properties as seen with respect to hazardous/non-hazardous and recyclable/non-recyclable.

Currently in United Stated there are no regulations for governing the recycling of solar panels and the recycling process varies by the manufacturer. The most commonly recycled components of the solar panels are glass (cover), aluminum frame and solar cells and hence do not pose any threat to the surroundings. Sometimes small quantities of valuable metals such as copper and steel are also recovered at the end-of-life of solar panels. "The ethylene vinyl acetate encapsulant and polyvinyl fluoride substrate are typically not recoverable and are removed through a thermal process. If not properly decommissioned, the greatest end-of-life health risk from crystalline solar modules arises from lead containing solders. Under the right conditions it is possible for the lead to leach into landfill soils and eventually into water bodies." (Good Company, 2010)

At the end stage of the solar panels, the main concerns are:

1. "Leaching of Lead: A highly toxic substance which can pollute the drinking water,
2. Leaching of Cadmium: Cadmium is a known carcinogen and is considered "extremely toxic" by the Environmental Protection Agency (EPA) and the U.S. Occupational Safety and Health Association (OSHA). Potential health impacts include kidney, liver, bone, and blood damage from ingestion and lung cancer from inhalation" (Texas Solar Energy Society, 2008),
3. If the solar panels are not reused or recycled, overtime there will be a significant loss of precious resources such as glass and aluminum,
4. As solar panels also use some rare metals like indium and gallium, not recovering them at the end life could cause their permanent depletion.

1.3 Scope of Work

In this project, research was carried put on two types of solar PV technologies namely, crystalline silicon and thin film, and the different companies or manufacturers that them. Through research, comparisons were done on various methods used by each solar PV technology's recycling, reuse, and disposal methods. Further, interviews were conducted with several cities' waste management departments in order to obtain further information on the actual practices performed.

1.4 Planning Procedure

The solar industry has the goal of providing an alternative method to harness energy; a method that is more environmentally friendly. According to First Solar, Inc. (First Solar website 2011), one of the objectives of their company is to "reduce dependence on scarce natural resources and curtail greenhouse gas emissions to improve our environment." The three major stages of an environmental friendly product's life cycle are manufacturing, usage, and end-of-life. During the usage phase, solar panels do not emit greenhouse gasses, can be used to reclaim degraded land, and reduces the need for energy generation from conventional energy sources. Since solar panels actually reduce their environmental impact during their usage phase, companies should focus on the environmental impact of the manufacturing and recycling stage.

In order for a solar company to succeed in this competitive market, companies need to reduce the cost of their product; one solution is to use reclaimed materials in lieu of raw materials. By recycling and reclaiming various materials during the panel's end-of-life stage, materials can be used for the manufacturing of new panels. In doing so, manufacturers will save money by avoiding the cost of harvesting new materials.

The focus of this research is on current disposal practices carried out at various manufacturers and communities. Research on methods of disassembling the panels and reusing majority of the materials for future panels was obtained. The focus of this study was on how to recycle, reuse and manage the waste that was produced throughout the end-of-life of the solar panels. Recommendations are given based on the current practices to improve the sustainability of the panels. This will ensure an environmentally friendly future for the solar industry.

At the end of the panel's life cycle, both solar modules and the various parts involved in manufacturing could be recycled. Furthermore, parts can be reclaimed if modules are defective, broken, or not needed by the customers. During the recycling process companies can reclaim the semiconductor materials used to make the PV cells, as well as aluminum, copper, glass, and other materials used. Once these parts are separated, either the same company or a third party can recycle the reclaimed materials using the existing recycling methods. Once recycled, solar companies can then use these materials to create new modules, bringing down their cost of manufacturing. Electronics companies have used similar process to reduce the environmental impact of their products. According to Recycling Solar PV Panels (2009), some of the major components of solar panels are glass, aluminum, and semiconductors. These components are also used in electronics products. Therefore, recycling practices can be used in both industries.

Investigation involving the cost of selling recycling parts to third party recycling companies and the cost of using recycled materials versus raw materials were studied for comparison. The data collected from these studies provided a better understanding of which materials are cost effective to recycle and allowed for a final data analysis to be presented and discussed.

A life cycle assessment (LCA) shows the environmental impact of a product over its life cycle, from raw material extraction to its end-of-life. By conducting an LCA, the parts that significantly contribute to a product's environmental impact can be determined and identified for further study. For this project, an LCA analysis was conducted on products similar to some of the major components used in solar PV panels. These LCA studies were generated using Gabi 4 education database and software tool. Data was drawn from previous LCAs and appropriate databases. For the purpose of this project, a full LCA will not be conducted.

First Solar is a solar company that produces thin film solar PV modules based on cadmium telluride technology (CdTe). Currently, First Solar makes up the majority of the CdTe based PV market and for this project First Solar will be used as a model company in this industry. Furthermore, First Solar is the only U.S. based PV company that has implemented a recycling program (Beck, 2010). First Solar has as established recycling program and is able to reduce their cost of manufacturing by reclaiming materials from their modules. This program was analyzed and studied in detail for comparison and recommendations to other solar technologies. An LCA analysis has already been conducted for First Solar's modules, however due to proprietary information; First Solar will not release a copy of their results. Also, an LCA was conducted on the amorphous silicon modules manufactured by Applied Materials, Inc. However, due to the same reason precluded the authors of this report from being able to obtain a copy of the report.

Currently, the majority of the solar market is silicon technology and it seems that there is not a recycling program at any of these companies. The analysis provided could encourage more solar companies to consider implementing such recycling practices

1.5 Justification

In order for the solar PV industry to be truly sustainable, it must account for their product's entire life cycle including the materials and pollutants emitted from the manufacturing processes to the solar panels' end-of-life. Furthermore, not only will the solar industry reduce its overall environmental impact through recycling, but could reduce their cost of manufacturing.

2.0 Literature Survey

Information was gathered from a variety of sources including published papers, journal articles, white papers, and seminars. Topics reviewed included the manufacturing processes, solar companies going green, proper waste disposal, and future issues regarding Solar PV manufacturing.

2.1 Electronic Waste

Personal Computers (PCs) have a relatively short-life-cycle due to the rapid changes in technology resulting in a large amount of electronic waste created at their end-of-life. The dismantling process is used in order to recover valuable materials and reduce the effects of hazardous materials from scrap PCs. During the dismantling process, both useful and hazardous materials are manually separated and retrieved. These recovered materials are then sent to the appropriate facilities for recycling and treatment. The most significant components that are recovered from this process are cathode ray tubes (CRT) and the printed circuit boards. Typical circuit boards are made of epoxy resin, fiberglass, and copper.

In one case study, recycling data from a scrap computer recycling plant in Taiwan was analyzed (Lee, 2004). After dismantling, simple materials are sold to local secondary material recycler and complex materials are treated before recycling or disposal. Smelting process, physical separation method, and scraping method is used in dismantling process. The data shows that the recycling plant can recover 94.75% weight of the PC's main machines.

A Silicon Valley Toxic Coalition White Paper (Mulvaney, 2009) states electronic waste is similar to solar panels in the respect that they would leave toxic materials if they were to end up in landfills (materials leach into groundwater), or incinerators (burning materials resulting in emission of toxic to the air). The recycling of PV panels can be complicated due to the different PV technologies and the diversity of materials used. Different crystalline silicon PV panels can mechanically or manually be disassembled in a process similar as e-waste and reused for future panels.

Proper recycling methods for the materials used in three different PV technologies are presented in “Toward a Just and Sustainable Solar Energy Industry”, A Silicon Valley Toxic Coalition White Paper (Mulvaney, 2009). The regulations and procedures in the electronic industry are similar to those followed by the solar PV industry. There are regulations for manufacturing chemicals and materials, PV product disposal, and end-of-life which need to be followed by solar industry. The regulations followed in the U.S. include: Toxics Release Inventory (TRI), Materials Safety Data Sheets (MSDSs), Resource Conservations and Recovery Act (RCRA), California’s Hazardous Waste Control Law (HWCL), and Environmental Protection Agency (EPA), Toxicity Characteristic Leaching Procedure (TCLP) standards (Mulvaney, 2009).

Some of the recommendations for reducing the environmental impacts of solar panels are (Mulvaney, 2009):

- Ensure manufacturers are responsible for lifecycle impacts of the products
- Expand recycling technology
- Reduce/eliminate toxic materials used
- Ensure proper testing of materials

2.2 Solar Companies Going Green

Abbaszadeh (2008) discusses two important challenges that the Photovoltaic (PV) industry faces today. First, the comparison of cost of electricity generated by conventional sources to solar energy, and second, the solar industry must ensure that it maintains a sustainable manufacturing profile. The overall study stated that there are excellent opportunities for PV industries to reduce both the manufacturing costs and environmental impact. Surprisingly, although most companies have initiated to develop recycling programs, they are proceeding under the assumption that recycling will cost more than it could save. Such companies are preparing for that expense by creating a variety of funding mechanisms based on the principle of producer responsibility (Gies 2010).

Due to the solid waste that solar PV creates, McDonald and Pearce carried out a study titles "the potential need for PV recycling policies by analyzing existing recycling protocols for the five major types of commercialized PV materials" (2010). These technologies included mono-crystalline, poly-crystalline, amorphous-silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS). With the expansion of the PV industry it is anticipated that there will be a remarkably large challenge of proper waste disposal in 25-30 years. Although PV creates relatively small solid waste, this amount cannot be ignored during the disposal phase of the solar modules.

2.3 Feasibility Studies

The feasibility of recycling photovoltaic cells is another theme that was prevalent in much of the research performed. In a study on end-of-life management and recycling of PV modules (Fthenakis, 2000), some long-term environmental strategies for solar cells are discussed. An idea of recycling the solar panels is proposed based on the current collection/recycling infrastructure and emerging recycling technologies. The study indicates that technologies already exist for the recycling of PV modules and the costs associated with recycling are not excessive.

The photovoltaic industry has been investigating ways to recycle used solar cells and manufacturing waste. Another recycling program was outlined (Fthenakis & Moskowitz, 2008), and presented effective and economical methods of separation that have been developed. These methods can be used in both small and large-scale recycling. Both studies showed that the recycling of solar panels is technologically and economically feasible.

An article by Tsoutsos, Frantzeskaki & Gekas (2005) analyzed the potential burdens to the environment that result from the construction phase, installation, and the demolition phase. During these phases, noise and visual intrusion, greenhouse gas emissions, water and soil pollution, energy consumption, labor accidents, impact on archaeological sites or on sensitive ecosystems, negative and positive socio-economic effects were measured. Research on the recycling of photovoltaic panels and manufacturing waste optimizes the recovery of glass, cadmium and tellurium while minimizing the life-cycle emissions and energy use were studied by Fthenakis et al. in 2006. During that study, the recovery of these items is what makes the manufacture of photovoltaic modules more economical as these items could be reused for future projects.

A seminar was attended on Life Cycle Assessment (LCA) to learn more about Life Cycle Assessment (LCA). The steps of an LCA procedure, such as goal and scope definition, inventory analysis, and impact assessment was explained. Further, functional unit, system boundaries and allocation procedure, and type of data used were defined. A case study of an LCA in IT department was presented and described the usefulness of an LCA analysis for improvements in different stages of operations and data centers (Shah, 2011).

3.0 Recycling

3.1 General Recycling Methods

Various municipalities in the bay area were contacted to determine the costs that consumers would receive for recycling common items. The city of Palo Alto uses Zero Waste and Green Waste for their recycling. In contacting Zero Waste, it was determined that the station was closed in July 2011. The Green Waste of Palo Alto and Mountain View use the Smart Station in Sunnyvale. The Sunnyvale Smart Station shared the costs that consumers may receive for recycling and table 1 shows the summary of these costs for different materials.

Table 1 Sunnyvale Smart Station's prices for various recyclable materials

Item	$/lb
Aluminum	1.504
Glass	0.104
#2 Plastics - HDPE	0.55
PVC	1.33
LDPE	1.98
Bimetal Cans	0.26
#1 Plastics - PETE	0.93
PCS	4.18
PP	0.31
#7	0.37

3.2 Process of Making and Recycling Glass

Glass has several properties and characteristics and is seen in various shapes and forms such as jars, bottles, glassware, etc. Glass making industry is very diverse and uses various technologies.

Production of glass comprises of two different steps depending on what we are trying to make:

1. The float glass process-produces sheet glass
2. Glass blowing-produces bottles and containers.

“The raw materials used to make glass are usually:

- Cullet (recycled glass)
- Silica sand
- Soda ash (brings down melting temperatures)
- Limestone (enhances durability)
- Materials added to produce different colors.”

(Environmental Overview, 2007)

Glass Packaging Institute, 2007 explains the procedure used in the production of glass as follows:

Batch house is one of the initial steps required in the production of glass in which the raw materials are taken to the batch house and are visually inspected to make sure their size are standard. The raw materials are then sent to the storage silo and before going into the furnace, they are separated into different batches and then weighed. After weighing and calibrating the raw materials, they are put into the mixer which is located right above the furnace. This mixed batch then is transported to the furnace by a horizontal belt conveyor.

To decrease the possibility of dusting and segregation, water is usually added to the mixed batch before it goes into the furnace.

Figure 2.Batch house
(http://www.gpi.org/glassresources/education/manufacturing/section-32-batch-house.html)

Once the wet batch of raw materials goes into the furnace, it is heated to 2350 °F at a constant temperature and the glass gob cools slowly to a working temperature around 2150 °F.

“Then the glass goes through a two-stage molding process by using either the press-and-blow or the blow-and-blow techniques.

The stages for this are:

- Obtain a gob of molten glass at the correct weight and temperature
- Form the primary shape in a first or blank mold by pressure from compressed air or metal plunger
- Transfer the primary shape into the final mold
- Complete the shaping process by blowing the container with compressed air to the shape of the final mold
- Remove the finished product from the post forming process.”
(Environmental Overview, 2007)

Process of recycling the glass is fairly simple and done throughout the United States. Consumers often buy various products such as juices and milk in the glass bottles and are charged with a small recycling fee at the time of purchase.

The consumers are expected to put their used glass bottles in the respective recycling bins. These are then collected by the recycling agencies and are taken over to the locations where the recovered glass is crushed into small pieces (cullet) and used as a raw material for manufacturing the new glass. Other raw materials mentioned above are added and hence a new glass packaging is formed.

3.3 Benefits of Glass Recycling

One significant advantage of glass recycling is that glass can be re-processed an indefinite number of times, which means they can be recycled again and again, with no loss of purity or quality in the glass. Bottling companies that produce bottles for beverages are much more cost efficient when they produce bottles from recycled glass. Everything you always wanted to know about recycling (2011) states that making glass from recycled glass (cullet) makes the glass less expensive to produce, because for every ton of recycled glass 1.2 tons of raw materials have been saved. Those savings can then be passed on to the consumer.

Figure 3.Recycling glass cullet
(http://www.recyclingfactsguide.com/advantages-of-recycling-glass)

The process of making new glass means heating sand and other substances to increasingly high temperatures, which requires a lot of energy and creates a lot of pollution. Making recycled glass products from cullet also consumes 40 percent less energy than making new glass from raw materials, because cullet melts at a much lower temperature. Less energy converts to less fossil fuel being burned creating 20% less air pollution and reducing the water pollution by 50%. This amounts to enough savings to light a 100-watt light bulb for hours. (West, 2011)

Glass recycling also means less garbage taking up landfill space. Recycling saves the glass that would otherwise be thrown into the landfills. Although glass is not harmful to the environment, it isn't biodegradable.

3.4 Existing Solar PV Recycling Methods

At the time of our research there were two solar companies that implemented a recycling process for their solar panels, Deustche Solar and First Solar.

Deutsche Solar recycling process was designed in 2003 for the recycling of crystalline silicon panels. Through a thermal process, plastic components are separated from the panel, while the remaining parts are manually removed. Once the components (glass, aluminum, steel, etc.) are separated, they are sorted and placed into their respective established recycling processes. The solar cells, on the other hand, are re-etched into wafers. This is done by placing the solar cells through a chemical process in which they are cleaned, until a new silicon wafer appears. At this point, the re-treated wafers are re-etched and can be used as a new solar cell. "The etching process involves the following sequence of steps: removal of metallization, removal of AR layer, isotropic removal of n+ and p+ doping, a surface finish, rinsing, and drying (Monier, 2011)"

First Solar's treatment process for their CdTe panels was developed in the late nineties and was established in 2003. The collected panels are first shredded and put into a hammer mill in order to break the glass down to four to five mm pieces. The semi-conductor materials are then separated through the addition of acid and hydrogen peroxide. The glass shards are then filtered out of the liquid waste through the usage of a vibrating screen. These shards are then rinsed, leaving the glass cullet, which can then be used to manufacture new glass pieces. The liquid that the glass was removed from gets pumped into precipitation unit where the semiconductor materials can be filtered out and recovered. Figure 4 displays the process in which First Solar's CdTe panels are recycled. First Solar states that their recycling process can recover 90% of the glass and 95% of the semiconductor materials for reuse in new PV panels. Currently, First Solar has implemented a recycling process at their three manufacturing plants. However, due to the lack of panels at their end-of-life, the recycling process is primarily used for recovering materials from broken panels or manufacturing scraps. (Monier, 2011)

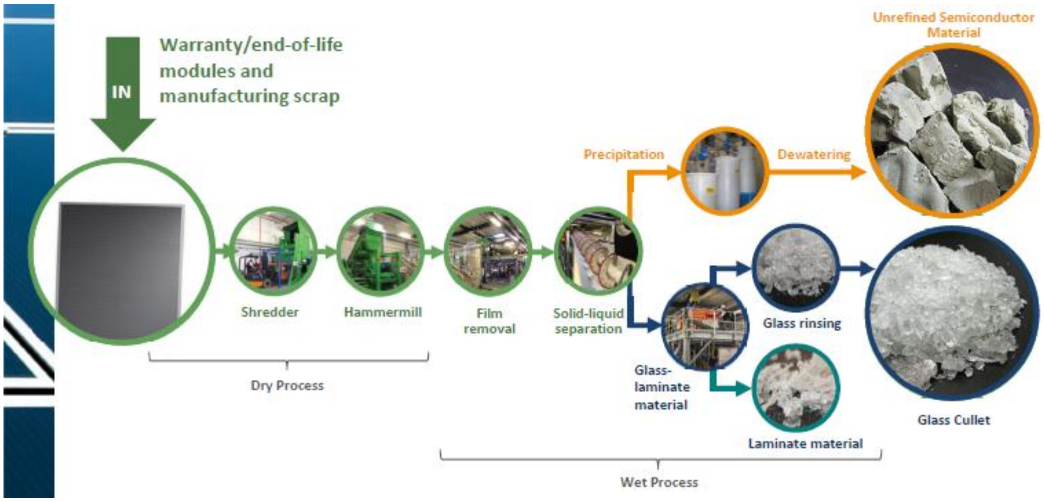


Figure 4.Design of First Solar's module recycling technology

4.0 Life Cycle Assessment

4.1 Life Cycle Assessment Overview

Life cycle assessment (LCA) is an analysis of a product's life cycle from its cradle-to-grave. In an LCA, raw material usage and pollutant emissions are quantified at every stage of the product's life: manufacturing, transportation, usage, and end-of-life stages. An LCA is valuable because it not only accounts for the materials that the actual product is made of, but also the machines or vehicles used to manufacture or transport the product. In a sense it takes into account the whole picture. Depending on the assumptions and system boundaries that are created, an LCA can be used to represent a very broad or very detailed process. The results generated by an LCA can be used to compare which products or methods are more environmentally friendly.

There are four key stages in an LCA, Goal and Scope definition, Inventory Analysis, Impact Assessment, and Interpretation; these four steps are shown in Figure 5.

1. Goal Definition and Scope – The product and purpose of the LCA is determined and described. It is in this step, defining the system boundaries, what types of environmental impacts are being considered, and the level of detail is determined.
2. Inventory Analysis – In this stage, a system model is built according to the defined goal and scope. This system model is usually displayed as a flow chart of linking activities and processes. Data collection also occurs during this stage, quantifying the raw materials used, products, waste, and emissions at each stage. The amount of resources used and pollutants emitted are then calculated based upon a defined functional unit that links each activity of the product's life cycle. A functional unit can be 50 bottles or 1 m2 of solar PV panel.

3. Impact Assessment – The data collected from the inventory analysis is then used to represent each stages environmental impact. In this step, the data is classified by the type of environmental impact and then characterized.

4. Interpretation – This step occurs at all phases and allows the sure to make revisions and share their results (Baumann, 2004). The result of the assessment is analyzed and presented in this step.

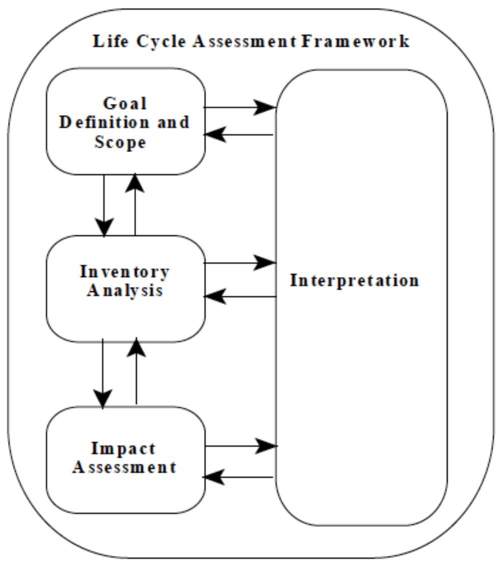


Figure 5.Phases of an LCA (Life Cycle Assessment: principles and practice, 2006)

4.2 GaBi Overview

According to GaBi website (2011), GaBi is an all-in-one software tool used for modeling products' life cycle. The software tracks material, energy, and emission flow of the model as well as work time, social issues, and economic cost. GaBi uses Life Cycle Inventory (LCI) database maintained by PE International to use in their modeling software. PE International offers sustainability software, sustainability consulting and environmental databases. Based on the customer's needs, different database will be provided with the software. GaBi offers an educational version of the software available for free to students. The educational version of the software, however, does not have the complete database available. For this project, GaBi 4 educational version was used to model the life cycle analysis.

4.3 Results of Case Studies

Due to lack of detailed data needed to perform the LCA's, some materials similar to the ones used in PV solar panels are used. The data is taken from different online websites since companies would not share this information due to confidentiality. Major components of a 0.65 m^2 polycrystalline silicon PV panel are glass (4700 g/module) and aluminum frame (1200 g/module) (Stoppato, 2006). LCA analysis is done on steel paper clip and white glass bottle. Two different end-of-life models are created for the steel paper clip; disposed or recycled/reused. The model for white glass bottle is created for disposal scenario, only. Further, a complete study of cradle-to-cradle of glass container is reviewed and the results are shown.

4.3.1 Cradle-to-Cradle: The Complete Life Cycle Assessment of North American Container Glass

North American glass industry has done a complete cradle-to-cradle Life Cycle Assessment (LCA) study of container glass in order to measure the complete impact of carbon footprint of the product. The Glass Packaging Institute (GPI) represented the data for the study. The data was collected from 105 furnaces representing 75 percent of the glass production in North America; producing 8.17 million metrics tons of glass containers produced in 2007. Wine, beer, foods, jams, condiments, spirits, non-alcoholic beverages, and cosmetics containers were used for the study. Figure 6 shows the complete life cycle flow diagram used for the study. The shaded areas indicate the processes which were not included in the study. The figure indicates the study includes all the manufacturing and end-of-life steps.

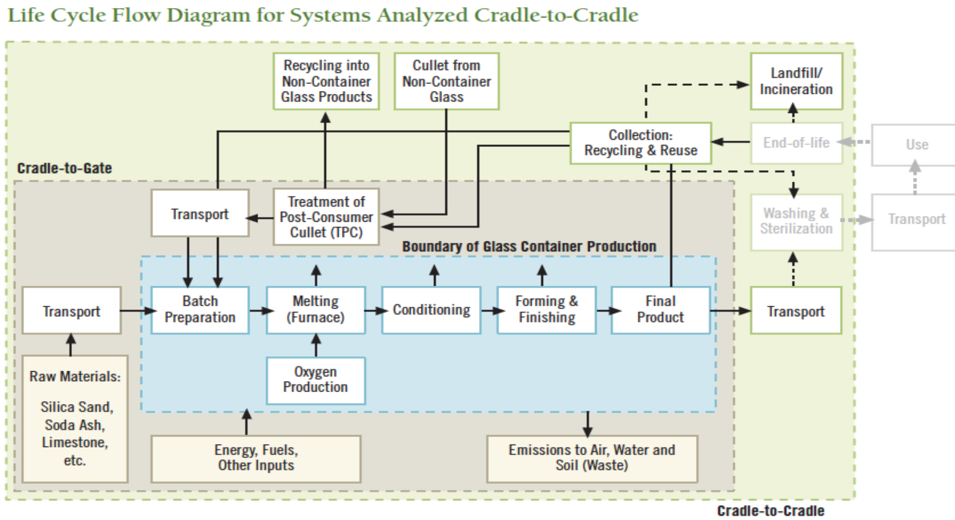


Figure 6.Life cycle flow diagram for systems analyzed cradle-to-cradle
(Cradle-to-Cradle: The Complete Life Cycle Assessment of North American Container Glass)

The study was conducted by PE Americas who are independent consulting group and part of PE International. The functional unit for this study was 1 kg of container glass.

The study includes:

- Extraction, processing, and transportation of raw material
- Extraction, processing and transportation of cullet
- Fuel and energy used for melting and shaping of the glass
- Transportation of the product to the end user
- Post-consumer cullet treatment
- Closed-loop process of glass packaging
- Recycling of glass packaging
- Loss due to landfill and incineration.

The results of the study indicate the total fossil energy consumer known as primary energy demand (PED) and global warming potential (GWP) decreases as the number of recycling and recovery is increases. The study shows greenhouse gas emissions; in particular CO_2 can be reduced during manufacturing process by using cullet instead of raw materials. During 2007, which this study was based on, 23 percent of post-consumer glass containers were recycled which saved 894 thousand metric tons of CO_2 emission. This is equivalent to annual greenhouse gas emissions from 159,024 passenger vehicles.

4.3.2 Steel Paper Clip

An analysis of steel paper clip is performed using GaBi 4 education software. The functional unit for this analysis is one paper clip. The mass of the paper clip is set to be 0.350g and the result of the data shows the analysis for manufacturing, usage, and recycling of 1000 paper clip. The data is taken from GaBi 4 education database provided by the software. The model is created for two different cases. Case A, represents cradle-to-gate life cycle of the steel paper clip under study. In this case, paper clip ends up in the landfill at the end of its life. Case B represents cradle-to-cradle life cycle of the steel paper clip under study. In this case, paper clip is recycled and 100% of the material is reused as raw material.

The study includes:

- Manufacturing of steel wire and paper clip bending
- Transportation of steel wire manufacturing and paper clip bending
- Use phase of paper clip

Assumptions for the analysis include:

Case A:

- No environmental impact, power consumption or release of emission during use phase
- Paper clip is thrown away

Case B:

- No environmental impact, power consumption or release of emission during use phase
- Paper clip is sorted out of municipal waste with magnetic separator
- Paper clip is recycled
- 100% of the recycled material is reused as raw material

Figure 7 and 8 show the flow chart used for modeling the life cycle for Case A and Case B respectively.

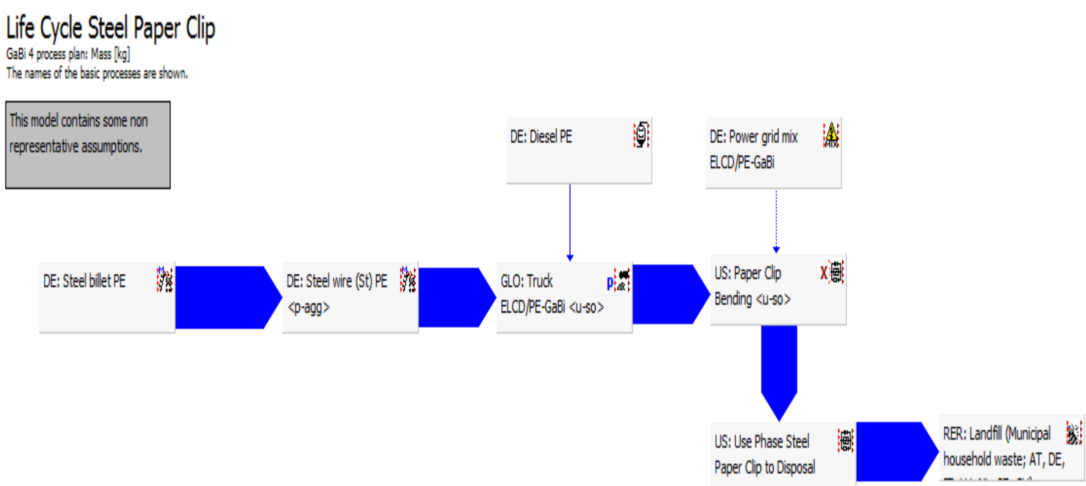


Figure 7.Flow chart of cradle-to-gate life cycle of steel paper clip (Case A)

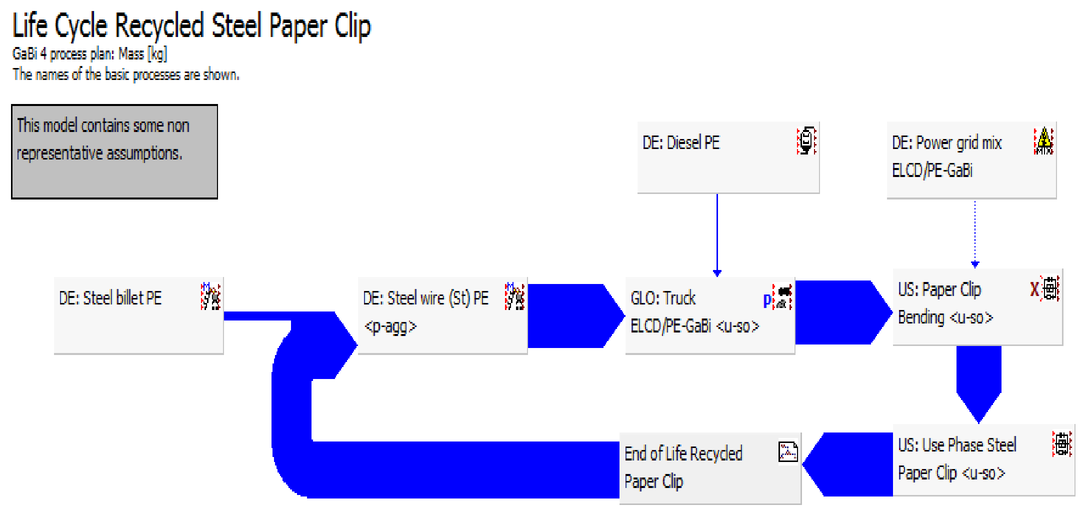


Figure 8.Flow chart of cradle-cradle life cycle of a steel paper clip (Case B)

The Global Warming Potential effects are studied using GaBi 4 education software. The weak points of the life cycle (more than 10% of the total sum of the emissions) indicate that CO_2 emission to air has the most impact on Global Warming Potential of the process. The GWP is calculated in carbon dioxide equivalents meaning that greenhouse potential of an emission is given relative to CO_2. The time range of 100 years is used for the GWP assessment.

Figure 9 represents the results of the study in terms of kg CO_2-Equiv. for Case A. The result shows for the sample size of 1000 steel paper clip, 0.587 kg CO_2-Equiv. of Global Warming Potential is emitted during the steel billet process. This is the manufacturing process of the flow where the raw material is turned into steel wire. Figure 10 represents the same result in the percentage term relative to other GWP's. It is shown that CO_2 emission during the steel billet process contributes to 60.361% of the GWP emission of the flow.

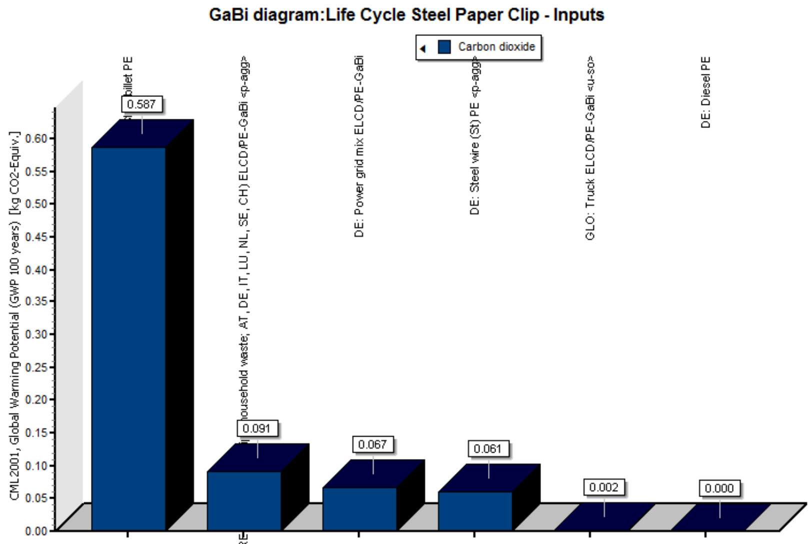


Figure 9.Global warming potential of CO_2 for Case A (kg CO_2 equivalent)

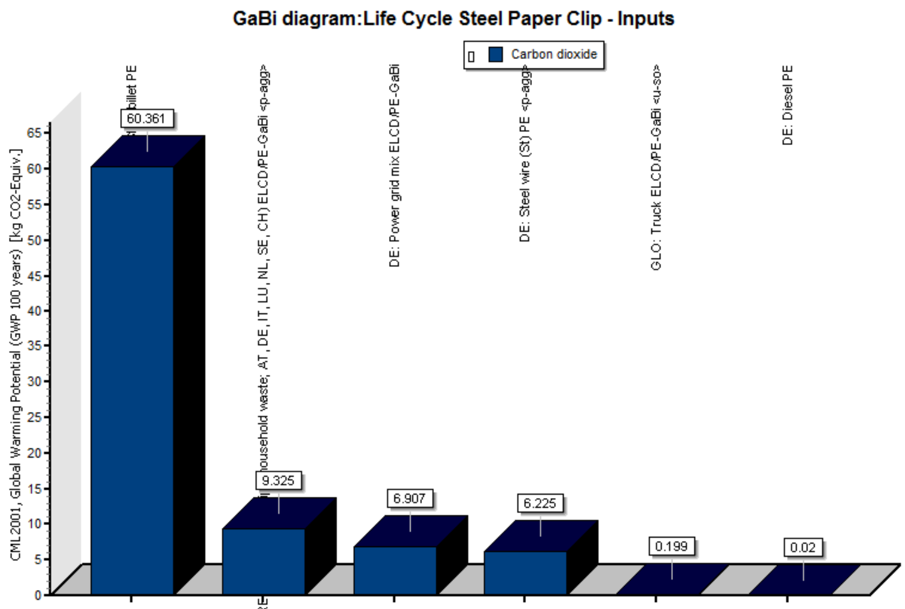


Figure 10.Global warming potential of CO_2 for Case A (relative percentage)

The amount of aluminum used in a 0.65 m^2 polycrystalline silicon PV solar panel is 1200g (Stoppato, 2006). The data presented for 1000 steel paper clip each weigh 0.350g (total weigh 350g) show 0.587 kg CO_2-Equiv. of GWP. Therefore, it can be estimated that one 0.65 m^2 polycrystalline silicon PV solar panel emits about 2.012 kg CO_2-Equiv. of GWP.

Figure 11 represents the results of the study in terms of kg CO_2-Equiv. for Case B. For the same sample size of 1000 steel paper clip, the largest CO_2 emission is during the recycling phase (0.177 kg CO_2-Equiv.) followed by steel billet process (0.093 kg CO_2-Equiv.). Adding the two emission values, the total emission during recycling and steel billet process is 0.27 kg CO_2-Equiv., which comparing to Case A's result (0.587 kg-CO_2-Equiv.), it shows the effect to GWP decreases by recycling the paper clips.

Figure 12 represents the same result in the percentage term relative to other GWP's. It is shown that CO_2 emission during the recycling process contributes to 42.737% and the steel billet process contributes to 22.163% of the GWP emission of the life cycle. The total percentage for the two processes is 64.9%.

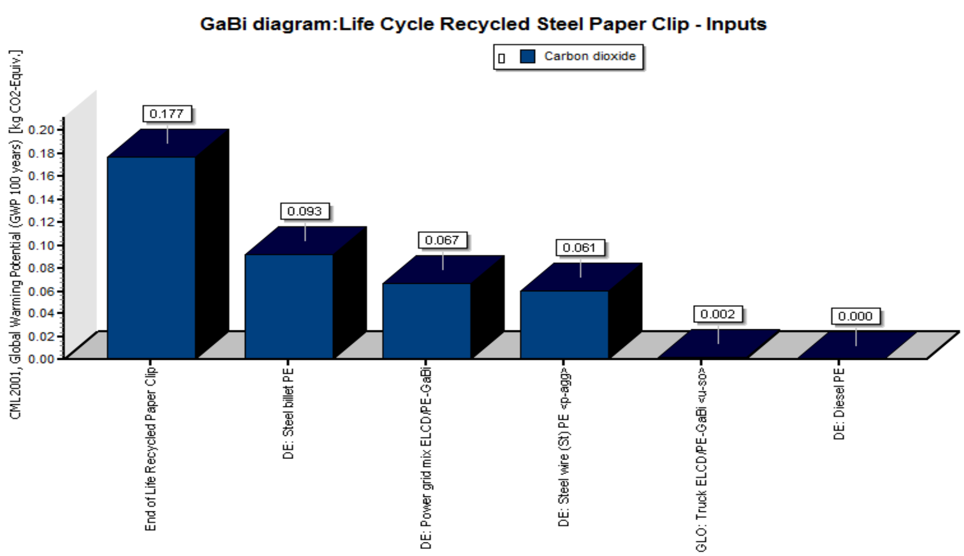


Figure 11.Global Warming Potential of CO_2 for Case B (kg CO_2 equivalent)

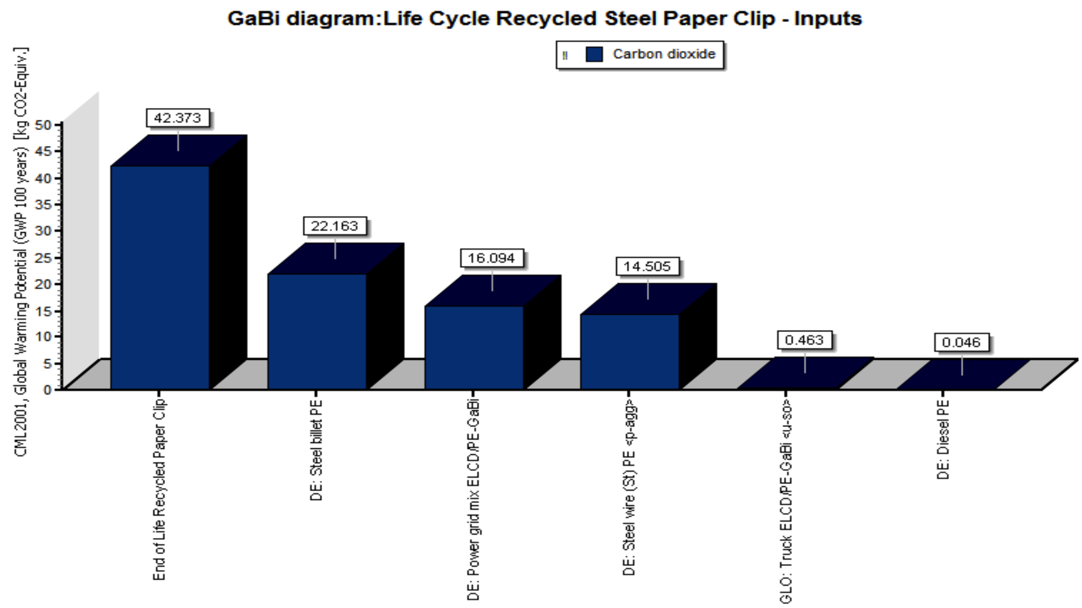


Figure 12.Global Warming Potential of CO_2 for Case B (relative percentage)

The data presented for 1000 recycled steel paper clip each weigh 0.350g (total weigh 350g) show 0.27 kg CO_2-Equiv. of GWP for the two processes. Therefore, for the same solar panel as compared in Case A, the processes emit about 0.926 kg CO_2-Equiv. of GWP.

4.3.3 White Glass Bottle

An analysis of white glass bottle is performed using GaBi 4 education software. The functional unit for this analysis is one white glass bottle, which weigh 0.395 kg. The color used for the bottle effects the process of making the glass bottle. Since data available for this study is for white glass bottle, this will be the only case studied for this project. The result of the data shows the analysis for manufacturing, usage, and disposal or 1000 white glass bottles. Due to lack of data for recycling phase of the life cycle, only one case is being studied; cradle-to-gate where the white glass bottle ends up in the landfill at the end of its life. Using GaBi 4 education, a flow diagram of the white glass bottle is generated. This flow is shown in figure 13. The data is taken from Hand Outs

Effective LCA with SimaPro7 (December 2007). Table 2 shows the summary of data used for manufacturing of one white glass bottle. The data for disposal process of white glass bottle was taken from the data base provided by GaBi 4 education software.

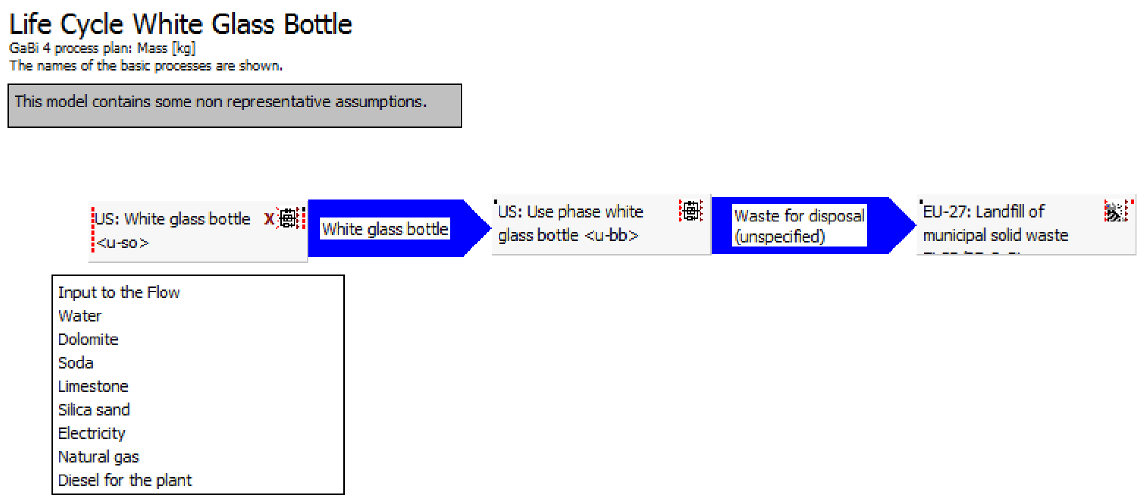


Figure 13.Flow chart of cradle-to-gate life cycle of white glass bottle

Table 2.Inputs and outputs for manufacturing one white glass bottle

Inputs from nature	2 lit water 53 g Dolomite
Material	73 g Soda 42 g Limestone 248 g Silica sand
Fuel/Electricity	0.244 kWh Electricity 3.57 MJ Natural gas 0.0147 MJ Diesel (plant)
Emission to Air	0.473 kg Carbon dioxide 0.000018 kg Hydrogen fluoride 0.0021 kg Nitrogen oxides

The study includes:

- Manufacturing of white glass bottle
- Disposal of white glass bottle

Assumptions for the analysis include:

- No environmental impact, power consumption or release of emission during use phase
- Bottle cap is not considered
- White glass bottle
- Labels for the bottles not considered
- Transportation to consumer and recycling center not considered

Figure 14 represents the results of the study in terms of kg CO_2-Equiv. The result shows for the sample size of 1000 white glass bottle, 473 kg CO_2-Equiv. of Global Warming Potential is emitted during the manufacturing process. During this process, raw material is turned into glass, melted, shaped and molded, and air blown. This study shows that the biggest impact is during the manufacturing phase which according to Cradle-to-Cradle: The Complete Life Cycle Assessment of North American Container Glass (2007), can be reduced if recycled glass is used instead of raw materials. Figure 15 represents the same result in the percentage term relative to other Global Warming Potential. It is shown that CO_2 emission during the manufacturing process contributes to 63.921% of the GWP emission of the flow.

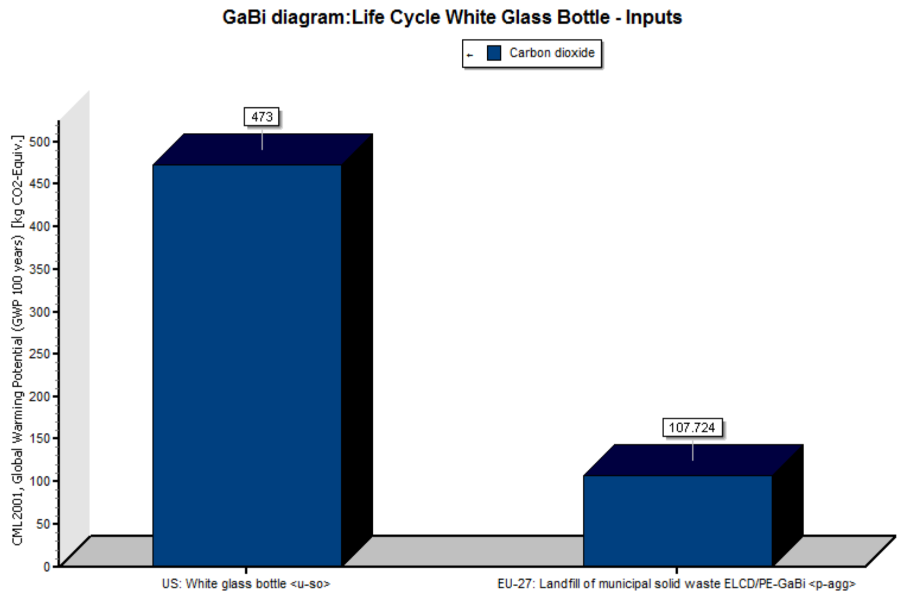


Figure 14.Global warming potential of CO_2 for white glass bottle (kg CO_2 equivalent)

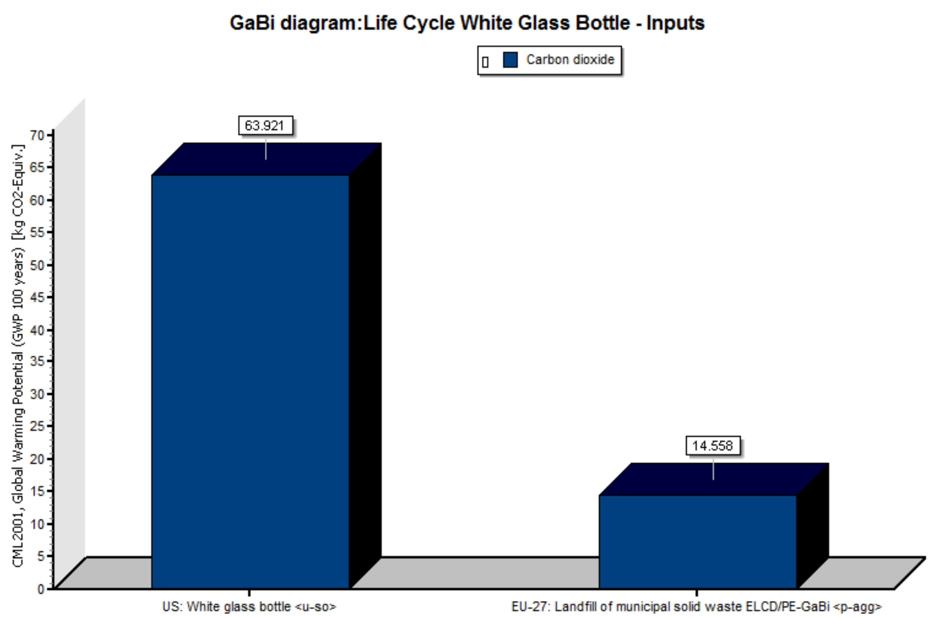


Figure 15.Global warming potential of CO_2 for white glass bottle (relative percentage)

The amount of glass used in a 0.65 m^2 polycrystalline silicon PV solar panel is 4700g (Stoppato, 2006). The data presented for 1000 white glass bottle each weigh 395g (total weigh 395 kg) show 473 kg CO_2-Equiv. of GWP. Therefore, it can be estimated that a 0.65 m^2 polycrystalline silicon PV solar panel emits about 5.628 kg CO_2-Equiv. of GWP.

5.0 Economic Justification

The following sections will provide the market size, competitors and customers that would be impacted by this study.

5.1 Executive Summary

The increasing awareness of waste management is leading many companies to think and come up with ideas that can prevent hazardous waste from ending up in landfills. Solar energy is a sustainable energy source and presents a clean solution; however issues regarding the solar panel's end of life stage must be addressed as well. This project attempts to present a sustainable method in which solar panels are safely disposed of.

Through research, our four person team collected information regarding current recycling schemes, how components of a solar panel can be recycled, and the economic feasibility of the actual recycling process. From our research we attempted to develop a business model in which we could create a firm that would act as a consulting company for various solar companies. As a consulting company, our firm would provide solar companies with a cost analysis focused on the profits that can be made through the recycling program. Through the analysis of the current and future solar market, we expect such a firm to excel and have numerous opportunities and customers. Furthermore since companies in the United States currently have not shown plans to recycle solar panels, our firm would have no potential competitors.

We also developed a cost analysis of our firm. By accounting for the development cost of this project and estimated future projects, we calculated a profit and loss statement, the break even point, and a five year return on investment.

5.2 Problem Statement

Solar energy is considered as a clean solution because it is a renewable energy source. However, if the solar industry is to truly present a sustainable solution it must account for the photovoltaic solar panels' end-of-life phase.

Established manufacturing processes in the electronics industry are creating alarming amounts of hazardous wastes at the end of their product's lifecycle. Companies within this industry lack concern for the proper disposal of their products and the effects that it has on the environment. If the solar industry is to provide a sustainable solution, it could learn from the mistakes of the electronics industry to change their approach in which they manufacture their product (Mulvaney, 2009).

This study attempts to present a safe and sustainable process for the disposal of the major components of PV solar panels. This is done by incorporating existing recycling and waste management processes in order to implement a sustainable method of reducing waste, leading to a safe and sustainable solar energy industry.

5.3 Solution and Value Proposition

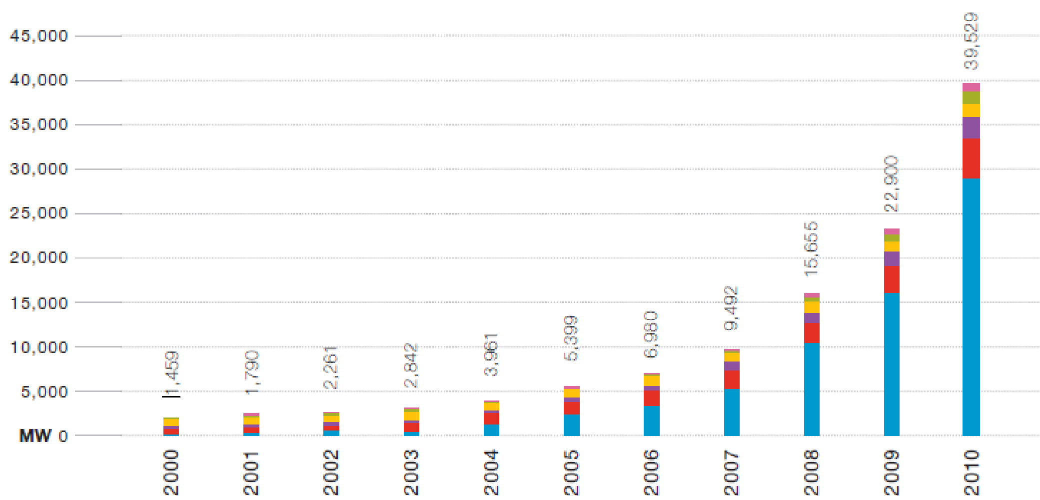
The firm we have chosen to create is an engineering consulting company with four partners. Our company concentrates on researching recycling processes, the environmental impact, and developing cost analysis for solar PV panels. The partners consist of one sales and marketing engineer who is focused on developing business opportunities and finding potential customers. The three remaining consultants are engineers who work closely together when consulting a company with a project. A life cycle analysis (LCA) is conducted by one of the engineering consultants; another engineer primarily works on researching current and potential recycling methods that can be practiced by the particular company, while other engineer develops addition solutions to improve the recycling program.

Once the sales and marketing engineer has been contacted by a corporation to discuss the possibilities within their company, that person puts together a proposal of the services that the company is able to offer. As soon as the offer has been negotiated into terms that both companies are ready to work with, the remaining 3 engineers are put to work. These engineers spend an extensive amount of time researching the various recycling opportunities that the company can utilize to maximize their recycling results. The sales and marketing engineer then gathers the team together to present the proposal to the company. Should they agree with the findings, all partners within our consulting company work together with their core management team to help implement the findings so that the company is now ready to maximize their profits.

5.4 Market Size

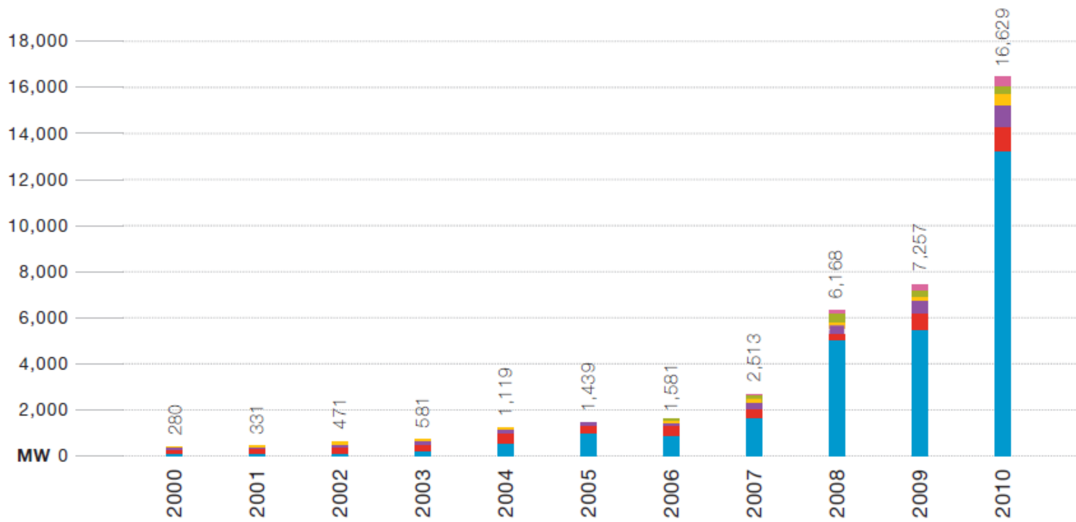
Currently solar companies in the U.S. do not have a clear recycling plan, and for this reason the market size for the recycling of solar panels is uncertain. The value that a solar company will place on implementing a recycling program is dependent on the profit that can be made. We believe with the exponential growth of the solar market and the increased production of solar panels, there will be opportunities for companies to take advantage of a solar PV recycling program.

The solar photovoltaic industry provides a solution to critical to environmental issues and sustainability. The industry has seen an exponential global growth in the market in the past decade shown in Figure 16. Between 2009 and 2010, the World's PV capacity doubled, and over the past decade the World's PV capacity has increased from 1,459 to 39,529 GW-a 2700% increase. Figure 17 displays the annual increase in global PV capacity.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
China	19	30	45	55	64	68	80	100	145	373	893
APEC	38	43	49	57	66	80	112	170	466	718	1,191
Rest of the world	758	814	894	971	1,000	1,010	1,128	1,190	1,303	1,427	1,844
North America	146	177	222	287	379	496	645	856	1,205	1,744	2,727
Japan	318	452	637	860	1,132	1,422	1,708	1,919	2,149	2,632	3,622
EU	181	275	414	613	1,319	2,324	3,307	5,257	10,387	16,006	29,252
Total	**1,459**	**1,790**	**2,261**	**2,842**	**3,961**	**5,399**	**6,980**	**9,492**	**15,655**	**22,900**	**39,529**

Figure16. Global cumulative installed PV capacity (GW) (EPIA, 2011)



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
China	0	11	15	10	9	4	12	20	45	228	520
APEC	5	5	7	8	10	13	33	59	300	258	473
Rest of the world	88	56	80	77	29	10	118	63	115	130	417
North America	23	31	46	65	92	117	149	212	349	539	983
Japan	112	135	185	223	272	290	287	210	230	483	990
EU	52	94	139	199	707	1,005	983	1,950	5,130	5,619	13,246
Total	**280**	**331**	**471**	**581**	**1,119**	**1,439**	**1,581**	**2,513**	**6,168**	**7,257**	**16,629**

Figure 17.Global annual installed PV capacity (GW) (EPIA, 2011)

Currently most solar panels are made of crystalline silicon wafers, while the second most common PV technology used in panels are thin-film as shown in Figure 18. Overtime, thin film and other emerging PV technology will increase their market share over the PV market. The market share of various thin film PV technologies through 2020 can be seen in Figure 19. The main tradeoff between these technologies is efficiency and cost per watt of electricity generated. Thin-films are less efficient when converting solar irradiation to electrical power but cost less to make. However, thin-films have the disadvantage of taking 15 to 40 percent more installation space due to the lower efficiency, limiting this technology to commercial buildings. (Wicht, 2009)

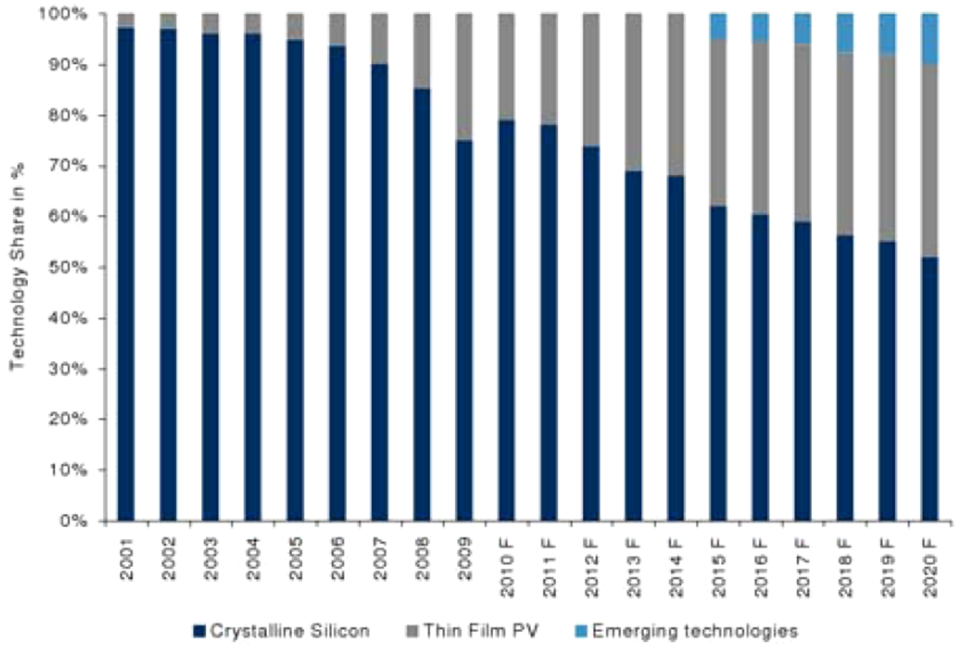


Figure 18.Global market share of solar PV technologies (GBI Research, 2010)

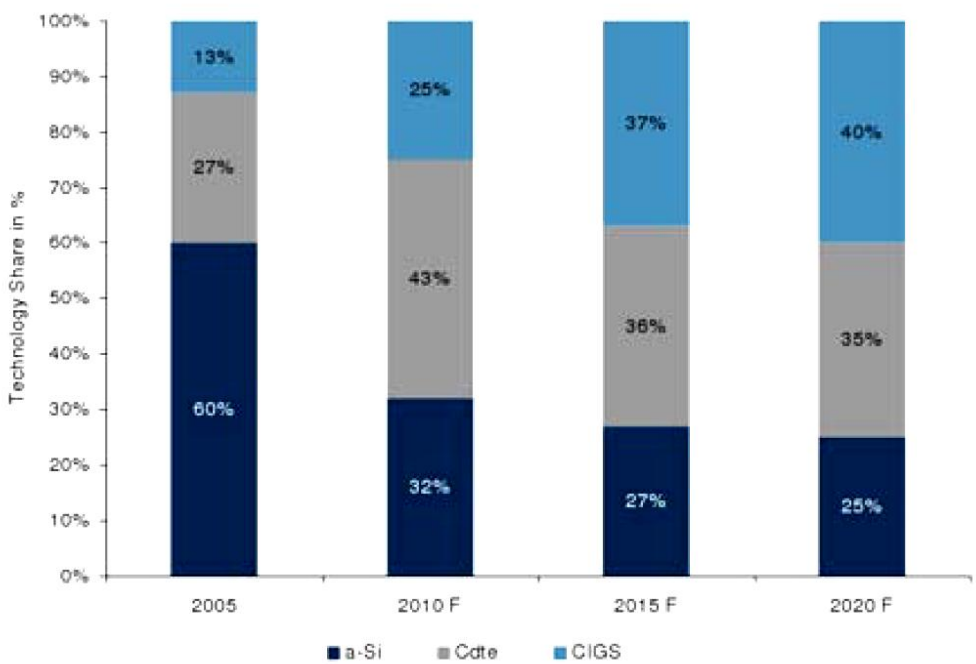


Figure 19.Thin film technology share within the thin film market (GBI Research, 2010)

Using the technology share percentages from Figure 19, and assuming steady growth between 2005 and 2010, an estimate of the capacity of each thin film technology was made. The results can be seen in Table 3 and Figure 20.

Table 3.Annual global PV capacity (GW) for various PV technologies

Year	Si	a-Si	CdTe	CIGS	Global
2005	1361	47	21	10	1439
2006	1473	58	32	17	1581
2007	2262	123	84	45	2513
2008	5243	400	339	187	6168
2009	5414	693	734	417	7257
2010	13087	1133	1523	885	16629

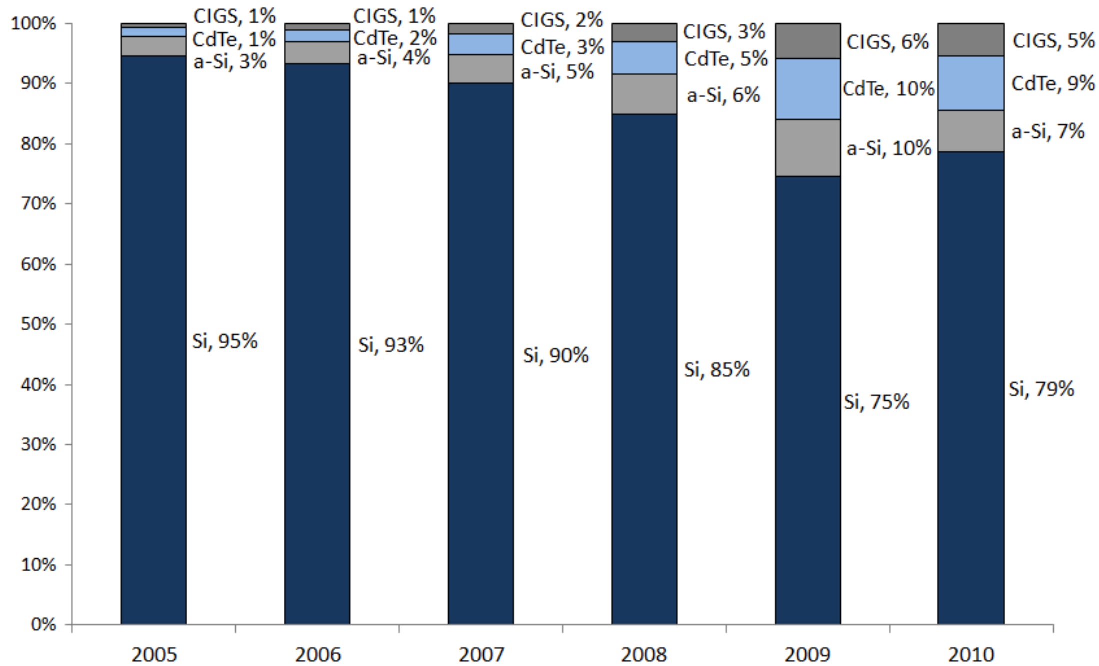


Figure 20.Market share of each PV technology from 2005 to 2010

Solar photovoltaic panels are designed to last for a long period of time by withstanding several years of snow, rain, and wind. The estimated lifecycle of the solar panels is about 25 years (Knight, 2010), a duration in which the customers are generally guaranteed that the solar panel will run at 80% of its original efficiency. According to an article by Green machine (Knight, 2010) solar panels have a lifespan of 25 years and those that were installed in the early 1990s are reaching their end-of-life soon. Although this may be true, there are few companies that are recycling their damaged solar panels. Yet as the oldest PV panels are reaching their end-of-life, this trend will continue to grow day by day and will have a significant increase after 2025.

Today, with the purchase of several electronic items like televisions, customers pay a recycling fee. A similar process of putting money into a custodial account for future recycling can be implemented for solar panels as well. Such a program will enable solar companies to implement a recycling program similar to the one implemented by First Solar. If companies realize the importance of recycling, it will be easier for the customers to understand why paying a recycling fee can be important and how recycling can save companies money in long term.

Customers of solar panels need to be informed of what happens to the solar panels when they are damaged or reach their end life, as well as what is being done in order to avoid any environmental damage. The benefits of recycling can be emphasized through the results of the LCA performed by the company. Once companies have an established way of disposing their solar panels, customers can be easily targeted and convinced to pay the additional recycling amount at the time of purchase.

This recycling and collection program is currently being used by First Solar, which uses CdTe technology. Through their program a customer can request the collection of their solar panels at any time in the future at no additional cost. This is possible because the customer was charged a recycling fee at the time of purchase. This program can maximize the recovery of valuable products for use in manufacturing new solar panels; hence minimizing the environmental impacts associated with PV system production.

Costs associated with solar panels are one of the biggest disadvantages of why people do not prefer using solar power. The initial costs are very high, though with an increasing demand for solar power this is changing. The price point is lowering as solar panels hit the market on a large scale.

According to an article (Future of Solar Panels, 2009), the future of the solar panels depends primarily on the cost. Some experts predict that grid parity, the point when solar power will be equivalent in cost to coal based electricity, is not far. The goal of the solar industry is to reach an installed price of $1/W; this is equivalent to 5 to 6₵/kWh. When looking at the installed cost of a system, not only is the cost of the module accounted for but also the cost of the balance of system. In 2010, the average installed cost was $3.40. In order to reach $1/W, it is expected that the cost for manufacturing PV module decreases from $1.70/W in 2010 to $0.50/W. (Lushetsky, 2010)

Various measures should also be taken by the Government in order to lower the cost and return on investment. Through stronger incentives made by the Government more people will consider using solar energy. When the costs are reduced, people will start considering using solar panels which have about double the efficiency for the same cost.

5.5 Competitors

Currently U.S. based solar companies do not have a recycling plan for solar PV panels; therefore there are no competitors for our company.

In the United States, technology for reusing silicon from solar cells is not commercially available. But according to European Photovoltaic Industry Association and PV Cycle, it takes 1/3 less energy to produce solar panels from recycled panels. Strategies are being developed to recover silicon, glass, ethylene-vinyl acetate (EVA) foil, and aluminum from panels. Furthermore the hazardous materials pollutants and heavy metal emissions (sulfur dioxide, nitrogen oxide, lead) associated with solar panels are due to raw material extraction and energy consumption during manufacturing.

Several companies have considered the end-of-life of the solar panels and have a clear recycling plan. First Solar is the only U.S. based thin-film manufacturing company which has implemented an active model scheme. The program implements an unconditional prefunded collection and recycling program for damaged and end-of-life panels. When First Solar sells their PV panels, sufficient funds are included within the price and set aside for future collection and recycling costs. Through First Solar's recycling process, approximately 90 percent (by mass) of the module is recycled and can be used for new modules. (Beck, 2010)

Solyndra's website (2011) stated that the company had taken into account the environmental impact of the solar panel from raw material to end-of-life recycling. Even prior to their bankruptcy, the company had seen the need to think past production and into the product's end-of-life. The goal of PV Cycle was to implement an industry-wide voluntary take-back and recycling program for PV panels, and to take responsibility for the entire value chain of PV panels. They estimated that by the end of 2010, a program would have been in place that would set aside funds at the time of sale for future recycling and reuse. Additionally this program also cover previously sold panels. However, due to bankruptcy of the company, the recycling program was not implemented making First Solar the only company in the US with a program planned and implemented.

5.6 Customers

Our company will target solar companies within the U.S. that use crystalline and thin film technologies. As a consulting firm we will provide a customized solution to each company based on their processes and the solar technology used for their panels. This will be established through a complete recycling analysis specific to our customer's needs.

5.7 Cost Analysis

A cost analysis was done on the actual recycling process that we would advise solar companies to implement. The following discusses regulations, current and future cost of precious minerals used in solar panels, and various collection methods.

Renewable Energy Focus' Kari Larsen investigated what happens to the solar panels when they arrive at their end life and explained that currently there are no regulations in the United States that specifically govern the recycling of solar panels. End-of-life disposal of solar panels is based on the Federal Resource Conservation and

Recovery Act (RCRA), and on state policies like California's Hazardous Waste Control Law (HWCL). (Larsen, 2009)

Applying "Cradle to Cradle Recycling" could be an important step to improve design for environment. Once these techniques are widely followed and accepted, companies will change their outlook towards recycling and further improve company's reputation among customers. Moreover, the earlier a company addresses changes within their product's design, the sooner they will be able to save money. One technique that can be implemented is designing their manufacturing process to use recycled materials.

Due to the scarcity of materials, some of the materials that are used in manufacturing solar panels could be more valuable in the future, hence providing an additional incentive to recycle. First Solar uses cadmium and tellurium in order to manufacture their solar PV panels. Cadmium is considered to be relatively abundant but tellurium is an extremely rare element, and is approximately 1-5 parts per billion (ppb) in the Earth's crust. "According to USGS, global tellurium production in 2007 was 135 metric tons. Most of it comes as a by-product of copper, with smaller byproduct amounts from lead and gold. 1 GW of CdTe PV modules would require about 93 metric tons (at current efficiencies and thicknesses), so the availability of tellurium will eventually limit how many panels can be produced with this material." (Alchemie Limited Inc., 2010)

Material prices have risen in recent years that recovering these materials at the end-of-life cycle can in turn help companies to make profit and reduce their manufacturing costs. Also, the recovery of these materials provides an environmental benefit by reducing the amount of raw materials used, therefore, reducing the total environmental impact of the solar industry.

According to Green, if the industry for CdTe and CIGS continues to increase at its current rates, there will be a resource issue between 2015 and 2020. This resource issue would cause the annual production of CdTe and CIGS to significantly decrease; this can be seen in Figure 21. One of CdTe's semiconductor materials is tellurium, which is categorized as one of the nine rarest minerals, and is a billion times less abundant than silicon. In 2010, tellurium was being harvested at \$500/kg. On the other hand, CIGS uses indium, one of the 12 rarest minerals.

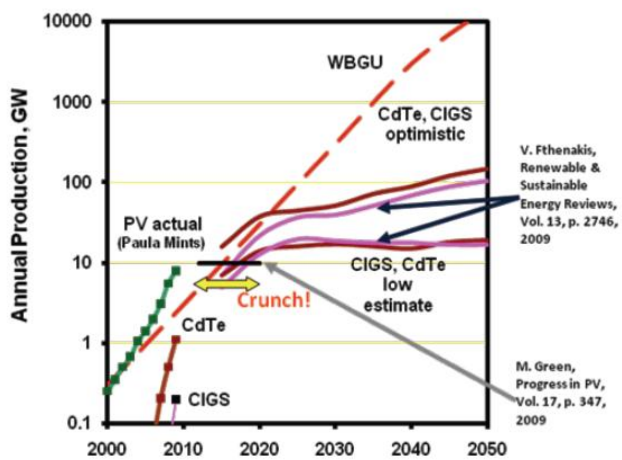


Figure 21.Predicted annual production (GW) for CdTe and CIGS (Green, 2010)

According to Green, both tellurium and indium are economically infeasible to directly mine and must be gathered as a byproduct of mining another mineral. In this case tellurium can be gathered as a byproduct of copper, and indium as a byproduct of zinc. Therefore in order to meet the future demands of tellurium and indium, more copper and zinc would also need to be mined. In recent years the demand for copper has been met through recycling efforts—a process that does not allocate copper for the production of tellurium. So with the increasing demand for tellurium and shortage of supply, the price of this resource will increase. Projecting from the increase in price of silicon during its supply shortage, the cost of tellurium could increase to $20,000/kg (Green, 2010). At such a time the opportunity to recycle CdTe will become not only feasible but profitable.

According to a study (Fthenakis, 2010), panels must be taken down and collected before recycling can take place. This study presents various techniques for recycling PV panels and describes how the collection methods will affect the overall costs. The "National Photovoltaic Environmental Research Center in the USA proposes three collection models in the value and feasibility of proactive recycling:

- Utility paradigm: large end users (utilities) are the primary owners and servicers and are therefore responsible for getting end-of-life modules to recyclers. Costs are embedded in the rates charge by the utility;
- Battery paradigm: manufacturers are collectively responsible for collecting and transporting modules to recyclers through the incorporation of a collectively supported PV-module recycling entity;
- Electronics model: manufacturers are individually responsible for collecting, consolidating, and transporting obsolete modules to the recyclers. Recycling services could be paid for by the generator, the manufacturer, or an escrow fund set aside when the PV systems were originally purchased." (Larsen, 2009)

Once companies start identifying the most favorable methods for the collection process, recycling policies can be implemented at a larger scale. Furthermore, PV Cycle, established by European PV industry in July 2007, suggested that producers of solar panels clearly label their products. This would inform owners about the proper ways of handling the panels and give information to those receiving and treating the panels at the end-of-life.

Overall, it depends how much financial risk the industries want to take with respect to the environmental and social impact. Once consumers become more aware of the generated waste content, it is believed that they will demand appropriate handling of the PV waste. It would then be necessary that the module manufacturers meet these demands in order to make a profit. Future regulations can also increase the fees for the disposal of certain materials such as tellurium, creating an additional incentive to recover this precious mineral.

5.8 Price Point

Currently we are going to charge each solar company $25,000 to analyze and develop a recycling program tailored to their company. Over time we expect the projected profits of a recycling process to also increase, due to regulations and mineral costs. In result we plan to also increase our fee based on the percentage of profits that a company can make.

5.9 Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis

A SWOT analysis analyzes a company’s internal and external factors. Internal factors are the strengths and weaknesses of the company in comparison to its industry. While external factors have the ability to control a company’s ability to grow, this is discussed through opportunities and threats.

By having a recycling program within their business plan, companies gain various competitive advantages. Some examples of strengths include: a credible brand name, good reputation among the market, and if they are an innovator, they could gain compensation for proprietary knowledge. On the contrast, if they fail to implement such a program, they could lose business, face future fines, and eventually go out of business. (Esty, 2009)

By becoming a leader in the green industry, a company has the ability to network and partner with other green companies. Today, some businesses that practice being green are only willing to partner with other companies that have the same initiatives, creating a network of green companies. (Esty, 2009)

Key external factors are the legislation and laws regarding the disposal of hazardous chemicals at the end of the panel's life cycle. One way to make recycling economically feasible is by implementing stricter laws and increasing the fines related to the proper disposal of these hazardous wastes. According to U.S. regulations, if solar panels are deemed hazardous waste, the federal Resource Conservation and Recovery Act (RCRA), and/or California's Hazardous Waste Control Law (HWCL) would be used to regulate their proper handling, recycling, reuse, storage, treatment, and disposal (Mulvaney, 2009). Additionally, solar panels are determined as hazardous waste if they do not comply with the U.S. Environmental Protection Agency (EPA) Toxicity Characteristic Leaching Program (TCLP) standards. (Mulvaney, 2009)

The changing social culture in America is another external factor that provides incentives to implementing a recycling program. Today, the costumer is becoming more aware and educated about environmental issues. As a result, many are seeking environmentally friendly products and services that are manufactured by green companies. By having a recycling program, a company will be able to showcase their forethoughts about sustainability and environmental issues. (Esty, 2009)

The development of recycling processes can be seen as both an opportunity and a threat. Depending on the development and improvement of the recycling process, the return on investment will vary. If the process for recycling specific PV technologies is available, the appropriate companies will have the opportunity to recycle their materials. On the other hand, if the recycling process for certain PV technology has not been developed, that technology as a whole will be at a disadvantage.

5.10 Investment Capital Requirements

Development Costs

The development costs of the project were charged for the man-hours necessary for our initial analysis:

- Research literature regarding topics related to the project
    - 4 weeks * 5 hours/week = 80 hours * $40/man-hour = $3,200
- Interviews and consultations
    - 50 hours * $40/man-hour = $2,000
- LCA Analysis
    - 150 hours * $40/man-hour = $6,000
- Team Meetings
    - 100 hours * $40/man-hour = $4,000
- Report Preparation & Preparation
    - 50 hours * $40/man-hour = $2,000

The total development cost = $3,200 + $2,000 + $6,000 + $4,000 + $2,000 = $17,200. The consulting fees that we have chosen to charge a potential customer is $25,000. For each project out total labor cost will be $19,200, Table 4 shows a breakdown of labor cost per position.

Table 4.Consulting Cost

	Marketing & Sales	Current Recycling Research	Future Recycling Research	LCA Analysis
Charged Fee	$5000	$5000	$5000	$10000
Man Hours	40 hours	60 hours	60 hours	320 hours
Labor Costs (hrs*$40/hour)	$1600	$2400	$2400	$12800
Profit	$3400	$2600	$2600	-$2800

Table 5 adds the total labour costs that we have associated per project as seen in Table 4. This adds the total costs that are associated with completing each project and shows that with our total labor costs at $19,200, we would generate profit of $5,800 per project. The break even point would occur after 2.965 projects, which can be seen in Table 6.

Table 5.Profit / Loss

Total Costs Charged	$25000
Charged Costs	$19200
Profit / Loss per Project	$5800

Table 6.Break Even Point

Development Costs	$17200
Profit / Loss per Project	$5800
Projects Required	2.965

Any additional projects that we take on after that point will be considered pure profit for our company as all the developmental costs have been replaced as well as any additional costs incurred on a per project basis. At that point, the $5,800 in profits per project can be divided up between the partners, in addition to the fees that they are charging.

5.11 Personnel

Our consulting firm will have four partners: one engineer familiar with LCA analysis, one marketing and sales engineer, and at least two other engineers who are familiar with solar manufacturing and processes.

5.12 Business and Revenue Model

By taking responsibility for photovoltaic modules throughout their entire value chain and addressing future recycling needs, we would like to prove to the industry that true sustainability with clean energy is indeed an option.

As a model, Europe is being reviewed as it has an open association, consisting of 37 members, currently representing some 75 percent of the European photovoltaic market (Appleyard, 2009). This association was created in order to provide a focused approach to realizing an adequate recovery system for end-of-life photovoltaic modules. Europe's policy shows a clear trend towards waste avoidance, recycling, and eco-design requirements. The industry plans to install an overall waste management and recycling policy across Europe.

The Photovoltaic Cycle Initiative hopes to demonstrate that it is both possible and profitable to implement recycling structures for photovoltaic products with no materials being disposed of without regards to the environment.

5.13 Strategic Alliances Partners

Along with pitching our ideas to potential companies, we believe that we can form a strategic alliance with other well-established organizations that may find our ideas beneficial. This will be done by showing companies future trends and how looking towards the future can benefit them in the long run. Though the cost savings may not be apparent, the long term effects will be felt by generations to come.

Phase 1 will concentrate on the companies we mentioned below. We will work with these companies to engineer a way that they manufacture their photovoltaic solar panels so that they are designed and manufactured for recyclability. By manufacturing solar panels to use recycled materials, companies can translate those savings to their products and customers. This will only entice the customers more towards purchasing their product

List of potential partners:

- First Solar
- Sun Power
- Solar City
- Akyna Solar
- Duraspray & Solar Center
- Peterson Dean
- Deustche Solar

Along with working with these companies, our company will show several municipalities how recycling various parts of solar panels can be mutually beneficial to them as well as to the customers and companies. Customers are being charged recycling fees to purchase these solar panels. If companies produce their solar panels more environmentally friendly, the various municipalities can take advantage by accepting those items for recycling and reusing or reselling those items to companies that can benefit from the reuse.

List of potential partners:

- City of San Jose
- City of Mountain View
- City of Palo Alto
- City of Sunnyvale
- City of Cupertino
- City of Santa Clara

Further, our company can partner with health insurance companies to get a better understanding of toxic material impacts of the solar industries and similar industries to inform companies and public of the environmental impacts their actions might have. Our marketing team can attend solar seminars to talk to different companies and make them be aware of this issue. Non-profit environmental organizations can also help our company to raise the issue up.

5.14 Profit and Loss Statement

Table 7 and Figure 22 show the expenses, revenue, and profits generate for the first five years of our company. The first year was this previous year in which we occurred development costs from research.

Table 7.Estimated total expenses, revenue, and profit

Year	No. of Projects	Expenses	Revenue	Profit
FY2010	0	$17,200	$0	-$17,200
FY2011	3	$57,600	$75,000	$200
FY2012	3	$57,600	$75,000	$17,600
FY2013	3	$57,600	$75,000	$35,000
FY2014	3	$57,600	$75,000	$52,400

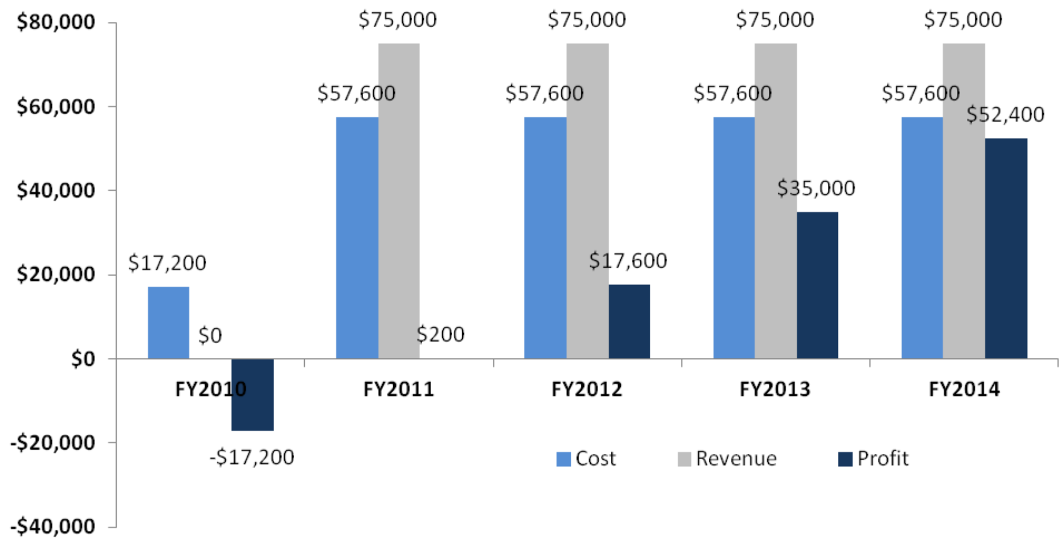


Figure 22.Estimate total expenses, revenue, and profit

5.15 Exit Strategy

The return on investment is a profit calculation that takes the difference between the investment's revenue (gain from investment) and its cost, comparing that to the cost of the investment (Investopedia, 2011).

$$ROI = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}} \qquad \text{Equation 1}$$

The return on investment of our firm over its first five years would be 205%.

ROI = (52,400 -17,200)/17,200 = 2.0465 = 204.7%

In this case, the gain from investment comes from the revenue generated by a recycling process. N. C. McDonald and J. M. Pearce (2010) published an article that discusses the potential profits for recycling of the five main PV technologies. The article primarily looked into three different recycling processes, a recycling process that is used for both mono and poly-crystalline modules (x-Si), one for CdTe, and another process for CIGS. When considering amorphous silicon (a-Si), the recycling process only looks at gains from selling recovered glass. According to Theressa Zhang, the process for recycling a-Si is similar to the process used for recycling automotive windshields (personal communication, 2011). In our ROI we assumed the profit recovering semiconductor materials from a-Si modules to be negligible. This is because there are currently no recycling processes that target recovering silicon from a-Si modules; this is due to the small amounts of semiconductor material (about 1 gram of silicon) used (McDonald & Pearce, 2010). For similar reasons we neglected the profits made form recovering aluminum from a-Si and CdTe panels; aluminum makes up less than one percent of its mass (WEEE, 2011).

When analyzing each recycling process, revenue was calculated from selling the recovered materials (P_R): semiconductor material (P_S), glass (P_G), and aluminum (P_{al}). The amount of material recovered from each type of module was determined from previous publications and normalized to a 1 m^2 module. In addition to the revenue from recovering materials the avoidance of disposal fees (D) was added. Finally, the cost of the recycling process (C) was deducted from the revenue created. The values used in the table below were drawn from several sources.

$$ROI = \frac{P_S + P_G + P_{al} + D - C}{C} = \frac{P_R + D - C}{C} = \frac{P_T}{C} \qquad \text{Equation 2}$$

Table 8. Return on investment for various PV technologies

	x-Si	CdTe	CIGS	a-Si
Profit from semiconductor, P_s	7.54	2.25	41.55	--
Profit from glass, P_g	0.06	0.06	0.07	0.06
Profit from aluminum, P_{al}	3.87	--	4.50	--
Profit from recovered materials, P_r	11.30	2.31	46.12	0.06
Avoided disposal Fee, D	0.60	6.45	0.87	0.67
Cost of Recycling, C	32.11	9.00	20.24	C
Total Profit, PT	-20.21	-0.24	26.75	0.73-C
Return on Investment	**-0.63**	**-0.03**	**1.32**	**(0.73-C)/C**

McDonald and Pearce (2010) illustrated in Table 8 that it only made sense to recycle CIGS since it produces $26.75 profit for every square meter panel, while CdTe is almost profitable at $-0.24. The feasibility of a recycling process for a-Si is uncertain since there currently is no recycling process or incentive to attempt to recover 1 gram of silicon.

Although it is suggested that CdTe is economically infeasible, McDonald and Pearce's calculations and parameters were derived from previous research and publications. For example, the value of recovered semiconductor materials has probably changed from the 2003 publication that it drew its values from. Furthermore, with the increasing scarcity of tellurium, the value of this mineral will continue to increase. Recycling crystalline silicon panels can be economically feasible if a cheaper recycling process can be developed.

5.16 Measurement of Success

In order to evaluate if a recycling process is economically feasible, a cost analysis is performed for each type of PV technology. After comparing profits gained from recycling various materials to the cost of disposal, the better method for handling solar PV panels at the end-of-life cycle can be determined. If the profits outweigh the cost of disposal, the option of recycling the panels will be recommended. However, if disposal turns out to be the economical choice, further analysis could project for a time in which recycling would become the better option.

Another measurement of success will be the ability to convince the municipalities to implement some sort of recycling program for solar panels. Although several companies are already integrating recycling into their business plans, municipalities have yet to take the same action.

6.0 Future Work

Once our company reaches its break-even point, we can do more research on the manufacturing process of the solar industry to reduce toxic materials used in the process and advice companies on manufacturing for recycling and manufacturing for reusing. We can also research the inverters used for solar panels and analyze their recycling process. This will expand our business and increase our customers.

7.0 Summary/Conclusion

The development of the PV market and its growing range of available products necessitate a recycling infrastructure that must be able to dispose or recycle the wide range of products in an economically viable manner. Photovoltaic products are also expected to expand in the next decade as newer technologies reach the commercial market. Further developments of newer photovoltaic products will likely drive design considerations, so the recycling and disposal of these products have been taken into account.

This project attempted to develop a safe and cost-effective process for the disposal of PV solar panels. Potential methods for the safe recycling of such byproducts and wastes generated by the solar panels at the end of their lifecycle was researched. It is now known that there are ways to recover and recycle components of solar panels that can help to save the environment. Not only can the reclaiming of such materials keep precious natural resources from being depleted, as well as keeping these wastes out of our landfills. The costs of recycling and the potential savings have been revealed and companies can now see the benefits.

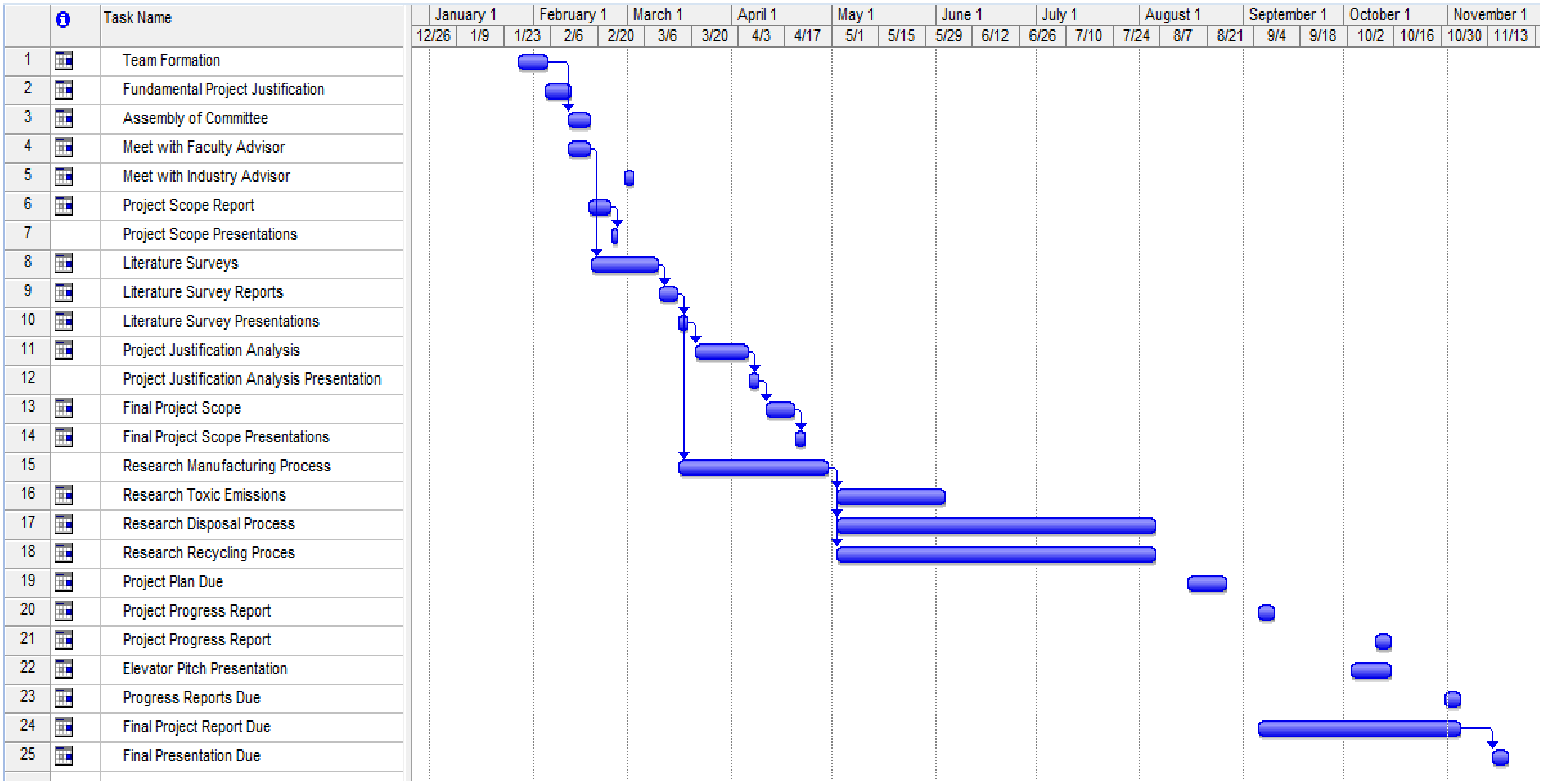
It is concluded that currently it is not economically feasible for PV companies to invest in recycling their solar panels. Currently, the cost to recover materials from PV modules outweighs the cost to simply use raw minerals. However recycling can become feasible in the future if the cost of the rare minerals used in these panels increase significantly, regulations mandating recycling or the increase of disposal fees are adopted, or the current recycling processes are improved.

The LCA analysis data also shows the amount of CO_2 emissions for one PV panel is negligible. However, as the market size for the panels is increasing, this value could add up at the end-of-life of the panels. Moreover, a more detailed LCA analysis with less limitations and assumptions might give a better idea on the amount of CO_2 emission at different process stages of the panel.

With the rising cost of electricity and advancement in solar PV technology, there will be an increase for the demand of solar PV technology within the residential and commercial markets. In 20 to 25 years these panels will reach their end-of-life and the cumulative amount of PV waste will force the solar industry to be more conscious about developing an environmental and cost sustainable method of disposing this industrial waste. However the industry should not wait until then to take action, and should start developing a recycling process that will prevent a significant amount of PV waste.

As the market size of solar panels increases, it is the vision of this team to propose sustainable methods supported by statistics and cost-analysis for companies so they can see the benefits of using reclaimed and recycled materials. Companies must take responsibilities in maintaining an environmentally friendly approach to control the waste.

8.0 Project Schedule



		Task Name	Duration	Start	Finish	Predecessors
1		Team Formation	7 days	Thu 1/27/11	Fri 2/4/11	
2		Fundamental Project Justification	6 days	Fri 2/4/11	Fri 2/11/11	
3		Assembly of Committee	5 days	Fri 2/11/11	Thu 2/17/11	1
4		Meet with Faculty Advisor	5 days	Fri 2/11/11	Thu 2/17/11	
5		Meet with Industry Advisor	3 days	Mon 2/28/11	Wed 3/2/11	
6		Project Scope Report	5 days	Thu 2/17/11	Wed 2/23/11	
7		Project Scope Presentations	2 days	Thu 2/24/11	Fri 2/25/11	6
8		Literature Surveys	14 days	Fri 2/18/11	Wed 3/9/11	4
9		Literature Survey Reports	4 days	Thu 3/10/11	Tue 3/15/11	8
10		Literature Survey Presentations	3 days	Wed 3/16/11	Fri 3/18/11	9
11		Project Justification Analysis	12 days	Mon 3/21/11	Tue 4/5/11	10
12		Project Justification Analysis Presentation	3 days	Wed 4/6/11	Fri 4/8/11	11
13		Final Project Scope	7 days	Mon 4/11/11	Tue 4/19/11	12
14		Final Project Scope Presentations	3 days	Wed 4/20/11	Fri 4/22/11	13
15		Research Manufacturing Process	33 days	Wed 3/16/11	Fri 4/29/11	9
16		Research Toxic Emissions	25 days	Mon 5/2/11	Fri 6/3/11	15
17		Research Disposal Process	70 days	Mon 5/2/11	Fri 8/5/11	15
18		Research Recycling Proces	70 days	Mon 5/2/11	Fri 8/5/11	15
19		Project Plan Due	10 days	Mon 8/15/11	Fri 8/26/11	
20		Project Progress Report	5 days	Mon 9/5/11	Fri 9/9/11	
21		Project Progress Report	5 days	Mon 10/10/11	Fri 10/14/11	
22		Elevator Pitch Presentation	10 days	Mon 10/3/11	Fri 10/14/11	
23		Progress Reports Due	5 days	Mon 10/31/11	Fri 11/4/11	
24		Final Project Report Due	45 days	Mon 9/5/11	Fri 11/4/11	
25		Final Presentation Due	5 days	Mon 11/14/11	Fri 11/18/11	24

Figure 24.Project schedule with dates

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