July 5, 2004

Anibal Alterno, Environmental Engineer
Fernando Serrano, Electrical Engineer
Componentes Intel de Costa Rica
Calle 129 La Ribera
P.O. Box 845-1150
Belén, Costa Rica

Dear Mr. Alterno and Mr. Serrano,

Enclosed is our report entitled “The Feasibility of a Photovoltaic System at Intel and Its Environmental Benefits.” It was written at Componentes Intel de Costa Rica during the period May 17 to July 5, 2004. Preliminary work was completed in Worcester, Massachusetts, prior to our arrival in Costa Rica. Copies of this report are simultaneously being submitted to Professors Salazar and Lew Yan Voon for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We appreciate the time that you have devoted to us.

Sincerely,

Aaron Beaudoin

Thomas Duszlak

Ryan Rackliffe

Report Submitted to:

Professor Guillermo Salazar

Professor Lok C. Lew Yan Voon

Costa Rica, Project Center

By

Aaron Beaudoin

Thomas Duszlak

Ryan Rackliffe

In Cooperation With

Anibal Alterno, Environmental Engineer

Fernando Serrano, Electrical Engineer

Componentes Intel de Costa Rica, Corporate Services Division

# THE FEASIBILITY OF A PHOTOVOLTAIC SYSTEM AT INTEL AND ITS ENVIRONMENTAL BENEFITS

July 5, 2004

# Abstract

This project involved a qualitative study of the feasibility of implementing a photovoltaic system at Intel in Costa Rica. The information presented in this project came from data collection, archival research, interviews, case studies, and the RETScreen Photovoltaic Project Modeling software. We used a cost analysis to determine that a photovoltaic system is currently not economically feasible, but identified what would make it feasible in the future. We also determined that a photovoltaic system may help preserve the Costa Rican ecosystem.

# Authorship Page

The writing of this report was done in equal parts by Aaron Beaudoin, Thomas Duszlak, and Ryan Rackliffe. Each contributed equal amounts in all aspects of the background, methodology, data analysis and results, and conclusions and recommendations chapters.

# Acknowledgements

We would first like to acknowledge Anibal Alterno, one of Intel's Environmental Engineers and our project liaison, for sponsoring this project. We would then like to specially thank and acknowledge another of Intel's Environmental Engineers Adolfo Quesada, Electrical Engineer Fernando Serrano, and all other Intel employees who have assisted us with our project. Finally, we would like to acknowledge those who gave their time to provide us information through interviews: PowerLight's sale representative Jenny Strauss, Jorge Rojas Vega from CONICIT, and Agustín Rodriguez from CICR. We would also like to thank our project advisors Professors Lok C. Lew Yan Voon and Guillermo Salazar for their advice and guidance. We would like to thank Professor Salazar for his assistance in translating documents.

# Table of Contents

# List of Tables

# List of Figures

# Executive Summary

This project between Worcester Polytechnic Institute and Intel came from Intel's need for knowledge about the feasibility of a photovoltaic (PV) system within their Costa Rican facility. With rising energy costs and environmental concerns, it is important to investigate this energy source. The main objectives of this project were to identify which part of Intel's facility the PV system could power, to determine if solar power is a feasible option, and to assess the environmental and social impacts that are associated with solar power.

The information presented in this report was collected from archival research, data collection, interviews, case studies of facilities that have made the change to solar power, information from potential suppliers, and through the use of the RETScreen Photovoltaic Project Model software.

The first part of this project was to identify which electrical applications within Intel's facility the PV system could power. After researching case studies of large facilities that have implemented PV systems, we concluded Intel should install a roof mounted on-grid PV system that sends the electricity produced directly into the substation. Then, the electricity would be distributed throughout the facility instead of powering a specific application. With this design, less electrical equipment is needed, such as wiring and power conditioning equipment. In addition, Intel will still rely on ICE, Instituto Costarricence de Electricidad, for the rest of its energy demand eliminating reliability issues when energy production is low.

The feasibility of a PV system was the next part of our project. The first thing to consider were any laws regarding implementation of a PV system. We found law number 7200, which prohibits private energy production of plants with a capacity over 20,000kW. Intel must apply for this concession to receive permission to produce energy. The capacities of the systems that we assessed were all under the 20MW limit because the largest PV system that would fit on Intel's roof is only 7.5MW.

Another important factor in determining the feasibility of a PV system was the possibility of government incentives. Government incentives would drastically decrease the high cost of a PV system, enabling the system to contribute sooner to positive cash flow. Positive cash flow is when the total amount saved by the system surpasses the total amount spent on the system. From our research, we found that Intel does not currently qualify to receive any government incentives. The incentives that do exist are given mainly to universities and industries that are working to improve renewable energy technologies. With the recent controversies over the construction of dams along the Peñas Blancas River and in Boruca, we recommend that Intel lobby for incentives from environmental and government agencies.

To assist with the feasibility study, we then developed cost analyses for initial costs and financial summaries of PV systems ranging in capacity from 50kW to 2,000kW and for the maximum 7.5MW system. We used a PV project modeling software, RETScreen, to develop the cost analyses and financial summaries. RETScreen is a reliable program to use because it was created by numerous experts and is used

worldwide. RETScreen is endorsed by organizations such as United Nations Energy Program (UNEP) and National Aeronautics and Space Administration (NASA). We concluded from the results of our cost analyses and financial summaries that any size system is currently not economically feasible for Intel to consider. This is because of Intel's current low cost of electricity, the current high cost of PV equipment, and the lack of government incentives. From our financial summaries, we found that no system would have a positive cash flow before the 30 year lifespan of its modules.

To determine when a PV system may be more feasible we researched recent and projected market trends of PV modules. From our research, we found that in the past four years, the price of the modules has decreased by 15% and the industry wants to drive the price below $2 per watt within the next decade. When this price goal is reached a PV system will be more affordable and Intel should then again consider implementation.

The final part of this project was to determine the possible environmental and social impacts that would come with a PV system. This topic was researched because Intel is very concerned with its environmental footprint in Costa Rica. We used RETScreen to calculate the reduction in greenhouse gas emissions and analyzed other environmental effects associated with both PV modules and hydroelectricity. Currently Intel receives 82% of its power from hydroelectricity. The reduction in greenhouse gas emissions was minimal because hydroelectricity produces no emissions. However, the damage that hydroelectric dams cause to the ecosystem was the main environmental issue. The problems associated with dams include habitat destruction, hindrance of fish passage, and degradation of water quality and flow. Dams may also displace people who live in future flood lands. The only negative effects related to PV modules occur during their manufacture. However, they can be prevented with precautionary measures, such as the use of personal protective equipment when mining silicon.

Intel would also experience other benefits by switching to a PV system. The arrays will protect the roof from thermal cycling and harmful UV degradation while adding extra insulation that will cause a reduction in their cooling costs. The arrays would also utilize unused roof space. A PV system can also be used to advertise Intel as a concerned company that wants to preserve the ecosystem by relying less on the dams created for hydroelectricity. None of these benefits could be accounted for with monetary values because of the lack of previous data on each subject.

We recommend that Intel not install a PV system at this time. However, Intel should be aware of the indicators that would lead to a system being feasible. We concluded, through a sensitivity analysis that these indicators are the cost of energy, the price of PV modules, and government incentives. For a system to become feasible, the cost of energy should increase to at least $0.10 per kWh, the price of PV modules should decrease below $2 per watt, and Intel needs to be eligible for substantial government incentives, 50% of total costs. All three of these situations could become a reality. $0.10 per kWh is the current price for energy in California and with growing controversy over dam construction, the price for Intel could rise to this level. In addition, the current cost of electricity for residential use in Costa Rica is over $0.10 per kWh. The cost of PV modules is expected to drop to below $2 per watt within the next decade. By advertising the possibility of solar power and the harmful effects of dams, Intel could gain public support in the push to initiate government incentives.

# Chapter 1: Introduction

Costa Rica is a small Central American country that borders the Pacific Ocean and the Caribbean Sea. Costa Rica has a population of approximately 3.8 million and is considered prosperous when compared to neighboring countries (CIA, 2003). This is mainly due to its high percentage of educated people, which also makes it possible for Costa Rica to have a technologically advanced economy (Energy Profile for Costa Rica, 2003). The economy is mainly based on tourism, agriculture, and electronic exports. Along with their advanced economy, Costa Ricans are concerned with energy conservation.

Hydroelectric power is the main source of energy in Costa Rica. Hydroelectric dams generate almost 82% of Costa Rica's energy, with small percentages produced by geothermal, wind, fossil fuel, and solar energy. ICE, Instituto Costarricence de Electricidad, controls Costa Rica's energy supply, providing 97% of the country's electricity. ICE estimates that Costa Rica's energy demand will rise annually by about 5.7% until the year 2020, requiring ICE to continuously develop its capability to generate electricity (Energy Information Administration [EIA], 2003).

Intel is an international company that manufactures supplies for the computing and communications industry. Intel has a facility located in Belén, Costa Rica to manufacture and test microprocessors and chipsets, which is one of the largest electricity consumers in Costa Rica. Efforts are under way at Intel to understand consumption rates and find a more efficient energy source. In addition to coping with the possibility of rising electricity prices, Intel also wants to be recognized as a corporate leader in the management of energy. Teams have been organized to lower the consumption of energy, which will reduce capital expenditure, and for the development and design of the most efficient source of energy. However, Intel is still unaware of the relative benefits and costs an alternative energy option would bring to its facility in Costa Rica.

Intel is considering implementation of a photovoltaic (PV) system at their Costa Rican facility to reduce peak usage and lessen their environmental impact. There are many possible benefits of installing a PV system at Intel's facility. First, the system can reduce high electricity costs from ICE during peak operating hours while preventing greenhouse gas emissions and damage to the ecosystem from dams. Second, implementing a roof top system can also prolong the life of a roof by shielding it from the elements and would utilize unused roof space. Third, a PV system brings good publicity to Intel if advertised correctly; many stakeholders appreciate this kind of environmental consciousness and responsibility.

The main purpose of this project was to research and determine the feasibility of solar power for Intel. This information will be used to help Intel make an informed decision about the implementation of a PV system within their Costa Rican facility. We also investigated the environmental impacts that Costa Rica would experience if a PV system were implemented at Intel. Additionally, this project recommends an implementation design of a PV system.

This project was prepared by members of Worcester Polytechnic Institute Costa Rica Project Center. The relationship of the Center to Componentes Intel de Costa Rica S.A. and the relevance of the topic to Componentes Intel de Costa Rica S.A. are presented in Appendix A.

# Chapter 2: Background

## 2.1 Introduction

This chapter first discusses Intel's facility in Costa Rica and describes its electricity demands and costs. Alternative energy is then defined and examples are provided. Next, extensive research on solar power is presented. This section on solar power presents the basic overview of a PV system. Finally, a brief description of RETScreen, a PV project modeling computer software used for cost analysis and feasibility, is presented.

## 2.2 Intel and Energy in Costa Rica

Intel is now one of the top five consumers of electricity in Costa Rica. They consume about 10 million kWh per month. They purchase their electricity from Instituto Costarricense de Electridad (ICE) (Appendix A.3). ICE is a government owned monopoly that produces 97% of Costa Rica's electricity (EIA, 2003). According to the Central Intelligence Agency (CIA), Costa Rica's energy production is largely, 81.9%, from hydroelectricity. 16.6% of Costa Rica's energy comes from geothermal, wind and solar power. A very small amount, 1.5%, comes from fossil fuels (CIA, 2003). During the dry season in Costa Rica, November through May, hydroelectricity is less available so ICE uses those other sources to produce energy.

Intel's current costs for electricity depend on the time of day the energy is used, and the peak demand. There are three categories for the time of day and for the price of energy. The price of energy is then calculated based on the time of day. The cost per kWh for February 2004 was $0.046 for peak hours, $0.025 for shoulder hours, and $0.010 for night hours (Alterno, personal communication, April 13, 2004). Intel's peak shoulder and night hours are shown in Table 1. Energy use distribution for Intel's plant is listed in Table 2. The information in these two tables was collected from Fernando Serrano, one of Intel's electrical engineers. For additional information on Intel in Costa Rica, refer to Appendix A.

**Table 1: Intel's peak, shoulder, and night hours for energy consumption**

| | |
|---|---|
| Peak | 10:00-12:30<br>17:30-20:00 |
| Shoulder | 06:00-10:00<br>12:30-17:30 |
| Night | 20:00-06:00 |

**Table 2: Intel's energy use distribution**

| Item | % Energy Consumption |
|---|---|
| Manufacturing operations | 37% |
| Air conditioning | 30% |
| Mechanical facilities | 25% |
| Illumination | 6% |
| Others | 2% |

## 2.3 Alternative and Renewable Energy

Alternate energy is any source of power that is considered non-conventional. Conventional energies include fossil fuels, hydroelectricity, and nuclear power. Examples of alternate energy are solar power, wind power, fuel cells, natural gas, and biomass (Berinstein, 2001, p. 9).

All energy sources are classified as either renewable or nonrenewable. Nonrenewable energies will become exhausted over time if consumed. A main issue with nonrenewable energy sources is that they will reach a level where it will be too costly or environmentally hazardous for their retrieval. In addition, due to combustion, most nonrenewable energy sources generally have larger negative environmental impacts. All fossil fuels, such as coal, are non-renewable. Natural gas is also non-renewable; see Appendix E for a brief discussion on natural gas. Due to fuel cells' reliance on natural gas as an input, they are a non-renewable source of energy. Information regarding fuel cells is presented in Appendix C.

Renewable energy sources create energy from the environment rather than through the use of mineral fuels (Fay, 2002, p. 143). Fay and Golomb have identified reasons why these sources are gaining interest. First, renewable alternate energy sources are less economically risky because they are independent of outside fuel suppliers and prices. Second, the resources needed for renewable energy generation are easily accessible and distributed almost everywhere in the world. However, they may be more risky when it comes to efficiency and a uniform distribution of output.

Solar power is renewable because it draws on energy emitted from the sun and does not deplete the resource, the sun. The earth being unevenly heated by the sun creates wind. Wind can then be used as power and is renewable because utilizing it does not affect the sun's ability to heat the earth. Wind energy is explained in Appendix D. Biomass, which utilizes the carbon in biotic matter to create energy, is also considered a renewable source of energy because new plants will replace those that were used to produce energy. Appendix F presents an overview of biomass.

There are also some problems associated with renewable energy sources. Renewable does not mean nonpolluting, but most have very little, if any environmental effects (Berinstein, 2001, p. 9). An example of a polluting renewable energy source is biomass, which will use combustion to form energy and emit $CO_2$ gas into the atmosphere. The current drawback of most systems is the relatively high cost when compared to conventional sources (Fay, 2002, p. 143). The next section covers background information on solar power to give a general understanding of PV systems.

## 2.4 Solar Energy

The sun has been a major source of heat and energy for millions of years. This valuable renewable resource has many feasible applications. Solar power can provide heat, hot water, light, electricity, and cooling to residential, commercial, or industrial facilities almost anywhere in the world (U.S. Department of Energy, 2004).

### 2.4.1 Photovoltaic Devices

A PV cell is a device that directly converts solar energy into electricity using semiconducting materials. This process is shown in Figure 1 and explained below. The conversion is carried out with no visibly moving components or fluids, which makes it an "electrically active but mechanically inactive device" (Warfield, 1984, p. 37). There is no maintenance to the cells due to the lack of mechanical movement (Warfield, 1984, p. 37).

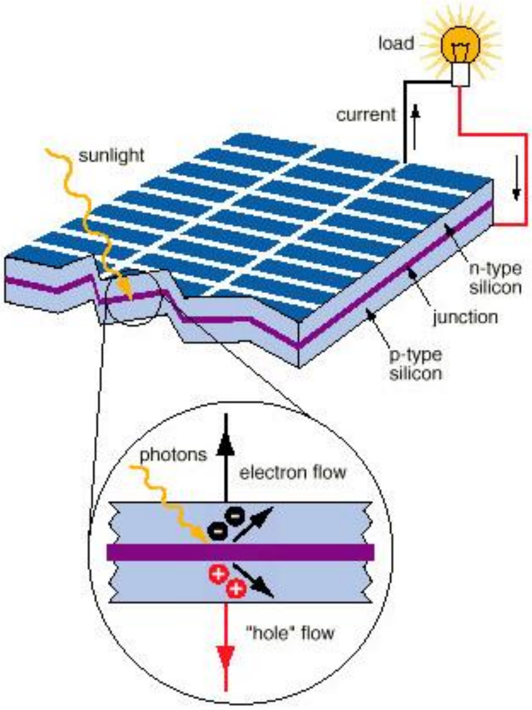


**Figure 1: P-N junction of a photovoltaic cell**

Semiconducting material is the main substance of a PV cell. The most commonly used material is silicon. Semiconductors have electrical properties that make them useful in electronic devices (University of New South Wales, 2004). The conductors can be treated to become either positive (p-type) or negative (n-type) (See Appendix B). PV cells operate by combining these semi-conductors to form a junction (University of New South Wales, 2004). The simplest junction is a p-n junction, which is an interface between the n and p regions of one semiconductor. All junctions contain a strong electric field (Markvart, 1994, p. 28). Figure 1 also shows the basic p-n junction of a PV cell.

## 2.4.2 Photovoltaic Systems

PV systems do not just consist of solar cells, but are also composed of many other subsystems, called the balance of equipment, to provide the required electrical supply (Markvart, 1994). Solar cells create a direct current, so some form of power conditioning is needed to run appliances that work on alternating current. Many systems also contain energy storage systems so electricity can be supplied at night or during periods of inclement weather. The main subsystems are an inverter, a PV generator with mechanical support with the option of a sun tracking system, and control equipment with requirements for measurement and monitoring of the system. Batteries for storage and a back-up generator are an optional for a PV system (Markvart, 1994, p. 77).

The main part of any system is the generator. The generator is simply the PV modules. A module is composed of solar cells, usually 36, connected together through circuitry. Cells are connected because a single cell only supplies a small amount of electricity, around 12V. When connected, the cells form a module; modules are then connected to form an array. Combining arrays can theoretically fill any amount of available area, whether mounted on the roof or the ground. Figure 2 shows that an array is composed of modules and a module is composed of cells.

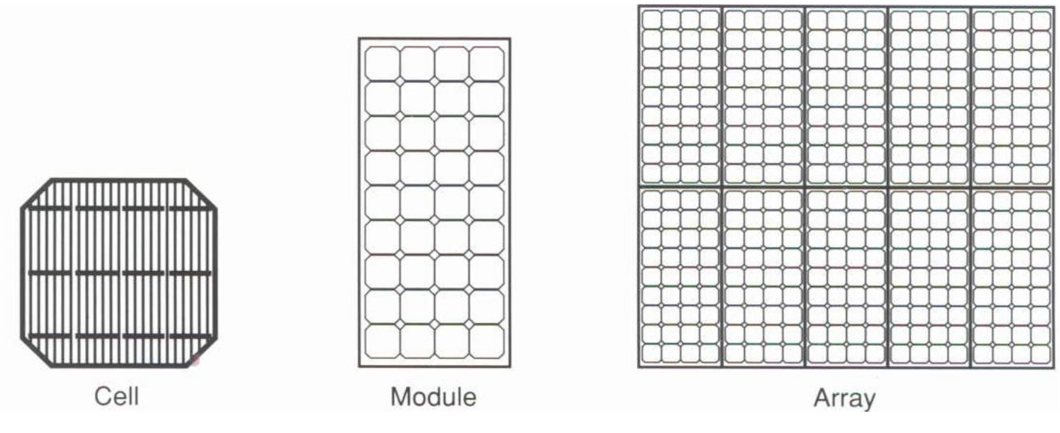


**Figure 2: Composition of a photovoltaic array**

### 2.4.2.1 On-grid Photovoltaic Systems

A grid-connected, or on-grid, system feeds energy directly into an electric utility grid. There are two main types of grid-connected applications: 1) distributed grid-connected, which can be used with integrated PV systems to power individual residences or commercial buildings, and 2) central power plant generation. When a system is grid-connected, batteries are not needed because energy is provided by the utility when the PV system is not producing enough (RETScreen, 2001). Figure 3 shows examples of distributed and centralized PV applications.

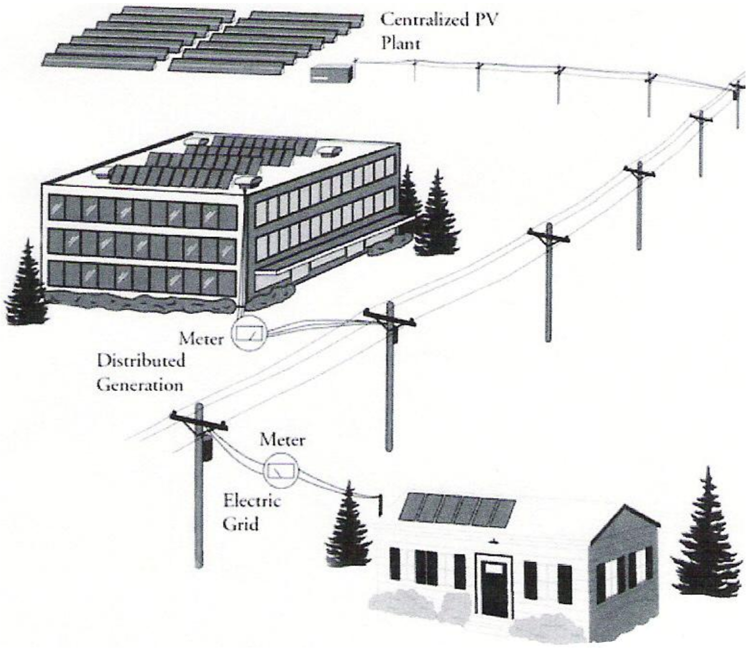
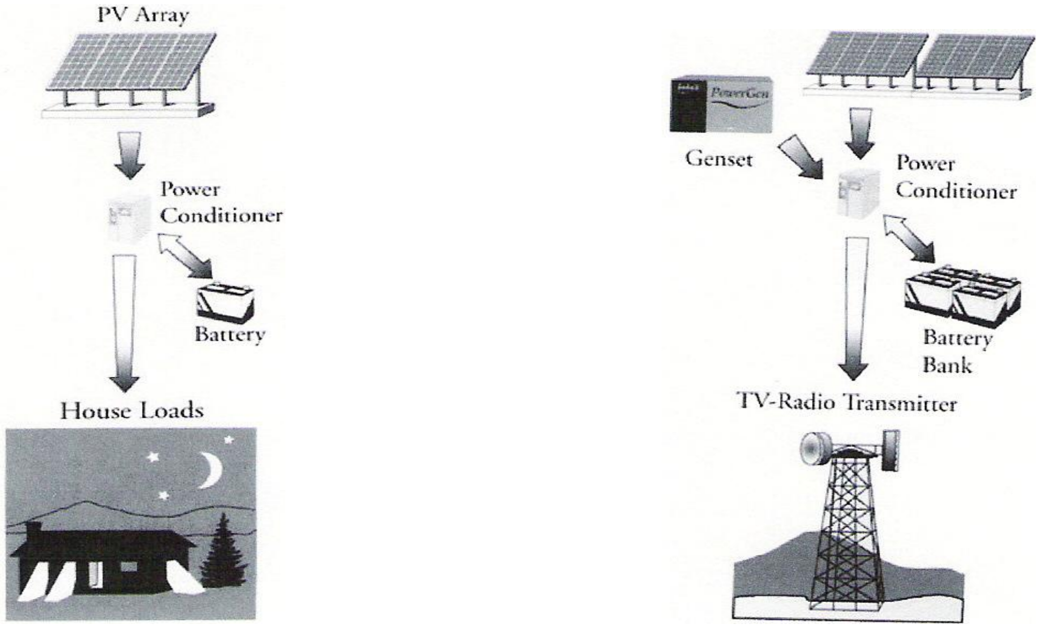


**Figure 3: Distributed and centralized photovoltaic applications**

The benefits of grid-connected systems are usually measured by their potential to reduce energy cost, generator capacity, and environmental benefits (RETScreen, 2001). The PV systems for distributed generation are located close to the site of consumption which helps to reduce energy (kWh) and capacity (kW) losses. Manufacturers of PV equipment are also developing PV modules that can be directly incorporated into the standard building components such as roofing tiles and curtain walls. This will reduce the cost of the PV system because the conventional building material will not be used. These options should be considered only for buildings that have not yet been constructed. For previously constructed buildings, modules can be placed over the existing roof. Currently a central generation application is not cost competitive due to the cost of energy transmission from the supplier to the consumer. Central generation systems have only been installed as test projects in the size of multi-megawatt generation sites (RETScreen, 2001).

### *2.4.2.2 Off-grid Photovoltaic Systems*

An off-grid application is independent of any electrical grid. Off-grid applications are very popular in isolated sites that are far from the electrical grid (RETScreen, 2001) and often require systems that provide relatively small amounts of power, around 10kW. In these applications, the PV system is usually used to charge a battery so energy can be stored and provided on demand. Energy storage cost and reliability are the main reasons that off-grid systems have smaller capacities. Off-grid applications can be either a stand-alone system or a hybrid system. In a stand-alone system the only power source are the PV modules, while a hybrid system incorporates a fossil fuel generator, genset, to help with some of the energy demand. A hybrid system is more reliable than a basic stand-alone system due to the genset (RETScreen, 2001). Figure 4 illustrates the difference between a stand-alone and a hybrid system. Note that the hybrid system has a genset in addition to PV modules and energy storage.



**(Stand-alone)** **(Hybrid)**

**Figure 4: Stand-alone versus hybrid systems**

## 2.4.3 Energy Storage of a Photovoltaic System

The most common type of energy storage within a PV system is the battery. A lead-acid battery is the most common because it is more affordable and is widely available. Batteries operate on various cycles to allow both maximum battery life and efficiency (Markvart, 1994). The process of charging a battery during daylight hours and discharging it during the night is known as the daily cycle. Batteries may also act on a climate cycle. This occurs when different climates are important in considering the performance of the PV system. In addition, batteries can act as seasonal buffers where the climates change throughout a season. The cycle chosen depends on the location and desired reliability of a system (Markvart, 1994).

### 2.4.4 Efficiency of a Photovoltaic System

The efficiency of a PV system depends on many factors. The type of system that is needed, on-grid or off-grid, will affect the efficiency of the system. Additional factors in a stand-alone system are the specific energy needs of the location and the different components involved, such as energy storage or genset, hybrid generators. The type of PV cells purchased will also affect the efficiency because there are many different types with varying properties, which depend on the manufacturer.

### 2.4.5 Costs of a Photovoltaic System

The cost of a PV system is based on watts per square foot. On-grid systems generally generate about 10 watts per square foot with a total initial cost of about $6 to $8 per watt. The total initial cost includes the cost of the modules and the installation cost. This cost does not include any amount incurred after the installation of the system. These generalizations of watts per square foot and cost per watt can be used to make an estimation for the cost of the system. For example, a 10,000 sq. ft. system will produce about 100 kW at a cost of about $600,000 to $800,000. These two approximations also show that the cost of a system increases linearly as the square footage increases (Strauss, personal communication, May 28, 2004).

Some factors considered when rationalizing the cost of PV systems are benefits to society and the secondary benefits that the generating structures can give. A benefit to society is the reduction in emissions a PV system brings to a community. Secondary benefits from a PV system include shade for parking lots or decreased roof wear because the panels add a protective layer to the roof.

### 2.4.6 Environmental Impacts of a Photovoltaic System

A PV system is a clean source of energy with almost no environmental impact. PV systems do not produce any carbon dioxide, toxic fuels, or noise (Fay, 2001). Most of the environmental impacts are involved with the manufacturing of the PV cells (Berinstein, 2001). A minimal amount of carbon dioxide is emitted, when compared with that of fossil fuels, during the manufacturing of PV cells.

Disposal can also have harmful environmental impacts. Silicon dust is hazardous if inhaled and the arsenic and cadmium that is found in some cells is a hazardous material

(Berinstein, 2001). However, most modules encase any hazardous material in glass or plastic.

### 2.4.7 Software to Aid in Developing a Photovoltaic Project Model

RETScreen software aided us in determining the initial parameters of the PV system. We discovered RETScreen in our search for a program to assist us in the calculation of the data we would be gathering. The CANMET Energy Diversification Research Laboratory (CEDRL) within National Resources Canada (NRCan) developed RETScreen with the help of experts from government, industry, and academia from around the world. RETScreen also has support from the United Nations Environment Programme (UNEP), Renewable Energy Information Office (REIO) in Ireland, National Aeronautics and Space Administration (NASA), and many other noteworthy organizations throughout the world. The RETScreen PV project model can be used to evaluate energy production, cost, life cycle investment analysis, and greenhouse gas emission reduction of the PV system. It can be used worldwide to evaluate three applications of PV systems: on-grid, off-grid (stand-alone and hybrid systems), and water pumping applications.

The inputs for RETScreen are as follows: location of the building on the earth, slope of the roof where the system would be implemented, the azimuth of the building, the capacity of the system, current price of PV modules, the current source of electricity, the current cost of the energy, inflation rate, annual energy cost escalation rate, and discount rate. In addition, RETScreen calculates the amount of solar radiation at the specified location.

When determining expected solar radiation, certain considerations must be taken into account. The sun’s intensity on the PV cells is governed by three main factors. First, the amount of atmosphere the rays must pass through and second, the angle at which the rays hit the surface of the PV cells. The third factor is the weather pattern. Future weather patterns are predicted using historical data about the location where solar power is desired (Buresch, 1983, p. 43).

The inputs plus data provided by RETScreen yielded the outputs that allowed us to evaluate the feasibility of a PV system. The outputs produced by RETScreen include a cost analysis, financial summary, greenhouse gas emission reduction, and the power outputs of the system. To find these outputs RETScreen does calculation through a series of algorithms that can be found in its manual (RETScreen, 2001).

# Chapter 3: Methodology

The main objectives of this project are:

- To identify the part of Intel's facility the PV system will power.
- To determine if solar power is a feasible option for Intel to consider.
- To assess the environmental and social impacts if Intel were to implement a PV system.

This chapter discusses the need for information, how it was collected, and how it was used to meet the objectives of this project.

## 3.1 Application to be Powered by the PV System

There were significant amounts of data collection used to meet this objective. To be able to recommend a PV system to power certain applications, we first needed to know each application's consumption rate. This would allow us to determine the size of the PV system. Fernando Serrano, one of Intel's Electrical Engineers, provided the data for the consumption rates. By interviewing Mr. Serrano, we identified different applications that we considered powering. We also went on a walk around the facility with Mr. Serrano for a general understanding of the different electrical applications and systems that exist within Intel.

To gain knowledge on implementation strategies we contacted Shuksan Consulting and PowerLight Corporation. These companies provided us with the information that we needed in determining the feasibility of a PV system. Shuksan Consulting is located in Washington; they supply businesses with information on alternative energy choices. They recommend the best energy option for a business based on cost and energy demands. PowerLight, located in California, has installed over 75% of the world's PV systems over 200kW making them the leading designer, manufacturer and installer of grid-connected solar electric systems. Both companies have dealt with projects similar to this one. We used those projects as case studies to learn from their experiences and as a guide in designing Intel's system.

## 3.2 Feasibility of Solar Power

After we identified possible commercially available PV systems, we then determined if one would be feasible for Intel. First, we conducted archival research to find any legislation restrictions regarding PV systems. We also performed a cost analysis of the different systems. After determining Intel's energy demand, we developed the cost analysis of different size systems by using RETScreen. To complete a cost analysis, RETScreen required longitudinal location of the system on earth, angle of arrays in relation to the sun, average monthly temperature, desired output, current cost of energy, and current cost of PV modules. The angle of the array is the slope of the roof which we acquired from the blueprints of the roof. We received the current cost of energy from Anibal Alterno, one of Intel's Environmental Engineers. We received the monthly temperature and longitudinal location from an online weather database provided by RETScreen.

Another factor that we needed for the cost analysis was the amount of government incentives available to help Intel pay for the system. To find these incentives, we did archival research within the Legislative Assembly offices in San Jose and made contact with CONICIT (Consejo Nacional para Investigaciones Científicas y Tecnológicas de Costa Rica), MINAE (Ministerio del Ambiente y Energía), and CICR (Camara de Industrias de Costa Rica). These offices were recommended to us by Mr. Alterno. He had recently made contact with them and felt that we would be able to gain information regarding government incentives.

The final part of our cost analysis was a discounted cash flow analysis done using RETScreen. RETScreen calculates the net present value of an investment using energy the cost escalation rate, inflation, discount rate, current price of electricity, and government incentives as inputs. RETScreen also uses the cost of the PV system calculated from the size of the system desired. The cash flow analysis yields the financial summary of the PV system over its lifetime. This analysis takes into account maintenance costs, overhaul costs (replacement costs), and all of the inputs.

We also conducted a sensitivity analysis, using RETScreen. A sensitivity analysis is conducted to determine how, and to what degree, different variables affect a desired outcome. For this sensitivity analysis, we kept all inputs the same while varying three inputs, one at a time. From this, we were able to determine how the feasibility of a PV system would change if only one variable was modified. The three inputs we varied were the cost of electricity, cost of PV modules, and amount of government incentives. The first case was to input an increase in the price of electricity only. Next, we decreased the cost of PV modules. The final scenario was to add government incentives. To get a more accurate analysis of future feasibility, we researched trends of Intel's cost of energy from Mr. Serrano and the cost of PV systems. We input the predictions from these trends into RETScreen to aid us in the determination of future feasibility.

## 3.3 Environmental and Social Impacts

The main methods used to fulfill this objective were archival research and data collection. This information was obtained from the local newspapers, The Tico Times and La Nación, and related websites. We gathered data about ICE's current sources of energy.

A PV system will allow Intel to rely less on the utility grid (ICE) by producing its own energy. This will cause a reduction in emissions that we calculated using RETScreen. The information gathered from Intel and ICE was used as inputs in RETScreen.

Finally, we researched the environmental impacts associated with hydroelectricity compared to those of a PV system. We researched the effects that hydroelectric dams have on surrounding ecosystems. We also looked into recent controversies over dam construction in Costa Rica. This information was collected from local newspapers. The environmental impacts of PV systems were also researched. We compared the two sources to determine if there was a significant enough difference between them to justify implementation of a PV system by Intel.

# Chapter 4: Results and Data Analysis

This chapter incorporates our results and our analysis of those results. First, this chapter discusses the legal possibility of implementing a PV system. Then additional research on the amount of energy PV modules produce is presented. We then used case studies to determine what kind of PV system we would consider and to establish the possible benefits that Intel would experience from one of these systems. These case studies highlighted economic savings, environmental benefits, and design strategy. In addition, we examined Intel's current energy use and cost. Next, we used RETScreen, a PV system modeling program, to develop the cost analysis, financial summary, and reduction of greenhouse gas emissions for a variety of systems. We also assessed the environmental effects of both hydroelectricity and PV modules. Recent price trends of the PV market were considered to predict future pricing of PV modules. We then conducted a sensitivity analysis to determine which factors would make a PV system more feasible.

## *4.1 Private Generation of Electricity in Costa Rica*

There are laws in Costa Rica regarding the private generation of electricity. These laws include the Authorization of Autonomous or Parallel Electric Generation Act, or law number 7200 of September 28, 1990 and its amendment law number 7508. By this law, private parties are not allowed to produce and sell electric power. However, under a concession granted according to the law private parties would be allowed to produce electricity as long as the capacity does not exceed 20,000kW. More than one concession may be granted to the same party but the same limitation will still stand that the combined capacity of the party's electricity generation may not exceed 20,000kW. This concession applies to any environmentally friendly energy production. The only plants that do not qualify for this concession are those that are fueled by hydrocarbons or mineral coal (Facio, 1996).

The first step to obtain a concession is to submit the application of eligibility statement to ICE. The next step is an environmental impact report processed through the Ministry of Natural Resources for plants with a capacity between 2,000kW and 20,000kW (Facio, 1996).

The result of this data analysis is that Intel should be eligible to qualify for the necessary concession to produce its own electricity through a PV system. This is because PV energy production is considered environmentally friendly and Intel would not install a system with a capacity greater than 20,000kW. This is true because Intel does not have enough available roof area to build a PV system over 7.5MW.

## 4.2 Photovoltaic Energy Production

The capacity of any energy source is the amount of energy that it will produce under optimal conditions. In the case of photovoltaic energy production, a 500kW system operating under optimal conditions for one hour will produce 500kWh of electricity. The annual energy output of a system is the amount of electricity that the system will produce in one year. This number depends on a number of factors including the slope of the system and the direction it faces. The output also varies based on where the system is located in the world because it depends on the amount of solar radiation available. The weather at the location also affects energy production. Even though PV systems produce energy in all types of weather, cloud cover decreases the amount of energy produced, which can vary on an hourly basis. Table 3 shows the approximate percentage of their rated power that PV cells produce in different weather conditions (RETScreen, 2001).

**Table 3: Energy production in different weather conditions**

| Weather Condition | PV Cell Energy Production |
|---|---|
| Clear | 100% |
| Overcast | 80% |
| Cloudy and Humid | 50% |
| Extremely Cloudy | 30% |

RETScreen also presents a simple estimation for calculating the annual energy output of a system, without using weather, location, slope, and azimuth information. It states that multiplying the capacity by 800 to 2000 yields a good approximation of the annual energy output the system. The 800 to 2000 multiplier stands for the number of hours in a year that the PV system will operate at 100% capacity out of a total of 8760 hours in a year. For a 100kW system, this estimation yields a range from 80,000kWh to 200,000kWh. RETScreen calculated the annual energy output of a 100kW system at Intel to be 157,000kWh. RETScreen considered the solar radiation at Intel plus the roof slope and building azimuth. The solar radiation information was retrieved from the national weather database through RETScreen.

## 4.3 Case Studies

The following projects, located in California, have all implemented on-grid PV systems. They were all designed and installed by PowerLight, a firm based in Berkeley, California. PowerLight is a consulting company that also designs and installs PV systems. PowerLight is discussed more in section 3.1. We chose to research and review three PV systems installed by PowerLight based on their size, recent installation date (2002), and because they were all installed after the buildings had been constructed. One of these companies, Cypress Semiconductor, was chosen because they perform the same operations as Intel. We used these systems as a basis for our recommendations and conclusions. The location, capacity, surface area, and estimated cost of each system are shown in Table 4 (PowerLight, 2004). Unfortunately, PowerLight did not provide us with the total initial cost of these systems, but said that they were around $6 to $8 per watt. This estimate includes the total initial cost of a PV system before any incentives. The total initial cost of a system includes the cost of the modules, installation, development, engineering, wiring, and circuitry. In Table 4 the capacity was multiplied by $7 to arrive at an estimated total initial cost.

**Table 4: Specifics about case studies**

| Company | Location | Capacity of system | Surface area (sq. ft) | Estimated Initial Cost |
|---|---|---|---|---|
| Cypress Semiconductor | San Jose, California | 325kW | 32,750 | $2,275,000 |
| Neutrogena | Los Angeles, California | 546kW | 62,000 | $3,822,000 |
| Alameda County (Santa Rita Jail) | Santa Rita, California | 1.18MW | 130,000 | $8,260,000 |

These PV systems were installed to combat high and rising energy costs, to rely less on natural gas, and to help further the technology of solar power. Currently in California, the energy cost averages out to be greater than $0.10 per kWh for commercial and industrial use. In addition, natural gas is the main source of energy in California; it accounts for 52.5% of energy produced. Table 5 shows the distribution of what sources produce energy for use in California (UCI, 2004). Another major reason why these companies opted to install PV systems was that California has significant government incentives. The government pays for 50 to 75% of the total initial cost of the system. The government offers these incentives because of the severe energy shortage in California and due to growing problems with pollution from natural gas in the larger cities.

**Table 5: Energy sources in California**

| Fuel type | Fuel mix (%) |
|---|---|
| Natural Gas | 52.5 |
| Hydroelectricity | 26.7 |
| Nuclear | 7.8 |
| Geothermal | 5.0 |
| Wind | 3.0 |
| Coal | 2.0 |
| Biomass | 2.0 |
| Solar | 1.0 |
| Electricity Mix | 100.0 |

Each PV system from these case studies was tailored to meet the facility's specific needs. All of these systems produce a partial percentage of the energy used at the site, so the rest of the energy demand is still purchased from the utility grid. Every system had lightweight PV modules installed over the existing roof membrane on previously constructed buildings. The modules create a DC output which is then converted to AC electricity by inverters and is stepped up to 480V. The electricity is then fed into a substation and distributed throughout the facility (PowerLight, 2004).

PV systems can be installed in phases to spread out the initial cost over a span of time. Cypress Semiconductor and Alameda County installed their PV systems in phases. Cypress Semiconductor installed its PV system in two phases. The first phase was a 122kW system installed on one building in January of 2002 and the second was a 203kW system installed on a different building in July of 2002. Alameda County installed its system in three phases of 519kW, 131kW, and 530kW, all feeding power to the same substation, over the span of a year and a half (PowerLight, 2004).

### 4.3.1 Benefits Experienced

Each facility experienced similar benefits from their PV system. Each experienced a reduction in cost for operating and energy demand. For example, the Santa Rita Jail reduced its use of utility energy during peak hours by 30% with energy from its PV system. The system saved the county $425,000 in the first year and is estimated to save over $15 million in its projected 25 year lifespan. Savings from the other two systems were not available. In addition to producing electricity, the PV modules also utilize unused roof space. The PV modules act as added insulation and thermal reflectors, reducing heating and air conditioning costs. The exact reductions in heating and cooling costs were not available to us. The panels are also protecting the roof from thermal cycling and UV degradation, which both reduce roof life.

## 4.4 Energy at Intel

To determine the feasibility of a PV system for Intel we used its own data related to energy demand and cost of energy. This was important in determining the size of the system. Currently, Intel's entire facility consumes around 10 million kWh per month. The total usable roof area for PV modules at Intel is 690,000 sq. ft. This total includes the roofs of CR1, CR2, and CR3; the roof of the Sprung office building is not suitable to install PV modules on because it is a temporary building and has too severe of a roof slope.

The cost of energy for Intel varies during the hours of the day. There are three pricing categories: peak, shoulder, and night periods. Tables 6 and 7, collected from Mr. Serrano, show energy costs for different periods and when those periods occur. From these tables, it is evident that most peak hours occur when the sun's rays are most powerful. PV systems produce most of their energy during these hours. Tables 6 and 7 also show when shoulder and night hours occur. In addition, these tables show the cost of energy for the two electricity seasons of the year. Table 6 illustrates the current cost of energy during the high season, January through August. Table 7 illustrates the current cost of energy during the low season, September through December. The dollar amounts in Tables 6 and 7 are the rates charged by ICE for electricity use (kWh) and hourly demand (kW) during each period. The number of kWh consumed in a month during a given time period is multiplied by the charge for energy use to get the total energy use cost for that time period for the month. The charge for hourly energy demand for a given time period is multiplied by the hourly demand in kW to get the total cost for energy demand for that time period for the month. The information in Tables 6 and 7 was collected from Mr. Serrano.

**Table 6: Cost of demand and energy: January through August**

| Time Period | Hours | Cost for energy use ($/kWh) | Cost of demand ($/kW) |
|---|---|---|---|
| Peak | 10:00-12:30<br>17:30-20:00 | $0.050 | $8.96 |
| Shoulder | 06:00-10:00<br>12:30-17:30 | $0.025 | $8.65 |
| Night | 20:00-06:00 | $0.010 | $3.93 |

**Table 7: Cost of demand and energy: September through December**

| Time Period | Hours | Cost for energy use ($/kWh) | Cost of demand ($/kW) |
|---|---|---|---|
| Peak | 10:00-12:30<br>17:30-20:00 | $0.030 | $6.72 |
| Shoulder | 06:00-10:00<br>12:30-17:30 | $0.010 | $3.20 |
| Night | 20:00-06:00 | $0.010 | $3.20 |

With the charges from Tables 6 and 7 and the approximate monthly energy usage of Intel we can estimate Intel's monthly electricity bill. To do this first we need to assume that Intel's energy consumption has a uniform distribution. A uniform distribution means that Intel would consume the same amount of energy every hour for the whole month. To get the amount of kWh consumed per hour, take Intel's monthly consumption and divide it by the number of hours in a month; the equation is as follows:

- Total Monthly Energy Consumption / Number of Hours in a Month = Hourly Consumption

With Intel's monthly consumption and the number of hours in a month plugged in, the equation is as follows:

- 10,000,000 / 720 = 13,888.89kWh = Hourly Consumption

To get the total cost for energy use, the hourly consumption needs to be multiplied by the number of days in a month. It also needs to be multiplied by the sum of the use charge per kWh for each time category, peak, shoulder, and night, times the number of hours in that category. The equation for the last calculation is as follows:

- Hourly Consumption * Number of Days in a Month * ( ( Peak Use Cost * Number of Hours in Peak Time ) + ( Shoulder Use Cost * Number of Hours in Shoulder Time ) + ( Night Use Cost * Number of Hours in Night Time ) ) = Total Energy Use Cost

With the numbers from the high season, January through August, plugged in, the equation is as follows:

- 13,888.89 * 30 * ( ( 0.05 * 5) + ( 0.025 * 9) + (0.01 * 10) ) = $239,583.35 = Total Energy Use Cost

To get the total cost of hourly energy demand, the cost per kW for each category needs to be added together and then multiplied by the hourly consumption. The equation for the total demand cost is as follows:

- Hourly Consumption * ( Peak Demand Charge + Shoulder Demand Charge + Night Demand Charge ) = Total Energy Demand Cost

With the charges from the high season plugged in, the equation is as follows:

- 13,888,89 * ( 8.96 + 8.65 + 3.93) = $299,166.69 = Total Energy Demand Cost

To get the total energy cost, the energy use cost and the energy demand cost need to be added together, the equation is as follows:

- Total Energy Use Cost + Total Energy Demand Cost = Total Energy Cost

With the solutions to the two previous equations plugged in, the equation looks as follows:

- 239,583.35 + 299,166.69 = $538,750.04 = Total Energy Cost

From this equation, we have an estimate for Intel's current electricity cost for one month during the high season, $538,750.04. Using the same equations, the estimated monthly cost for Intel during the low season is $323,888.91. Both of these estimates assume a uniform distribution of energy consumption throughout the day and the month, so they are rough estimates of the monthly cost for Intel. Taking a weighted average of these two, based on the number of months in each season, yields an average cost of $467,129.66 per month for electricity. Intel provided us with average cost of $500,000 per month for electricity. From this, we see that our estimate is a good approximation.

## *4.5 RETScreen Inputs*

The data needed for the RETScreen inputs was collected from Mr. Alterno and Mr. Serrano. This data was used to develop system outputs, a cost analysis, a financial summary, and the environmental impacts of a PV system. The first choice in RETScreen was to decide on an on-grid or off-grid PV system. Since any PV system would not be able to power the entire Intel facility, we determined that an on-grid system would be the only option for Intel to consider. This was also how all three PV systems from the case studies were designed. An on-grid system supplies energy to the site while the utility company still provides some energy too. Next, we chose the capacity of the system. The largest system that the facility could accommodate is a 7.5MW system, due to roof space limitations. This system would only produce about 12,000MWh of energy a year, or one tenth of Intel’s yearly demand, at a total initial cost of about $47 million. However, we limited the size of the system to 2,000kW due to the cost of the system and because there are only a handful of PV systems in the world larger than 2,000kW. This system would cost Intel approximately $12 million dollars and would never pay for itself over its lifespan. Any system with a larger capacity also had no breakeven point. This was also a reason for not looking into a system with a capacity larger than 2,000kW. We then chose to vary the capacity from 100kW to 2,000kW, in increments of 100kW, to compare different size systems. Another reason for choosing systems ranging between 100kW and 2,000kW were the similarities between Intel and our case studies. The three case studies had systems that ranged from 325kW to 1.18MW so we expanded that range to get boundaries for the system Intel should consider.

The important inputs we used to generate the financial summary in RETScreen are shown in Table 8. Even though there is such variation in the pricing of electricity for Intel, the cost of energy avoided by implementing a PV system is around $0.05 per kWh. This is because Intel’s monthly consumption is around 10 million kWh and their monthly bill for energy is around $500,000. The avoided energy cost is the cost of energy that Intel is currently paying for energy that the PV system could be producing. The energy cost has not changed in the past couple years and is projected to remain the same for the next few years. This is why the cost escalation rate for electricity is 0% as shown in Table 8. Most manufacturers have a 20 year warranty on their PV modules. We are extending the project life to 30 years, the estimated module lifespan, to find any breakeven points after a warranty would expire. Following Table 8 are explanations for the discount rate and inflation rate and section 4.6 discusses the incentives input.

**Table 8: RETScreen financial summary inputs**

| | |
|---|---|
| Avoided Energy Cost | $0.05/kWh |
| Energy Cost Escalation Rate | 0.0% |
| Prime Rate | 9.07% |
| Inflation | 12.18% |
| Project Life | 30 years |
| Incentives/Grants | $0.00 |

Inflation and prime rates were also collected to produce the financial summary and aid in our prediction of future trends. A graph of the monthly inflation rates in Costa Rica from 1995 to 2002 is shown in Figure 5; they are not cumulative rates. These rates were also collected from Banco Central de Costa Rica (BCCR, 2004). The inputs also helped with enabling us to predict any possible inflation trends. From Figure 5, we noted that the inflation rate has remained around 9% for the past 5 years. 9.1% was projected in The Tico Times as the inflation rate for 2004. We decided to use the average inflation rate from 1995 to 2002, 12.18%, as an input into RETScreen. We chose to use the average instead of the current rate because we believe that the average is a more accurate prediction for future trends in the inflation rate.

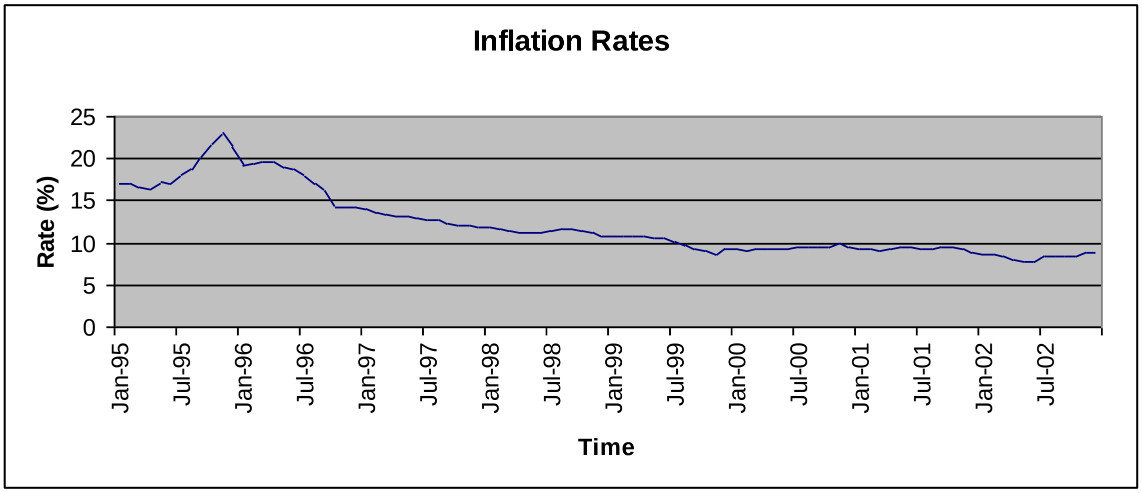


Figure 5: Inflation rates from 1995 to 2002

The prime rate was another input needed for RETScreen. Costa Rica uses the U.S. prime rate. Figure 6 shows the U.S. prime rates, on a monthly basis, for the past 29 years, from June of 1975 to June of 2004. This data was collected from Bank of America. We took the average of these prime rates, 9.07%, as our input into RETScreen. We believe this is an appropriate prediction for the prime rate for the next 30 years.

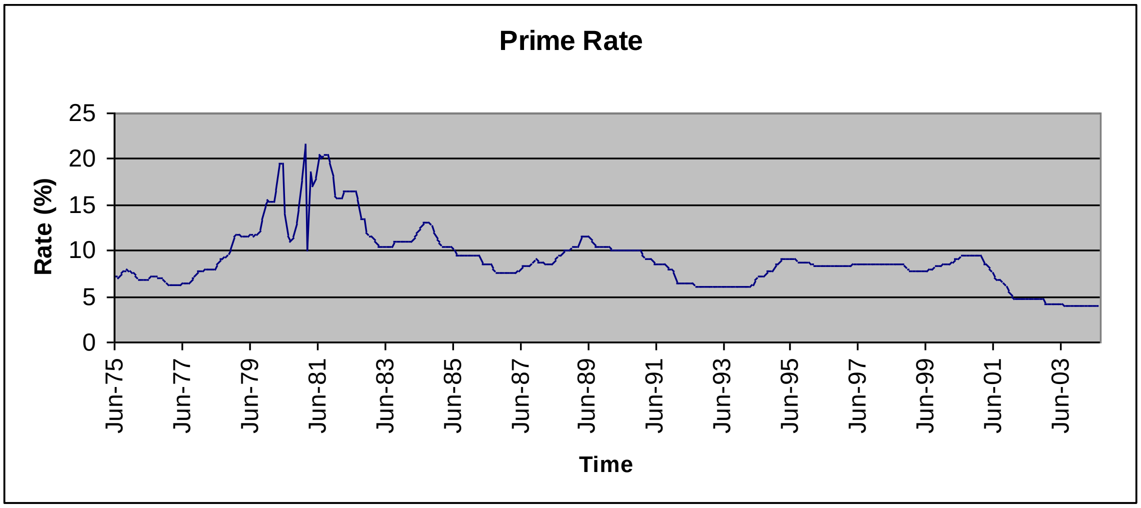


**Figure 6: Prime rates from 1975 to 2004**

From our review of the RETScreen manual, we have found that there are various reasons for installing a PV system at different slopes. To gain maximum energy output from a PV system the system needs be installed at an angle equal to the absolute value of the latitude of the site, although to do this usually requires expensive support structures. The alternative to this is to install the PV modules directly over the existing roof. This will not produce the maximum energy output but it will save money and also be more aesthetically pleasing. Many people feel that support structures under modules are less visually pleasing than modules placed with no supports directly on top of the roof.

Architectural data was collected from the blueprints of Intel’s facility. The data collected was the slope of the roofs and the azimuth of the buildings. From the cross sectional roof plans, we found the slope of CR1 and CR3 to be 5º. With a 50kW system, at Intel, which has a latitude of 10º, it would save $65,000 to install the system directly over the existing roof. This roof has a slope of 5º and the system would only produce 120kWh less per year than a system with a slope of 10º. These numbers were calculated using RETScreen. Figure 7 shows a section of the of the roof plan, we received this information from an AutoCAD drawing.

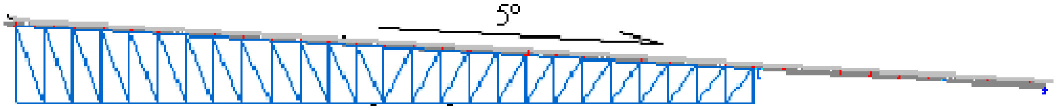


**Figure 7: Cross section of the roof of CR1**

The azimuth is an important initial input into RETScreen. We needed to find the angle between the projection of the normal surface and local meridian with zero due South. If the system is located in the northern hemisphere the cells should be facing the equator with an angle as close to zero as possible. This creates maximum sun exposure. If the PV cells were mounted over the existing roof, the azimuth would be equal to that of the roof.

The azimuth of the building was taken from similar blueprints and was equal to 25 degrees from South. Figure 8 shows the angle of the building CR1 when compared to true South. CR2 and CR3 are oriented the same way; therefore, all buildings have the same azimuth.

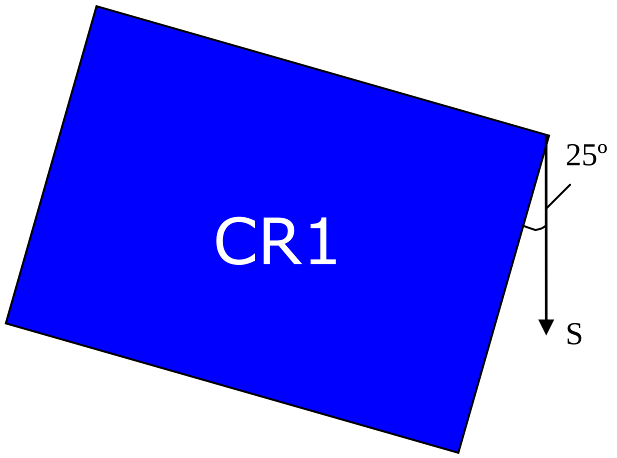


**Figure 8: Azimuth of CR1**

Additional RETScreen inputs were the current sources of energy in Costa Rica. These were used to determine the environmental impacts from the reduction of emissions due to implementation of a PV system. Intel receives all of its energy from ICE which produces most of its energy from hydroelectricity. Table 9 shows the distribution of the different types of energy produced by ICE (CIA, 2003).

**Table 9: Distribution of ICE's energy production**

| Fuel type | Fuel mix (%) |
|---|---|
| Hydroelectricity | 81.9 |
| Geothermal | 9.0 |
| Solar | 4.6 |
| Wind | 3.0 |
| Fossil Fuels | 1.5 |
| Electricity Mix | 100.0 |

## *4.6 Government Incentives*

Through our archival research and the contacts that we made, we found that Intel does not qualify for government incentives. The laws that we found, number 7169 and number 7447, explain that the incentives are given to universities or industries trying to further the development of renewable energy. Because Intel is not working to develop a renewable technology, they do not qualify for this incentive. In addition, the amount of the incentive, around $2,000, is minimal in comparison to the cost of the PV systems we evaluated. Our contact within CICR, Agustín Rodriguez, explained that the application process was long and tedious and would not be worth the small incentive. Another contact that we made was Jenny Strauss, a sales representative from PowerLight. She said that without incentives the PV system would not be worth implementing due to its high cost and current low cost of electricity. She estimated that Intel would not see any economic benefits, with a 100kW system, until at least 20 years after the installation date.

## 4.7 RETScreen Outputs

This section describes the outputs from RETScreen. The most important for this project were the system, cost analysis, financial, and environmental outputs.

### 4.7.1 System Outputs

Figure 9 shows the relation of system capacity to its annual energy output. We used RETScreen to calculate the output in MWh of a given capacity of a system at Intel's location. This graph is important because it shows how much energy a system will produce over the period of one year.

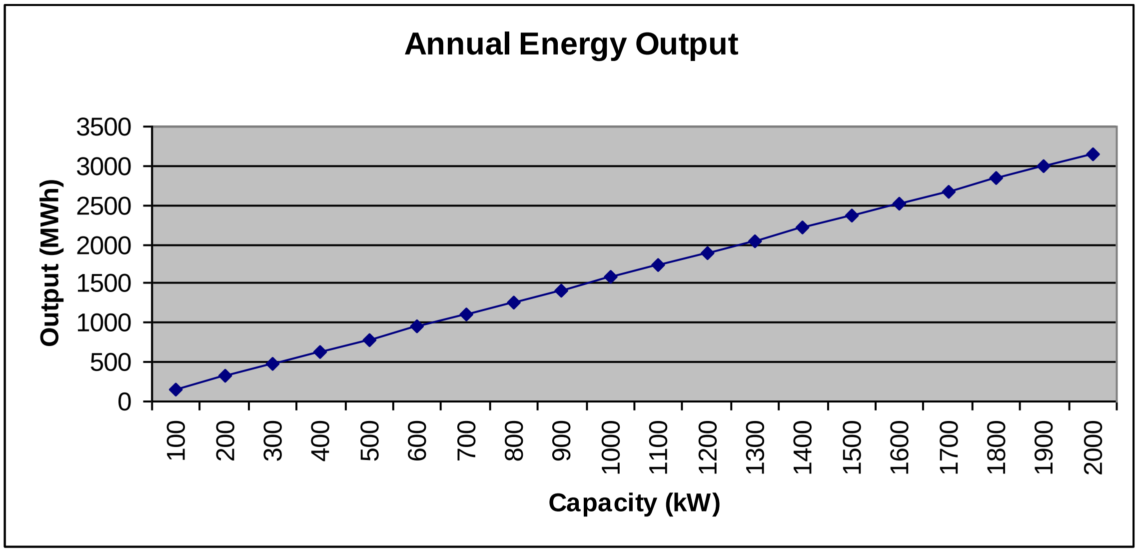


**Figure 9: Annual energy output of photovoltaic systems**

As Figure 9 shows, a 2MW system would produce only around 3,200MWh. This is a very small percentage, 2.67%, of the 120,000MWh consumed by Intel each year. Figure 10 shows our estimated annual savings for a range of PV systems. To estimate the annual savings of a system we used its annual energy output because it is directly related to the amount of money a PV system would save Intel. This is due to the fact that the annual energy output is the amount of energy Intel would not have to purchase from ICE because it is supplied by the PV system. Multiplying the annual energy output of a system by the current cost of energy yielded a rough estimate of the annual savings of that PV system.

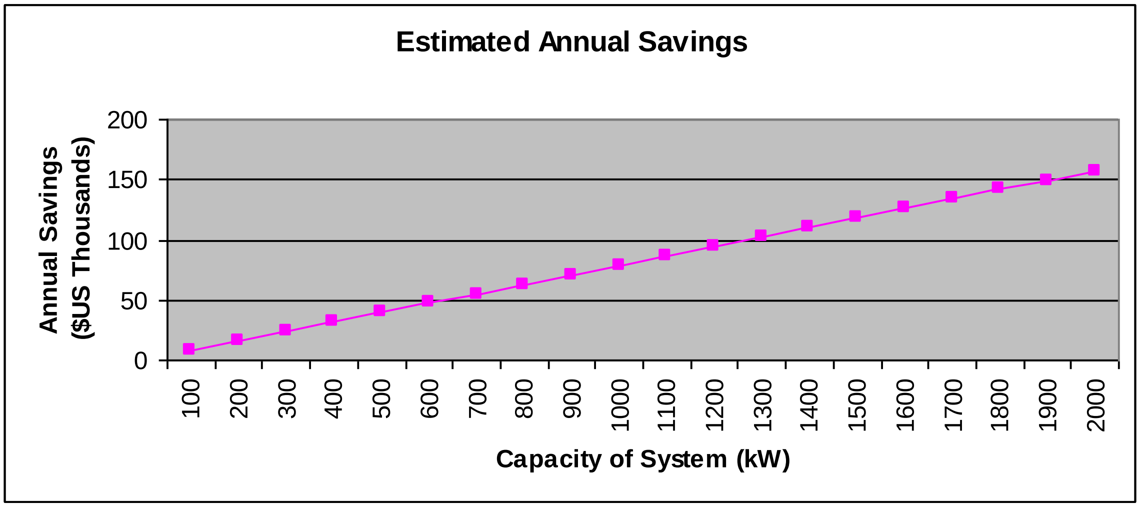


**Figure 10: Estimated annual savings**

Another system output given by RETScreen was the surface area of different size systems. By increasing the capacity of the system, Figure 11 shows that the area increases linearly. Note that the usable roof space at Intel is approximately 690,000 sq. ft.

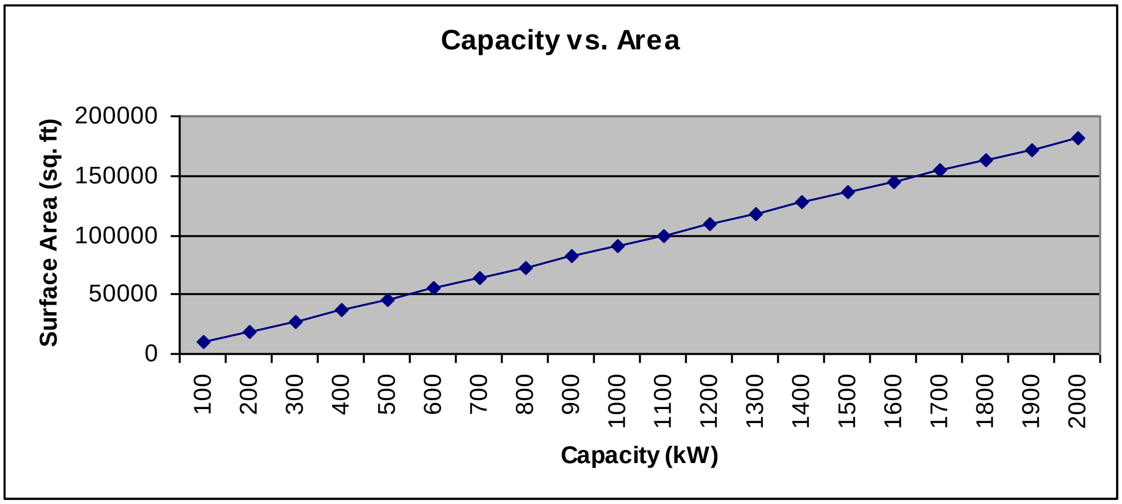


**Figure 11: Surface area of photovoltaic system**

Mrs. Strauss of PowerLight provided an estimate for the surface area of a PV system based on its capacity. She stated that the area of a system is about one square foot for every 10 watts. Our calculation using RETScreen shows that a 100kW PV system has a surface area of 9,600 sq. ft., which is very close to 10,000 sq. ft. estimate given by Mrs. Strauss.

### 4.7.2 Cost Analysis Outputs

The different parts of the cost analysis outputs include the cost of a feasibility study, development, engineering, renewable energy equipment (PV modules), and additional equipment needed in the system. The cost analysis only includes the initial costs of the PV system. However, the financial summary, discussed in section 4.7.3, considers both the initial costs and any costs that will be incurred after the system has been installed.

Again, we started with a 100kW PV system and then increased the capacity by 100kWs until we reached a system size of 2,000kW. The outputs allowed us to form a linear correlation of how the price will increase as the capacity of the system increases. Figure 12 shows module and total initial costs. Module cost is linear because each module produces a certain amount of energy. To double the system's capacity would require doubling the number of modules, which doubles the price. See Table 10, one of RETScreen's cost analyses, for everything that is included in initial cost.

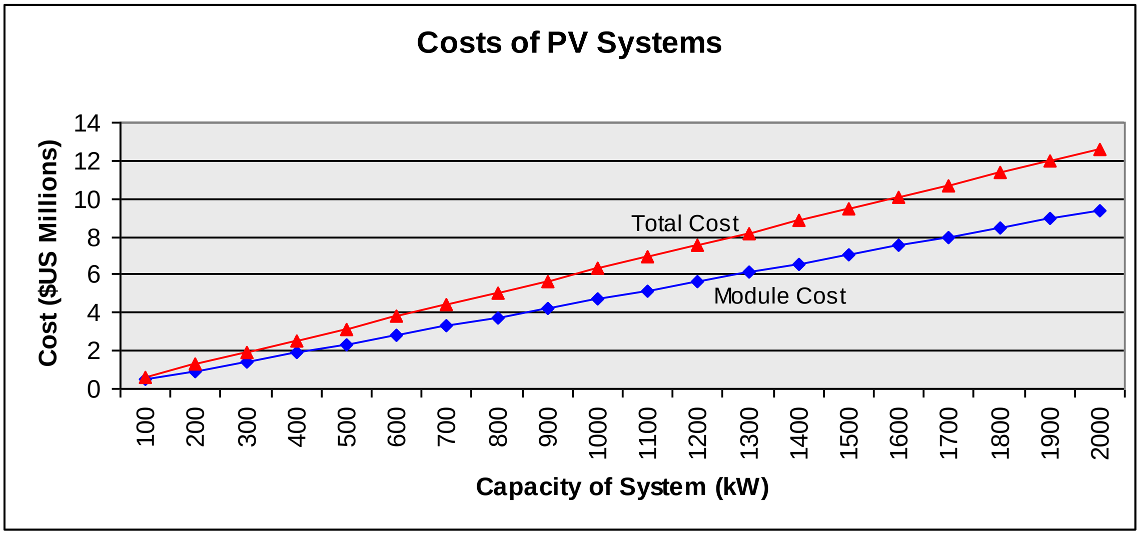


**Figure 12: Cost of photovoltaic systems**

These costs are very similar to those that PowerLight would quote on a PV system. PowerLight's estimate is $6 to $8 per watt which would make a 100kW system cost between $600,000 and $800,000. Using RETScreen, we calculated the cost of a 100kW PV system to be $644,000, which is within the range of PowerLight's estimate.

Once RETScreen has all of the inputs it calculates the initial cost of the PV system. Table 10 shows the cost analysis produced by RETScreen for a 100kW PV system.

**Table 10: Cost analysis of a 100kW photovoltaic system**

| **Feasibility Study** | **Unit** | **Quantity** | **Unit Cost** | **Amount** |
|---|---|---|---|---|
| Site investigation | Per hour (p-h) | 8 | $ 65 | $ 520 |
| Preliminary design | p-h | 20 | $ 65 | $ 1,300 |
| Report preparation | p-h | 10 | $ 65 | $ 650 |
| Travel and accommodation | p-trip | 1 | $ 1,200 | $ 1,200 |
| Credit – Base case system | Credit | 1 | $ 3,000 | $ (3,000) |
| Sub-total : | | | | **$ 670** |
| **Development** | | | | |
| Permits and approvals | p-h | 4 | $ 65 | $ 260 |
| Project management | p-h | 50 | $ 85 | $ 4,250 |
| Travel and accommodation | p-trip | 1 | $ 2,000 | $ 2,000 |
| Credit – Base case system | Credit | 1 | $ 5,000 | $ (5,000) |
| Sub-total : | | | | **$ 1,510** |
| **Engineering** | | | | |
| PV system design | p-h | 15 | $ 65 | $ 975 |
| Structural design | p-h | 20 | $ 65 | $ 1,300 |
| Electrical design | p-h | 32 | $ 65 | $ 2,080 |
| Tenders and contracting | p-h | 11 | $ 65 | $ 715 |
| Construction supervision | p-h | 15 | $ 65 | $ 975 |
| Credit – Base case system | Credit | 1 | $ 4,000 | $ (4,000) |
| Sub-total : | | | | **$ 2,045** |
| **Renewable Energy (RE) Equipment** | | | | |
| PV module(s) | kW | 100.00 | $ 4,700 | $ 470,000 |
| Transportation | Project | 1 | $ 800 | $ 800 |
| Sub-total : | | | | **$ 470,800** |
| **Balance of Equipment** | | | | |
| Inverter | kW AC | 0.2 | $ 1,200 | $ 240 |
| Other electrical equipment | kW | 100.00 | $ 700 | $ 70,000 |
| System installation | kW | 100.00 | $ 900 | $ 90,000 |
| Transportation | Project | 1 | $ 8,000 | $ 8,000 |
| Sub-total : | | | | **$ 168,240** |
| **Miscellaneous** | | | | |
| Training | p-h | 6 | $ 65 | $ 390 |
| Sub-total : | | | | **$ 390** |
| **Initial Costs – Total** | | | | **$ 643,655** |

Table 10 also shows the variables needed to determine the total initial cost of a PV system. Mr. Alterno informed us to use U.S. costs for all of our analysis. Calculated from Table 10, the PV modules and the balance of equipment account for 99% of the total initial cost. The balance of equipment includes the system installation and additional electrical equipment, such as circuitry and wiring. The feasibility study, development, and the engineering associated with the initial design of a PV system are almost insignificant values when compared to the costs of the PV modules and the balance of equipment.

In addition, Table 10 shows the current cost of PV modules at $4.70 per watt. This module cost causes the initial cost of the PV system to increase as the capacity of the system increases. In addition to adding more modules, increasing the capacity of the system increases the amount of the mounting equipment needed and installation costs. The implementation of any system with a capacity larger than 100kW can be calculated from Table 10. All of the unit costs would stay the same, but the quantities would change in relation to capacity. For example, if the capacity of the system was doubled, from 100kW to 200kW, the number of PV modules would double and the amount of mounting equipment would also double making the total initial cost of the PV system approximately double. As shown by this example, the increase in system cost is linear to the increase in system capacity, which applies to systems of all sizes.

### 4.7.3 Financial Outputs

After we finished the cost analysis and entered the financial inputs into RETScreen, it produced a financial summary for each system throughout its life. In graphical form, it shows the cumulative cash flow and in spreadsheet form, it shows the yearly cash flow. The cash flow also considers scheduled maintenance costs. We generated a financial summary for each system size (100kW to 2,000kW). This was done to find if there was a system with a positive cash flow. We used each financial summary to determine if a PV system would be economically feasible for Intel to consider. From each system's cash flow analysis, we determined that any system larger than 100kW would not see a payback within its 30 year lifespan. Figure 13 shows the cash flow analysis produced by RETScreen for a 100kW system. The y-axis of this graph shows the cumulative cash flow of the system throughout its lifespan, the parenthesis signify a negative number. The cumulative cash flow at a given time equals all of the savings since installation minus the total initial cost of the system and any maintenance costs. Using the annual savings from avoided energy costs RETScreen produced this cumulative cash flow. Avoided energy cost and annual energy production are the major components in determining how much money the system will save each year. The x-axis gives the year with the system's implementation date as year zero. This cash flow only considered the next 30 years because that is the projected lifespan of the system.

The results were similar for larger capacity systems because as the capacity of the system increased, the annual energy production and the total initial cost of the system also increased. The increase in annual savings does not contribute to a faster payback of the system due to a proportional increase in the total initial cost. The below equation illustrates an estimate of the percentage of a system's total initial cost that it will cover through annual savings during its 30 year lifespan. Even though they are minimal, it is important to note that this estimate does not include maintenance costs. Some economic factors, such as inflation and electricity cost escalation rate, are also not considered in this estimate.

- Savings over 30 Years / Initial Cost = Lifetime Payback of Initial Cost
- 100kW system = ( $7,869 * 30 ) / $643,655 = 37%
- 2,000kW system = ( $157,358 * 30) / $12,613,655 = 37%

Note that both systems only cover 37% of their total initial cost. This percentage would need to be over 100% for a system to have a positive cash flow. From the equations, it is evident that an increase in the cost of energy and a decrease in the cost of systems would lead to a better payback ratio. The annual savings used in these equations were calculated using Intel's current cost of energy. The results from this equation also show that varying the capacity of the system does not change the breakeven point of the system.

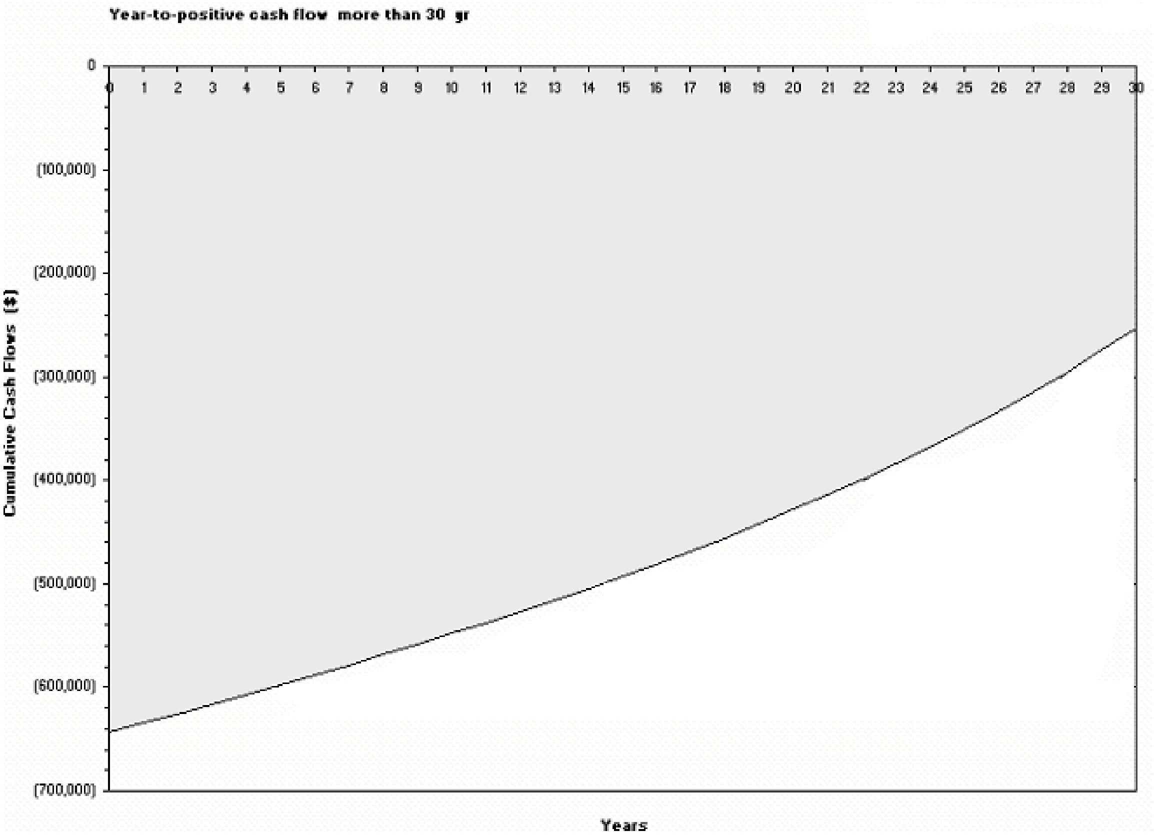


**Figure 13: Cash flow of a 100kW photovoltaic system**

### 4.7.4 Outputs of a 50kW System

After a review of larger systems, we decided to determine if a smaller system would be feasible. We chose a range of systems from 20kW to 90kW. This section summarizes all the RETScreen outputs for a 50kW system. We decided to show all of the outputs for a 50kW system to further illustrate that the capacity of the system does not affect the breakeven point. Table 11 shows the cost analysis of a 50 kW system.

**Table 11: Cost analysis of a 50kW photovoltaic system**

| Initial Costs (Credits) | Unit | Quantity | Unit Cost | Amount |
|---|---|---|---|---|
| **Feasibility Study** | | | | |
| Site investigation | p-h | 8 | $ 65 | $ 520 |
| Preliminary design | p-h | 20 | $ 65 | $ 1,300 |
| Report preparation | p-h | 10 | $ 65 | $ 650 |
| Travel and accommodation | p-trip | 1 | $ 1,200 | $ 1,200 |
| Credit – Base case system | Credit | 1 | $ 3,000 | $ (3,000) |
| Sub-total : | | | | **$ 670** |
| **Development** | | | | |
| Permits and approvals | p-h | 4 | $ 65 | $ 260 |
| Project management | p-h | 50 | $ 85 | $ 4,250 |
| Travel and accommodation | p-trip | 1 | $ 2,000 | $ 2,000 |
| Credit – Base case system | Credit | 1 | $ 5,000 | $ (5,000) |
| Sub-total : | | | | **$ 1,510** |
| **Engineering** | | | | |
| PV system design | p-h | 15 | $ 65 | $ 975 |
| Structural design | p-h | 20 | $ 65 | $ 1,300 |
| Electrical design | p-h | 32 | $ 65 | $ 2,080 |
| Tenders and contracting | p-h | 11 | $ 65 | $ 715 |
| Construction supervision | p-h | 15 | $ 65 | $ 975 |
| Credit – Base case system | Credit | 1 | $ 4,000 | $ (4,000) |
| Sub-total : | | | | **$ 2,045** |
| **Renewable Energy (RE) Equipment** | | | | |
| PV module(s) | kW | 50 | $ 4,700 | $ 235,000 |
| Transportation | project | 1 | $ 800 | $ 800 |
| Sub-total : | | | | **$ 235,800** |
| **Balance of Equipment** | | | | |
| Inverter | kW AC | 0.2 | $ 1,200 | $ 240 |
| Other electrical equipment | kW | 50 | $ 700 | $ 35,000 |
| System installation | kW | 50 | $ 900 | $ 45,000 |
| Transportation | project | 1 | $ 8,000 | $ 8,000 |
| Sub-total : | | | | **$ 88,240** |
| **Miscellaneous** | | | | |
| Training | p-h | 6 | $ 65 | $ 390 |
| Sub-total : | | | | **$ 390** |
| **Initial Costs – Total** | | | | **$ 328,655** |

A 50kW system placed over the existing roof at Intel will produce 78,689kWh per year, about 0.07% of Intel's yearly demand. RETScreen was used to calculate these values. This system produces enough energy in one year to power the whole facility for 5.74 hours. It would occupy 4,679 sq. ft. of roof space, which is around 0.68% of Intel's usable roof area. The current initial investment needed for this system is around $330,000.

Figure 14 shows the cash flow of a 50kW PV system, which is similar to Figure 13, the cash flow for a 100kW system. From Figure 14 you can see that a 50kW still does not see a positive cash flow during the lifespan of the system.

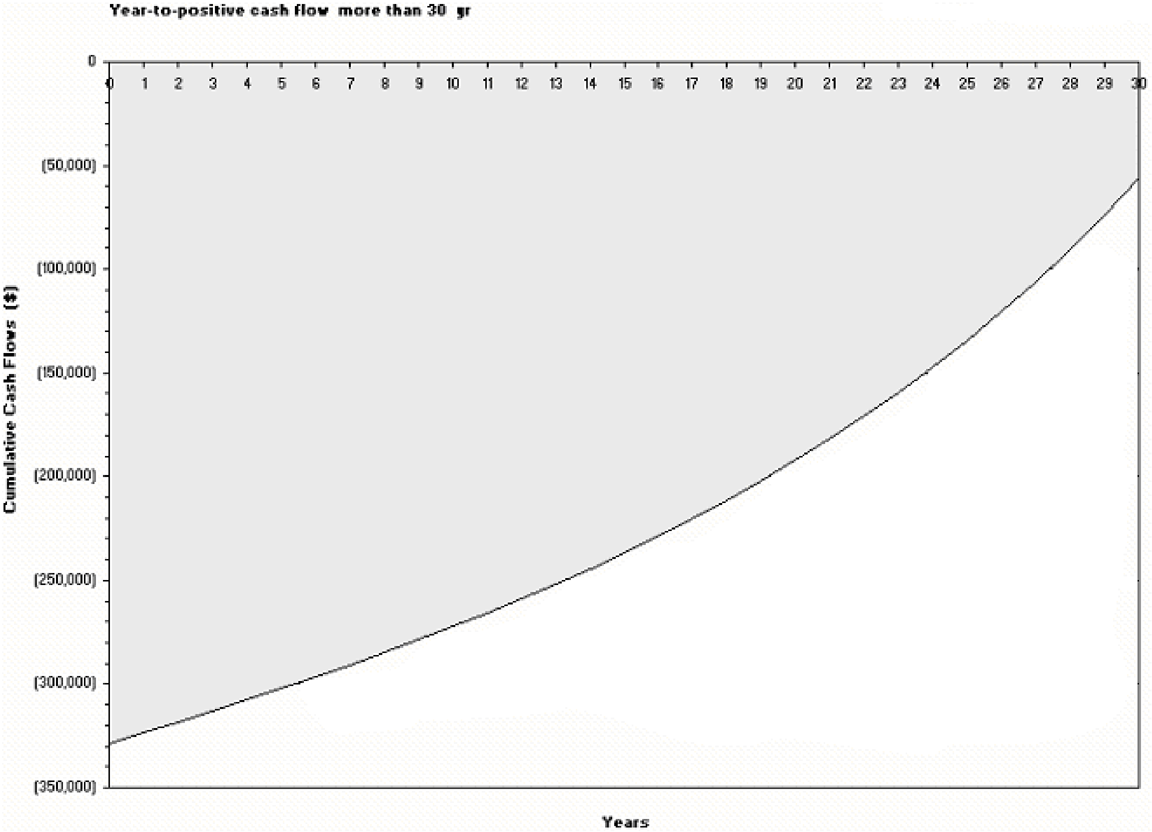


**Figure 14: Cash flow of a 50kW photovoltaic system**

### 4.7.5 Environmental Outputs

For the environmental impacts of the PV system, RETScreen calculated the yearly reduction of greenhouse gas (GHG) emissions. This was conducted for each size system, 100kW through 2,000kW. Figure 15 shows how much the amount of gas reduction increases as the capacity of the system is increased. The larger the system becomes, the less energy Intel will need to purchase from ICE. The decrease in demand will directly affect the amount of energy produced by ICE. This will then lessen the amount of pollution emitted through the production of electricity.

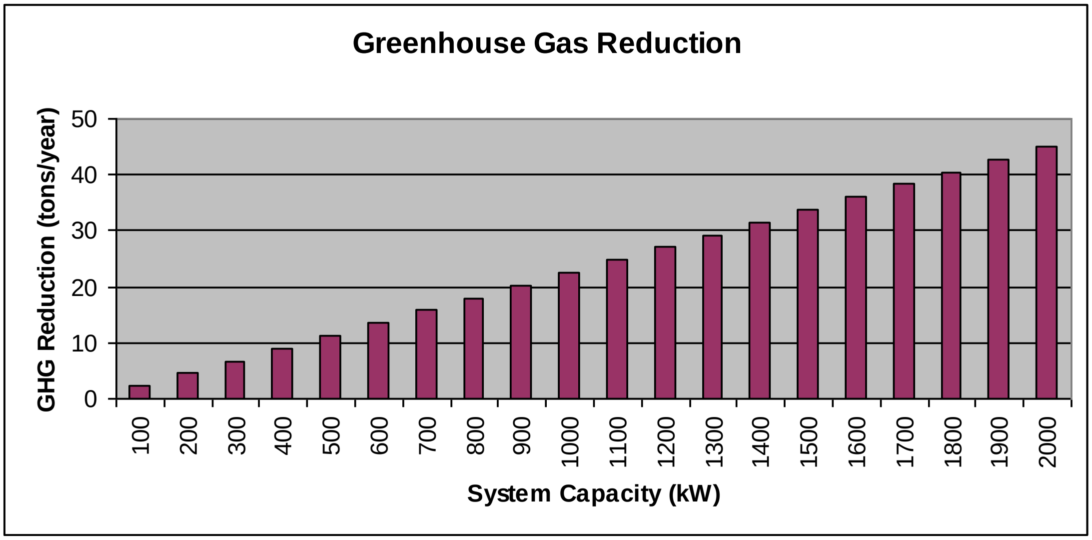


**Figure 15: GHG emissions reduction of photovoltaic systems**

Also compiled from RETScreen, Figure 16 illustrates the difference in potential emission reduction between California and Costa Rica for systems of varying capacities.

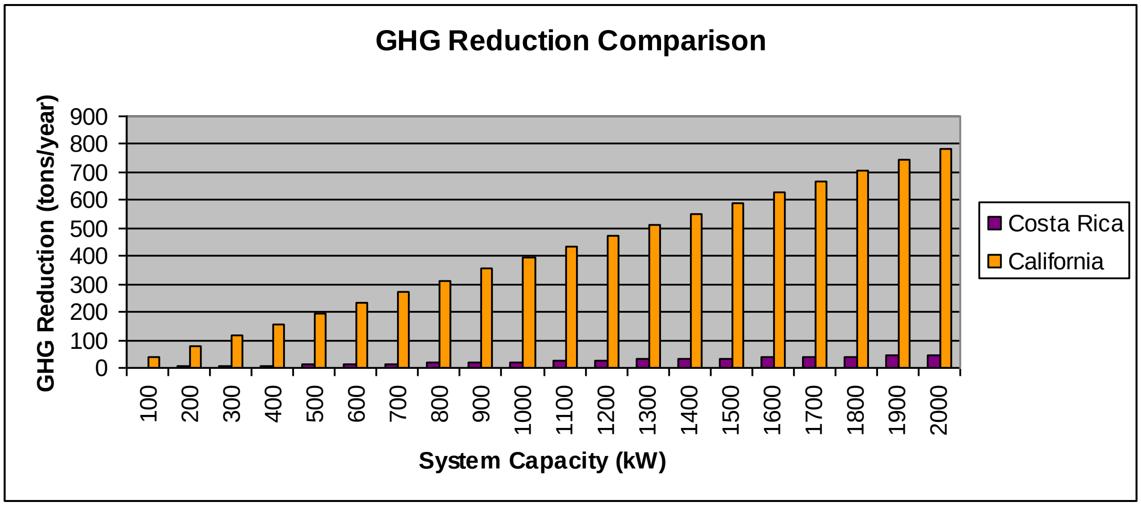


**Figure 16: GHG reduction of California and Costa Rica**

From Figure 16 it is evident that the GHG reduction is not as significant an amount in Costa Rica as it would be in California. This is because ICE produces 82% of its electricity from hydroelectricity and only 1.5% comes from fossil fuels. In California, over 50% of electricity comes from natural gas, which pollutes through combustion.

When a renewable energy source is used in California, it replaces the usage from the grid and eliminates the emissions that would be produced by natural gas.

## 4.8 Environmental and Social Issues

Intel currently receives most of their energy, 82%, from hydroelectricity. Hydroelectricity does not produce any emissions, does not pollute the water, and does not produce a substantial amount of solid waste. Even though there are no environmental impacts as severe as fossil fuel's, there are still some associated with hydroelectricity. These environmental impacts include habitat alteration, fish passage, water quality, and water flow. Large hydroelectric plants require construction of a dam that keeps a reserve of water for use in energy production later. This leads to an altered habitat in the form of a lake, or flooded area. Drastic changes in the flow of water through the dam can affect wildlife downstream (DOE, 2004b).

When the flow of the river is brought to a standstill, the water on the bottom of the lake becomes colder and the dissolved oxygen levels drop. Both of these factors make the bottom of the lake inhospitable to fish. In addition, when this water is released through the dam, it can kill some fish downstream due to the reduced oxygen levels (DOE, 2004b).

Fish passage is another issue arising from hydroelectricity. A dam blocks fish from swimming upstream and downstream. This can affect various fish populations in different ways. Some fish need to swim upstream to lay their eggs and some fish need to swim downstream to reach a better habitat. Alternatives to promote fish passage around dams are currently being researched. Side channels and fish ladders are examples of structures that aid in fish passage (DOE, 2004b).

Costa Rica currently has 60 operating hydroelectric dams that have a combined capacity of over 7,000MW. There are also plans to construct 135 additional dams (The Tico Times, March 7, 2003). The construction of hydroelectric dams has lead to controversy and protest. One claim that dam supporters make is that the dam will produce jobs for locals. The truth is that the majority of jobs created are only for the duration of the construction of the dam, which is usually only two years long. Environmental impacts are the main reasons for protest. The following paragraphs describe two current examples of protest in Costa Rica.

Along the Peñas Blancas River in northern Costa Rica, a proposed dam will be constructed in September of 2004. Even though it would be a small dam, only three meters in height and with a capacity of 26MW, it would permanently damage the ecosystem, according to officials from MINAE (Environment and Energy Ministry). Near the construction site is a delicate aquifer and springs that would be affected. Currently there is another dam downstream that residents claim has already caused irreparable damage. This dam is operated by ICE and was constructed in late 2002. In October of 2003, thousands of fish were killed downstream when silt filled water was released (The Tico Times, June 11, 2004). There are many other similar instances occurring in Costa Rica.

In Boruca, in southern Costa Rica, there is a similar situation. This dam, if constructed, would be the largest hydroelectric dam in Central America. It would stand at least 200 meters tall and have at least a capacity of 840MW. This project has been in planning for over 20 years. The main issue stalling the construction is that there are several groups of indigenous people living in the future flood zone that refuse to leave (The Tico Times, February 22, 2004).

The mounting controversy over dam construction may raise the price that ICE charges for electricity. Prices may rise if some dams are prevented from being constructed and demand cannot be met. An increase in electricity cost would make a PV system more feasible for Intel to consider.

A 7.5MW system, installed at Intel, would produce about 11,775MWh each year. Based on a nationwide consumption of 6.839 billion kWh in 2001 and a projection from ICE of a 5.7% increase in demand each year, the current demand for electricity is around 8.076 billion kWh. If Intel installed a 7.5MW system, it would reduce nationwide electricity demand from ICE by 0.15%. This decrease in demand may influence the construction of dams in the future.

There are some environmental concerns with PV systems as well. Some modules are classified as hazardous waste, which means that special care needs to be taken when disposing of the modules. However, only 2% of modules made now are classified as hazardous. This problem can be resolved by purchasing non-hazardous modules. PowerLight’s modules, along with most of the industry’s, are not hazardous waste. The remaining 98% are safe for disposal in landfills because any harmful material is either insoluble or enclosed in glass or plastic.

During manufacture, a variety of toxic chemicals may be used to create the modules. Basic safety and protection methods can prevent any damaging effects from these chemicals. Some waste is also produced during manufacture of the PV modules, but is minimal compared to other energy sources. Silicon is another environmental concern with PV modules. Silica particles can be released during mining and refining, but are only harmful to workers and can be overcome with simple safety measures, such as a respirator.

## 4.9 Price Trends of PV Modules

Over the last four years, the price of PV modules has dropped by 15%. In the next decade, the industry has set a goal of lowering the price of modules to $1.50 to $2 per watt. This would make a grid-connected PV system more feasible without subsidies or government incentives. Figure 17 shows the retail price trends of PV modules from June 2000 to June 2004. This figure shows that the cost of PV modules has been decreasing over time. If this trend continues and the industry’s goal is reached, implementation of PV systems will become more economically appealing within the next decade (Solarbuzz, 2004).

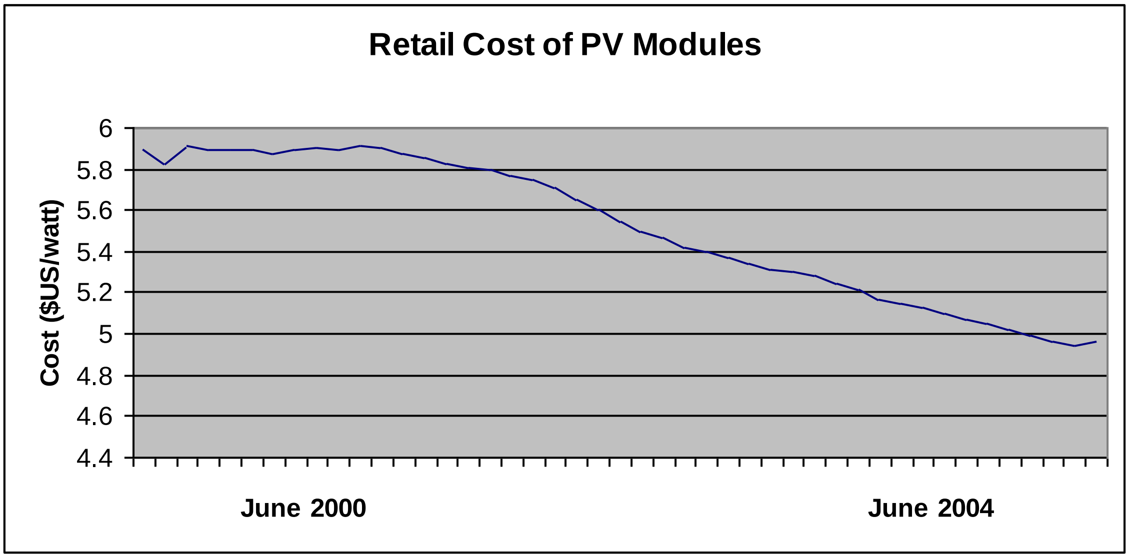


**Figure 17: Price trends of photovoltaic modules**

## *4.10 Sensitivity Analysis*

A sensitivity analysis was conducted to determine the best scenario for implementing a PV system. We looked at three different scenarios and then established a fourth, which was the ideal situation. In all the scenarios, we were looking for a payback period of ten years because this is an ideal payback period. For all scenarios, we used a 100kW system as an example because the capacity does not affect the outcome.

The first scenario we looked into was only an increase in the cost of electricity for Intel. With all other variables constant, a 100kW system will have a positive cash flow after ten years if the cost of energy was $0.40 per kWh. Next, we looked into a decrease in the cost of PV modules. We determined that a reduction in the cost of PV modules will never lead to a payback within ten years. This is due to the cost for installation, wiring, maintenance, etc. The annual energy savings with the current cost of energy is so low that it never covers these costs in ten years or less. The last scenario was if Intel were to receive government incentives. Intel would need to have the incentives cover 85% of the total initial cost of a system. The current initial cost of a 100kW system is $635,000 and incentives would need to cover $540,000 to achieve a payback in ten years.

Since the previous scenarios are unlikely to happen, we developed a more probable case. We used the industry’s goal of $1.50 per watt for the cost of PV modules. We used government incentives covering 50% of the total initial cost of the system. $0.10 per kWh was used as the cost of energy. This is the same amount of incentives given in California so it is a reasonable value to use. We also used $0.10 per kWh as the cost of electricity, which is the current cost in California. This amount could become a reality if the controversy over dam construction continues or nationwide demand increases significantly. Another factor to justify a cost increase to $0.10 per kWh is that the current residential energy cost is higher than industrial energy cost. The cost of electricity for a residential house is around $0.11 per kWh, while the cost for Intel is $0.05 per kWh. We found it to be $0.11/kWh from a local residence’s electric bill in San Jose. They pay around $307 per month for electricity with a total consumption of 2,717kWh. By dividing the total cost of electricity by the total consumption of kWh, we gained the average cost per kWh for that residence. The following equation shows our calculation:

- 307 / 2717 = $0.11 / kWh

With residents currently paying this price for electricity in Costa Rica it is very possible that one day Intel may be paying this same price or even higher.

With the rise in energy cost, decrease in the cost of PV modules, and the initiation of government incentives a PV system would achieve a payback in nine years. Therefore, when all these conditions are met the system would be economically feasible. Figure 18 shows the cash flow of a 100kW system under these conditions. As we increased the size of the system, the results were similar to those of a 100kW system. The only difference was that the initial cost was greater for larger capacity systems.

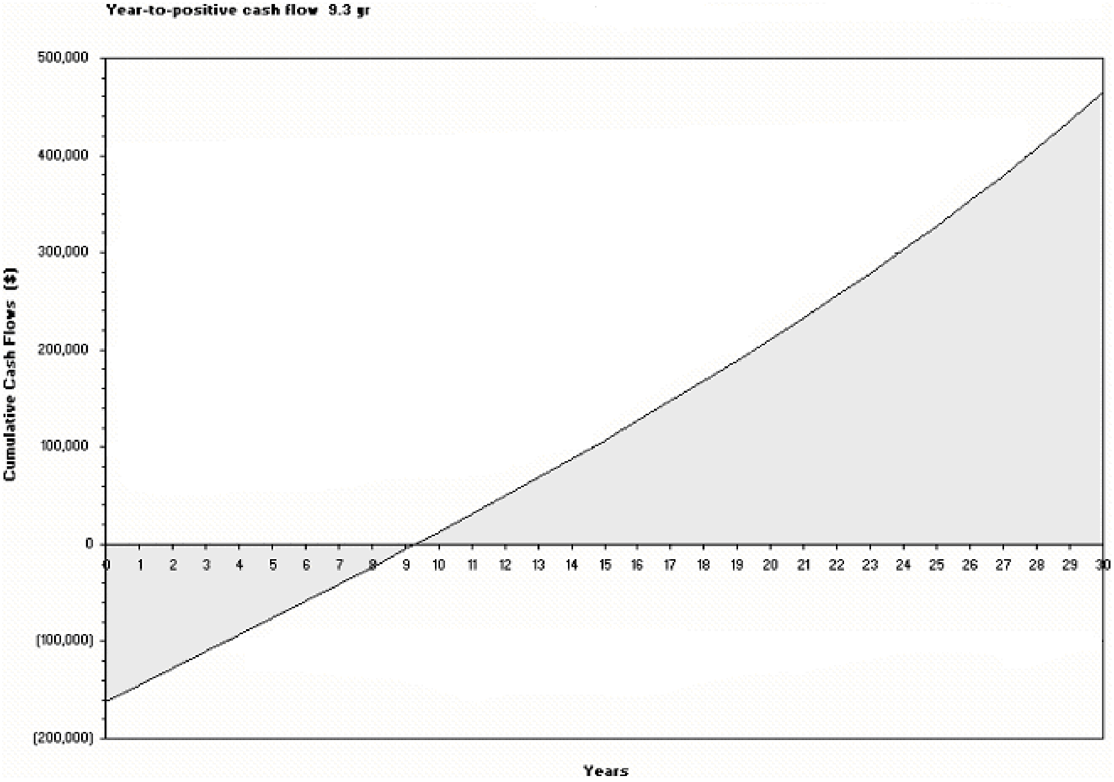


**Figure 18: Predicted cash flow of a 100kW photovoltaic system**

# Chapter 5: Conclusions and Recommendations

After analyzing our results, it is apparent that Intel will not benefit economically by implementing a PV system at their facility in Costa Rica while the cost of electricity is $0.05 per kWh. We came to this conclusion by performing a detailed cost analysis and financial summary supported by RETScreen software on different size systems and with varying economic conditions. We also used opinions provided to us by the firm PowerLight as well as experts in Costa Rica.

## *5.1 Current Feasibility*

Energy cost, PV module cost, and government incentives were the main factors considered in determining the feasibility. The present value of an investment on PV system should break even within ten years of its installation date. Our analysis shows that with a 100kW system, the breakeven point is beyond the 30 year lifespan of the system. As the system increases in capacity, the breakeven point remains beyond 30 years due to the proportional increase in cost and annual savings. From our sensitivity analysis, we determined that the current energy cost that Intel pays is the most influential factor. The cost is directly related to annual energy savings, which is what makes the system break even. Due to the current low cost of energy, Intel would not economically benefit by implementing any size PV system.

## *5.2 Future Feasibility*

From our sensitivity analysis, we concluded that to financially justify implementing a large PV system there would need to be a few changes. The cost of energy would need to increase from $0.05 to at least $0.10 per kWh, the price of PV modules would need to decrease to below $2 per watt from the $4.70 they are at now, and Intel would need to be eligible for substantial government incentives, 50% of total initial costs. The future cost of energy is hard to predict, but an increase of $0.05 is not a substantial amount. This increase could be a result of mounting controversy over dam construction or due to increased demand throughout the nation. Module cost is expected to drop below $2 per watt within the next decade. An incentive that would cover 50% of is a reasonable estimate based on California’s current incentives of 50 to 75%. To determine if a PV system would be more feasible in the future Intel should be aware of these three factors. If a system does become feasible, Intel should apply for the concession regarding law number 7200. This concession would allow cogeneration of electricity between Intel and ICE.

## 5.3 Environmental and Social Conclusions

The emission reduction resulting from Intel implementing a PV system is not significant enough to rationalize its cost. However, comparing hydroelectricity's potential damage to ecosystems with the small effects of PV technology we believe that implementation of a PV system at Intel would benefit the Costa Rican ecosystem. All negative environmental effects during PV module manufacturing and disposal can be prevented with simple precautionary measures. Building a dam however causes irreversible damage to the ecosystem. These effects to the ecosystem cannot be controlled by similar measures like the effects of PV modules.

Intel should pursue solar energy incentives from environmental and government agencies. With recent protests against dam construction, Intel may be successful in a push for incentives that would make a PV system more affordable. In addition, implementing a PV system would keep Intel on its environmental objectives towards minimizing its environmental impact in Costa Rica.

The implementation of a PV system could also have social impacts. A PV system at Intel could show support of the residents that oppose dam construction. These residents are concerned with the quality of the river and the habitats. There are also residents who live in future flood lands. With prevention of dam construction, these residents could have their homes saved. Intel would also make other firms and people aware of the harmful effects of dams and the possibility of relying less on them, leading the way to the preservation of the Costa Rican ecosystem.

## 5.4 Design and Implementation Recommendations

This section describes our recommendations about the initial design of Intel's potential PV system. This information should be used if Intel decides to implement a PV system in the future when it becomes more feasible. After researching other similar systems that Intel should compare its PV system to, we have concluded that Intel should run the PV generated electricity directly to its substation, which will then distribute it throughout the facility. We recommend that Intel does not power any specific application within the facility. Powering specific applications requires more equipment and a higher installation cost.

The size of the system depends on how much Intel is willing to invest. After reviewing systems ranging from 100kW to 7.5MW, the maximum size system Intel could implement due to roof limitations, we recommend that Intel consider the implementation of a PV system with a capacity of at least 100kW. Following, we provide information about a 100kW system as an example. A 100kW system will occupy 9,600 sq. ft. of roof space, around 1.36% of Intel's usable roof area. After this system is installed, if Intel chooses to increase the capacity, they would be able to add additional modules with minimal efforts. This recommendation for at least a 100kW system was made because of our study of the cost analysis and financial summary produced by RETScreen. The current initial investment needed for a 100kW system is around $643,655. If the industry meets its goal of $2 per watt, the cost would be $373,655.

The PV modules should be placed on the south side of building CR1. This will reduce the length of the wiring to the substation because CR1 is the closest building to the substation. It will also put the cells at the best angle to receive the sun's radiation because the modules will be facing the equator. In addition, it will allow the system to be visible from the street, which will aid in public awareness of Intel's environmental efforts.

We do not recommend that the system use a sun tracking system because they are only efficient for smaller systems, under 10kW. The modules should be installed over the existing roof with no additional support structure. This will place modules at 5° from the horizontal. The optimum angle for any fixed system is the equal to the latitude, which puts the sun at the best angle year round. This would be 10° at Intel's facility. However, placing the modules at this angle would require additional support structures increasing the cost by 20% ($130,000) for a 100kW system, would only increase the annual output by 0.15% (232kWh), and would be less aesthetically appealing. This system placed with no support structures will produce 157,378kWh per year, about 0.13% of Intel's yearly demand. This system produces enough energy in one year to power the whole facility for 11.48 hours.

The investment in this PV system would let Costa Rica realize that Intel is serious about protecting the environment. This can be used to advertise Intel as a concerned company that wants to preserve the ecosystem by relying less on dams created for hydroelectricity. By advertising the possibility of a system, Intel could also gain public support in the push to initiate government incentives.

# References

American Wind Energy Association. (2002). The Most Frequently Asked Questions About Wind Energy. Available at: http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF

Berinstein, Paula. (2001). Alternate Energy: Facts, Statistics, and Issues. Westport, CT: Oryx Press.

Brown, G. (Ed.) (2000, October). Connection. Latin Trade (English), v8 i10 p54.

Buresch, M. (1983). Photovoltaic Energy systems. New York: McGraw-Hill.

Central Intelligence Agency. (2003). The World Factbook: Costa Rica. Retrieved April 2004 from the World Wide Web: http://www.cia.gov/cia/publications/factbook/geos/cs.html

Department of Energy. (2004a). Energy Efficiency and Renewable Energy. Retrieved April 2004 from the World Wide Web: http://www.eere.energy.gov/RE/solar.html

Department of Energy. (2004b). Hydroelectricity. Retrieved June 2004 from the World Wide Web: http://www.eere.energy.gov/RE/hydro_enviro.html

Energy Information Administration. (2003). Regional Indicators: Central America. Retrieved April 2004 from the World Wide Web: http://www.eia.doe.gov/emeu/cabs/centam.html

Energy Profile for Costa Rica. Retrieved April 2004 from the World Wide Web: http://www.bu.edu/cees/classes/binna/304/energy_profiles/Costa_Rica.htm

Facio. (1996). Private Generation of Electricity in Costa Rica. Retrieved July 2004 from the World Wide Web: http://www.natlaw.com/CR/Topical/eg/spcreg/spcreg1.htm

Fay, J., & Golomb, D. (2002). Energy and the Environment. New York: Oxford University Press.

Florida Solar Energy Center. (2003). Photovoltaics & Distributed Generation. Retrieved March 2004 from the World Wide Web: http://www.fsec.ucf.edu/pvt/pvbasics/index.htm

Gipe, P. (1999). Wind Energy Basics. White River Junction, VT: Chelsea Green.

Herbert, J.H. Clean Cheap Heat: The development of Residential Markets for Natural Gas in the United States. New York: Praeger.

Intel. (2004a). Intel's Environmental, Health and Safety Policy. Retrieved April 2004 from the World Wide Web: http://www.intel.com/intel/other/ehs/policy.htm

Intel. (2004b). Goals, Targets and Indicators. Retrieved April 2004 from the World Wide Web: http://www.intel.com/intel/other/ehs/goals.htm

Intel. (2004c). EHS Leadership. Retrieved April 2004 from the World Wide Web: http://www.intel.com/intel/other/ehs/leadership/costarica.htm

Intel. (2004d). Intel in Your Community – Costa Rica Environmental Involvement. Retrieved April 2004 from the World Wide Web: http://www.intel.com/community/costarica/environment.htm

Intel Expands Operations. (2003, December). Latin America Monitor: Central America Monitor, v20 i12 p7.

Klass, Donald. (1998). Biomass for Renewable Energy, Fuels, and Chemicals. San Diego: Academic Press.

Loos, C. (2001). Forecasting the Growth of Green Power Markets in the United States. Oregon: National Renewable Energy Laboratory.

Macavoy P.W. (1975). The Economics of the Natural Gas Shortage. New York: American Elsevier.

Manwell, J., McGowan, J., & Rogers, A. (2002). Wind Energy Explained: Theory, Design and Application. New York: John Wiley & Sons.

Markvart, T. (Ed.) (1994). Solar Electricity. New York: John Wiley and Sons.

Neville, R. C. (1978). Solar Energy Conversion. New York: Elsevier Scientific.

Noyes, R. (Ed.) (1977). Fuel Cells for Public Utility and Industrial Power. New Jersey: Noyes Data.

Oppenhelmer, E.J. (1989). Natural Gas, the Best Energy Choice. New York: Pen & Podium.

Pasqualetti, M., Gipe, P., & Righter, R. (Eds.) (2002). Wind Power in View: Energy Landscapes in a Crowded World. New York: Academic Press.

PowerLight. (2004). Powering Business and Government Though Solar Technology. Retrieved April 2004 from the World Wide Web: http://www.powerlight.com/

Rapp, D. (1981). Solar Energy. New Jersey: Prentice-Hall.

RETScreen International. (2001). Renewable Energy Project Analysis: Engineering & Cases Textbook. Retrieved April 2004 from the World Wide Web: www.RETScreen.net

Solarbuzz. (2004). Solar Module Price Environment. Retrieved June 2004 from the World Wide Web: http://www.solarbuzz.com/moduleprices.htm

State of Hawaii, Strategic Industries Division. (2003). Solar Energy. Retrieved March 2004 from the World Wide Web: http://www.state.hi.us/dbedt/ert/solar.html

Stone, B. (2000, August 28). A Silicon Republic. Newsweek, v136 i9 p42.

University of California, Irving. (2004). California Electrical Energy: Peak Demand and Sources. Retrieved June 2004 from the World Wide Web: http://www.physics.uci.edu/~silverma/demand.htm

University of New South Wales. Solar Cells. Retrieved April 2004 from the World Wide Web: http://www.pv.unsw.edu.au/info/solarcel.html

Vergara, W. (1990). Natural Gas: Its Role and Potential in Economic Development. San Francisco: Westview.

Veziroglu, T. N. (Ed.) (1980). Solar Energy and Conservation: Technology, Commercialization, Utilization. New York: Pergamon Press.

Vielstich, W. (1970). Fuel Cells: Modern Process for the Electrochemical Production of Energy. New York: Wiley-Interscience.

Warfield, George. (1984). Solar Electric Systems. Washington: Hemisphere.

# Appendix A: Intel

Intel Corporation was founded in 1968. Today Intel is the leader supplier of microprocessors, having about 90% of the market. They also produce chipsets and motherboards along with various other components for the computing and communications industries.

## *A.1 Intel's Facility in Costa Rica*

This project was completed at Intel's Costa Rican facility. Components Intel de Costa Rica is located in the town of Belén, Costa Rica. It is located in the central valley of Costa Rica and about 13 miles northwest of the capital, San Jose (Brown, 2000). This facility currently assembles and tests Pentium 4 and Intel Xeon processors, the microprocessors that power many of today's personal computers and servers. In addition to processors, the facility will start manufacturing a new chipset, for computer motherboards, before the end of 2004 (Latin American Monitor, 2003).

Brown (2000) states that in 1995 Intel was searching for a country in which to construct a manufacturing plant. Intel had $500 million to invest and was expecting to create 3,500 new jobs (Brown, 2000). At the end of 2003 Intel's facility in Costa Rica only employed half of that estimate, 1,750 people. However, with the introduction of the new chipset line, it is estimated that the facility will jump to 2,350 employees (Latin American Monitor, 2003).

In 1997, Intel accepted a deal that Costa Rica was offering to all large corporations at the time. It included eight years of no income tax (until 2005) plus an additional four years after that (until 2009) of a 50% tax rate (Stone, 2000). It also included an initial bulk rate on electricity. The Costa Rican government showed its eagerness to host Intel's plant in the country by processing all of the permits for Intel in just 60 days. An electrical sub-station was also built on site for Intel's use (Brown, 2000). Intel has had a major impact on Costa Rica since they constructed a manufacturing plant there in 1997. From 1997 to 2000, Intel accounted for 37% of Costa Rica's total exports (Stone, 2000).

Intel's property in Belén is about 125 acres. The square footage of the two equal sized manufacturing buildings (CR1 and CR3) and the distribution center (CR2) totals 690,000. On site is also the Sprung building, but this is a temporary structure. On Intel's property there is room for two additional manufacturing buildings, the same size of the existing manufacturing buildings, and a parking structure. For a map of the property see the project letter from Intel in section A.3.

# *A.2 Intel's Mission*

Intel prides itself on being a leader in environment, health, and safety (EHS) policy (Intel, 2004a). When Intel arrived in Costa Rica, there were few regulations regarding the environment and no agency to enforce any that existed. Despite this fact, Intel has held itself to the U.S. standards for industry in Costa Rica (Brown, 2000).

Intel has some very specific goals to lessen its environmental impact, including: recycle 45% of chemical waste, recycle 60% of solid waste, use 30% recycled content for printer and copier paper, use 25% reclaimed water, and many emission reduction goals. In 2002, Intel surpassed all of its goals worldwide and achieved International Organization for Standardization (ISO) 14001 certification for all of its facilities throughout the world (Intel, 2004b). ISO 14001 is a certification given for meeting the ISO standards for environmental management. All of Intel's recycling proceeds in Costa Rica are donated to the community (Intel, 2004d).

Intel has also had increased energy concerns in the recent years. They desire to be recognized as a leader in energy management. Intel has created systems, processes, and teams to work on energy issues. Some of these include understanding consumption rates, maximizing reliability and quality, providing energy consulting for other companies, and researching use of natural resources.

## A.2.1 Intel's Mission in Costa Rica

Employees at the Costa Rican Intel facility have developed an environmental stewardship program. The program aims to teach children about the environment and how they can contribute to making it a better place. Together with education professionals and a design team, Intel created a textbook for young children focusing on recycling, air, water, and wildlife. This text was so successful that they later developed a textbook for high school students. The text for teenagers stresses that students should learn through creating science fair level projects in addition to learning in the classroom (Intel, 2004c).

Intel has several other environmental programs. To raise knowledge of pollution prevention and conservation of resources Intel established the energy conservation program. They have also implemented a car pool program, Let's Save the Planet (an environment awareness program), a storm water pollution prevention program, and a program dealing with refrigerants management.

No direct negative environmental effects of Intel's facility have been linked to the Costa Rican environment. In 2000 Intel was the only large industrial facility out of 50 in Belén to have its own waste-treatment plant. Human wastewater is the only type of waste that Intel releases into the environment of Belén. Concern for wastewater is important because the whole town of Belén sits above an aquifer. Intel's wastewater treatment plant has an efficiency over 99%. In addition, to be aware of any significant changes it may have on the aquifer Intel has four monitor wells around the facility. All toxic waste from the facility is safely shipped to the U.S. for disposal because the plant lacks a toxic-waste-treatment plant. This adds up to thousands of pounds of lead waste, but the U.S. is ultimately dealing with the negative environmental effects of this lead waste (Brown, 2000). They are also the only company exporting chemical waste to the U.S. for proper disposal instead of dumping the waste in Costa Rica.

### A.2.2 Intel's Organization in Costa Rica

This project was completed for the Environmental, Health, and Safety (EHS) department at Intel Costa Rica. The EHS department ensures that all employees have a safe place to work. EHS also guarantees that Intel is environmentally friendly by following all regulations in Costa Rica as well as all regulations that they would have to follow in the U.S. EHS employs 17 people and two doctors as shown in Figure 19. Two employees are the environmental engineers Anibal Alterno and Adolfo Quesada. Mr. Alterno is in charge of air, waste, Emergency Medical Services (EMS). Mr. Quesada handles the water program and decontamination.

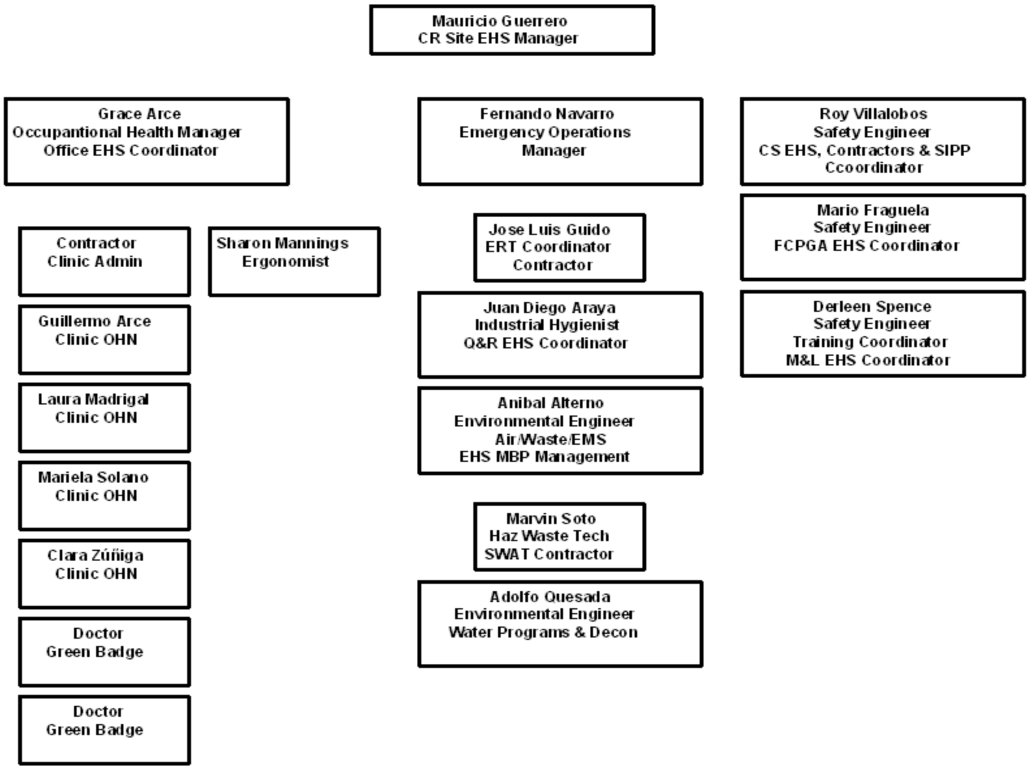


**Figure 19: Organization chart of EHS at Intel in Costa Rica**

## *A.3 Project Letter from Intel*

On the next page is the letter we received from Intel regarding our project.

COMPONENTES INTEL DE COSTA RICA

Corporate Services Department

# Use of solar energy at the Assembly and Test Plant of Componentes Intel de Costa Rica

## Project Objective:

The main objective of this project is to identify and assess (technically and financially) potential uses of solar energy to power specific applications at the Intel facilities in Costa Rica and recommend an implementation strategy for the site.

## Project Background:

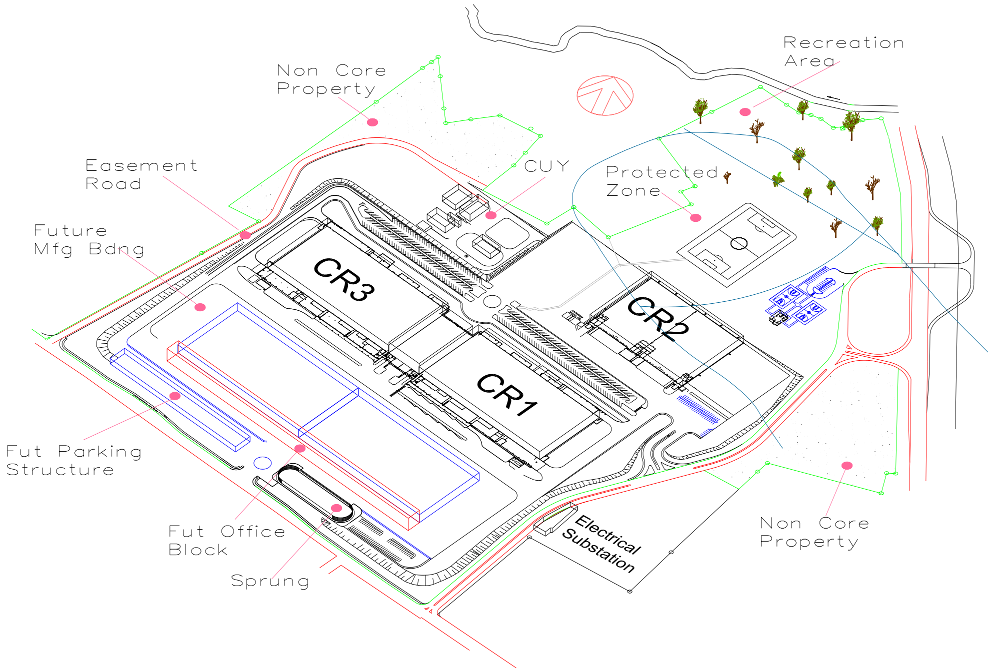
### *A. Corporate Policy*

Energy use has become an increasing concern for Intel as a corporation; several efforts are currently under way to understand our consumption rates and to establish methodologies for efficient energy use. In general, our vision is to be recognized as a corporate leader in the management of energy. To do this, systems, processes and teams have been integrated to:

(1) Optimize Intel's energy supply and consumption to reduce our operating and capital expenditures, minimize environmental impact, and achieve the lowest total cost solutions for our global partners.
(2) Support manufacturing by maximizing reliability and quality of Intel's energy sources.
(3) Proliferate cost effective energy management technologies and practices throughout Intel.
(4) Provide support and guidance in Intel's participation in shaping the energy business environment.
(5) Develop and implement annual Energy Goals to drive continuous improvements in the efficient use of energy.
(6) Design and operate Intel's facilities and manufacturing processes to ensure optimal cost, reliability and use of natural resources.

### *B. Intel in Costa Rica*

Intel Corporation established a microprocessors assembly and test operation in Costa Rica nearly 7 years ago. Site build up is composed of two main manufacturing buildings (CR1 and CR3), two office buildings (Sprung and central office area located between the two manufacturing buildings), a distribution center (CR2) and a utilities yard (CUY). The site can accommodate two more manufacturing buildings and a parking building at full build out.



**Costa Rica Intel Site Master Plan**

The total property measures nearly 125 acres; the distribution center has nearly 150,000 sf$^2$ and each one of the main buildings is nearly 270,000 sf$^2$. As of 2004, about 30% of the property has some construction area and another 15% is reserved as an aquifer protection zone.

Currently, all site electrical needs are provided by an external contractor (government owned, called ICE –Instituto Costarricense de Electricidad) through a near by substation which is fed at 230 kV and provides electricity to the site at 34.5 kV. Electricity is then directed to internal unitary substations which transform it to 480V (three-phase). The substations are distributed across all the buildings and are grouped in a way that some of them supply power only for facilities needs (i.e. air conditioning equipment, air dryers, compressed air, illumination, etc) and others supply power to manufacturing tools. There are a total of 13 stations with 4000A capacity each.

Site consumption is nearly 10E06 KHW per month, which positions Intel in the top 5 electricity consumers in the country. Approximate energy distribution is shown below:

| Item | % Energy Consumption |
|---|---|
| manufacturing operations | 37% |
| air conditioning | 30% |
| mechanical facilities | 25% |
| Illumination | 6% |
| Others | 2% |

Project Specific Objectives:

1. Record and compare (pros/cons) current available technologies regarding alternative energy generation ($H_2$ cells, gas, photovoltaic cells, etc).
2. Summarize current applications of solar energy as an alternative power supply in industrial facilities: focus on semiconductor industry.
3. Conduct a full site inspection and identify potential uses.
4. Assess identified uses from a technical (compatibility, reliability, etc) and financial perspective (Return on Investment, short/long term savings).
5. Prepare a proposal on top 5 feasible alternatives, indicate an implementation strategy.
6. Survey and recommend potential suppliers of equipment and infrastructure needed to implement feasible alternatives.
7. Quantify positive environmental impact of implementing the measures.

# Appendix B: More Information about Solar Power

## B.1 PV Configuration

PV cells come in various configurations, but must have two crucial components. The first part, an absorber is where solar energy is transferred to electrical charges of opposite polarity allowing it to move freely through the material. The second component has a built-in electric field, where the electric current is produced. According to Berinstein, electrons move to one side of the cell creating a negative charge and the other side receives a positive charge. Connecting a circuit to the two sides will form an electric current (Berinstein, 2001, p. 65). In addition to these main components, electrodes and coatings are used to maximize the sun’s rays (Warfield, 1984, p. 37).

## B.2 Silicon as a Semiconducting Material

Silicon is considered a semiconducting material because of its crystal lattice and band structure. According to Markvart, electricity can only be produced by semiconductors if carriers are introduced to the empty conduction band or removed from the valence band of the element. This is achieved by alloying the semiconductor with an impurity, which is known as doping. Doping makes it possible to gain control over the electrical properties of the semiconductor (Markvart, 1994, p. 26).

## B.3 Types of Semiconductors

There are two main types of semiconductors: n-type where current is carried by negatively charged electrons and p-type which carries current by holes of missing electrons that act as positively charged particles.

# Appendix C: Information about Fuel Cells

A fuel cell can be thought of as a black box that consumes natural gas and produces useful electricity and usable waste heat (Loos, 2001, p. 3). The black box also consumes a limited amount of potable water, and produces a plume of water vapor and a stream of processed liquid water. The inside of the black box looks a bit like a battery, with stacks of anodes and cathodes surrounded by carbonate electrolytes. Absent are the moving parts and any sort of combustion process (Loos, 2001, p. 3).

## *C.1 Fuel Cell Configuration*

Today's fuel cells are broadly classified into five types: Alkaline, Proton-Exchange Membrane, Phosphoric Acid, Solid Oxide and Molten Carbonate. The FuelCell Energy design uses a molten carbonate type, so named because it uses a carbonate material mixture as an electrolyte. Molten carbonate fuel cells, and notably the FuelCell Energy design, feature high efficiency and low emissions (Loos, 2001 p. 3).

## *C.2 Energy Storage for Fuel Cells*

In a battery, the chemical energy is stored within the cell, and the capacity of the battery is governed by the size and weight of the electrodes (Noyes, 1977, p. 8). Fuel cells are unlike batteries in that the reactants are supplied from outside the cell and the cell itself does not undergo an irreversible chemical change. Thus, it can continue to operate as long as fuel and oxidants are supplied and products are removed (or at least until the electrodes fail because of mechanical or chemical deterioration) (Noyes, 1977, p. 8).

All fuels cells operate in pure hydrogen fuel (Loos, 2001, p 3). Typically, an external device called a reformer is used to strip hydrogen from natural gas. By contrast, FuelCell Energy, Inc. has trademarked a fuel cell design called the FuelCell Energy design. This design uses a more efficient internal reformer that is directly integrated into the fuel cell process. This direct reformer feature is a key advantage of the FuelCell Energy design, hence the "DFC" (direct fuel cell) designation in the fuel cell model number cell (Loos, 2001, p 3).

## C.3 Fuel Cell Efficiency

When it comes to the efficiency of a fuel cell in the one MW size range, fuel cells out perform other existing technologies such as reciprocating engines, gas turbines and micro turbines. The DCF 1500 fuel cell provides 49% electrical efficiency. The next best technology, natural gas fueled reciprocating engines, make a strong showing at 37%, while micro turbine efficiency is the lowest at approximately 25% efficiency.

## C.4 Impact of Fuel Cells on the Environment

Fuel cells emit less carbon dioxide per kilowatt-hour than gas fired engines or micro turbines. Carbon dioxide emissions are inversely proportional to efficiency. Fuel cells consume less fuel per kWh than gas fired engines or microturbines and therefore produce correspondingly less carbon dioxide. Carbon dioxide is a greenhouse gas that has been implicated in global warming (Loos, 2001, p. 6).

An important advantage of fuel cells over conventional power sources is that emissions are negligible because fuel cell operation is not based on combustion (Noyes, 1977, p.18). In conventional power plants, considerable quantities of polution are produced. Examples of these are nitrogen oxides, sulfur dioxides, hydrocarbons, and particulates. Fuel cell systems emit an exhaust mostly of air, carbon dioxide, water vapor, and heat, which are not harmful to the environment.

## C.5 History of Fuel Cells

Fuel cells were discovered in an experiment by W.R. Grove in 1839. His experiment can be regarded as the first electrochemical reaction of a fuel cell with oxygen in a galvanic, electrified, cell. Grove electrolyzed sulphuric acid with two platinum electrodes and found that the gases obtained, hydrogen and oxygen, were electrochemically active and established and open-circuit rest-voltage between the electrodes of about one volt. The current density that this ‘electrolytic gas cell’ could provide was, however, so small that it was of no practical use at all (Vielstich, 1970, p. 5). Although this was not of much practical use it was used as a stepping stone for the scientists of the next generation. The first practical use of fuel cells was by NASA in the 1960s during the early space missions. NASA needed a clean, ultra-reliable power source for the Apollo spacecraft, and fuel cells were the best solution. Intensive fuel cell development continues today as manufacturers strive to produce fuel cell based power plants and cars (Loos, 2001, p. 5).

# Appendix D: Information about Wind Power

Wind energy consists of turning the energy of the wind into another form of energy, be it mechanical or electrical. It is also technically a form of solar energy because wind is created by the sun unevenly heating the earth (Berinstein, 2001, p. 99). Wind energy is a renewable source of energy and has very little environmental impact. The main problem with wind power is that it is so variable. With other sources, there are ways to store the generating power, like storing water with a dam or storing coal to burn. However, there is no way to store wind; energy production must wait until there is wind available.

According to Manwell, McGowan, and Rogers (2002, p. 18), the total capacity for wind energy around the world was around 20,000 megawatts (MW) in 2001. Pasqualetti, Gipe, and Righter (2002, p. 5-6) report that in 2001 that total energy generation in the world for wind turbines was 30 terawatt-hours (TWh) of electricity. They also claim that The European Wind Energy Association has set a goal to have a capacity of 40,000 MW installed in Europe alone by 2010. Europe today accounts for 70% of wind energy generation (Pasqualetti et al., 2002, p. 5-6). If the world's capacity grows at the same rate that Europe plans to, the world capacity of wind energy will be around 57,000 MW.

## *D.1 Technical Information about Wind Power*

Some wind turbines include a braking mechanism in their drive train. The brake is used to stop the blades from spinning if the wind speed is too fast to prevent damage to the turbine (Manwell et al., 2002, p. 5). When a safe wind speed is reached, the brakes are released and energy production continues. An alternative to brakes is called furling, where the rotor is turned toward the tail vane to slow the rotation of the rotor and thus prevent damage in high winds. The rotor still spins, but not as fast, because it is not directly facing oncoming wind. Furling reduces energy production greatly because of the drastic decrease in rotor rotation speed. The way that this furling occurs is dependent on the turbine's design; some tilt the rotor towards the tail vane while others tilt it vertically (Gipe, 1999, p. 27). When braking or furling begins, the turbine's cot out wind speed has been reached.

For large, utility size turbines (250kW or larger), there are three types of towers to choose from, all are free standing: steel tubes, concrete towers, and lattice towers like the towers seen on old windmills. The former two would be the most reliable since they are sturdier than lattice towers. In addition, tower height is generally between 1 and 1.5 times the diameter of the rotor (Manwell et al., 2002, p. 6). However, the basic rule is that the height of a tower should also be at least 10 meters above any obstruction within 100 meters to avoid most of the wind disturbance due to trees, buildings or any other obstacles (Gipe, 1999, p. 71).

Determining the location of future wind turbines is crucial. There are two options: mounting on a rooftop or on a foundation in the ground. Rooftop towers have been suggested in the past; however, the manufacturers of these rooftop towers have marked them for use on unoccupied buildings only. Another issue is that rooftops create turbulence that gently shakes the towers and this drastically reduces a wind turbine's lifespan. The wind turbine itself also creates vibrations and passes these on to the building underneath. These vibrations create a variety of disruptive and annoying noises (Gipe, 1999, p. 41).

## D.2 Wind Turbines

Windmills convert wind power directly into mechanical power. Wind turbines, however, convert wind energy into mechanical energy and then into electricity. Today, the most widely used wind turbine is the horizontal axis wind turbine (HAWT). The HAWT looks like a propeller that is perpendicular to the ground and attached to a tower. This means that the rotating axis is parallel to the ground (Manwell et al., 2002, p. 3). The propeller-like part of a wind turbine is called the rotor and usually has two to three blades. A complete wind turbine consists of a rotor, a nacelle (enclosure) containing a drive train including a gearbox and an electric generator, electronic equipment, and a tower to support the rotor and drive train (Berinstein, 2001, p. 100). The nacelle cover protects the drive train and generator from the weather (Manwell et al., 2002, p. 5).

Wind turbines vary greatly in size. The largest turbine today, with a 2MW capacity, has a 70 meter diameter rotor while others are small enough to hold in your hands. The most common design today is an upwind rotor with three blades (Manwell et al., 2002, p. 5) and a rotor diameter of about 30 meters installed on a tower 30 to 40 meters. This turbine configuration would generally have a capacity of about 250 kW (Pasqualetti et al., 2002, p. 8). Generally, the height of a wind turbine tower is about the same as the diameter of its rotor, although this is not always the case because tower height may need to be increased to avoid wind interference from nearby wind obstructions (Pasqualetti et al., 2002, p. 8).

## D.3 Efficiency of Wind Energy

The capacity given for a wind turbine is the amount of energy it can produce at its peak production; it the projected amount of energy that the turbine can produce if the wind speeds are optimal. A wind turbine's efficiency depends on many factors but is usually about 33%; in comparison, a conventional power plant has an efficiency of 40 to 80%.

The efficiency of a wind turbine is affected by its cut-in, cut-out and rate wind speeds. The cut-in wind speed of a turbine is when the generator actually begins making power. The cut-out wind speed is the speed at which furling begins or the brakes stop the rotor (Gipe, 1999, p. 20-21). This is consequently the speed at which the energy production of the wind turbine is severely limited or ceased.

Rated wind speed is the wind speed at which the rated power of the turbine is reached and likely the maximum power output of the generator. At this speed, the maximum amount of energy is being produced and is usually just before the cut-out speed (Manwell et al., 2002, p. 8). However, a wind turbine is sometimes capable of producing more energy than it is rated for. This can happen if the cut-out speed is too high or if the rated power is estimated too low, although this is not usually the case (Gipe, 1999, p. 27).

## *D.4 Environmental Impacts of Wind Energy*

Wind energy has very few environmental disadvantages. It does not deplete a natural resource, produce air or wind emissions, or cause damage to the environment due to extraction or transportation. According to the American Wind Energy Association (AWEA), the only emissions that come from wind energy are during manufacturing and construction. Even when these phases are considered, the emissions of $CO_2$ for wind energy are only 1% of coal’s and 2% of natural gas’ emissions per unit of electricity generated.

The main environmental concerns regarding wind energy are erosion, bird and bat kills, and visual and noise disturbances. Erosion can be avoided with landscaping and installation techniques and is only a concern in deserts where the hard-packed top soil will be penetrated during installation. Bird and bat deaths due to collision with a wind turbine are miniscule when compared to other human related causes of death to these animals. It is projected that bird deaths from wind turbines will never surpass 1% of their total deaths caused by humans regardless of the degree to which wind power is implemented. Special care should be taken however if any endangered species live in the area (AWEA, 2002, p. 15-16).

The amount of a visual annoyance wind turbines create is a debatable issue. Although there is no formula to overcome visual objections to wind turbines, their visually unpleasing qualities can be minimized through planning with uniform turbine size and spacing (Pasqualetti et al., 2002, p. 24). Noise pollution was much more a problem with downwind rotor configurations where the nacelle produced a ‘wind shadow’ that resulted in a non-uniform wind speed hitting the blades (Manwell et al., 2002, p. 5). Other technical advances have reduced the noise output by wind turbines including improved blade shape, but they still emit sound (AWEA, 2002, p. 16).

Water usage is a concern for all energy sources, but wind energy uses minimal water. Water is only used to clean dirt and insects off the blades when rain is not available to do so. This totals to about 0.004 liters of water per kWh, whereas coal uses 1.9 liters per kWh (AWEA, 2002, p. 16-17).

# Appendix E: Information about Natural Gas

Methane, the principle ingredient of natural gas, originates from the following sources: (1) organic matter in sediments, whose decomposition is being promoted by heat; (2) the action of anaerobic (living) microorganisms that convert organic material into methane; (3) the transformation of oil and other heavy hydrocarbonates into methane at high temperatures, usually in deep locations, and (4) coal, which releases methane as it matures (Oppenheimer, 1989, p. 17). Some scientists believe that methane may have been present at the time earth was first formed. This hypothesis postulates that methane may in part come from nonbiological sources. The validity of this theory remains to be proven (Oppenheimer, 1989, p. 17).

The terminology used in the reporting gas resources can be quite confusing. Generally, there are three basic levels: *proved reserves;* economically *recoverable resources;* and *in-place* or *total resources*. Gas in the first category already has been discovered, and is considered producible under current economic and operating conditions. Gas in the second category is believed to exist and is estimated to be producible under economic and operating conditions that are presently considered likely to exist in the foreseeable future. Gas in the third category is the total resource believed to exist in all deposits, of which some portion (depending on technology and economics) could be produced. With some time and technological development more and more of this gas resource will become economically reversible (Vergara, 1990, p. 4).

## *E.1 Natural Gas Storage and Distribution*

Natural gas production is brought to the surface where liquid byproducts are removed (Macavoy, 1975, p.4). Then the pipeline companies take the gas in the field and deliver it to wholesaler industrial users or to retail distributing companies that in turn deliver it into individual households, commercial establishments or to retail industrial users (Macavoy, 1975, p.4).

## *E.2 Efficiency of Natural Gas*

Over the years, large improvements have been made not only in the ability to deliver natural gas but also the efficiency of natural gas use (Herbert, 1992, p. 2). Moreover, these efficiency improvements have frequently resulted in health benefits as well. In the second decade of this century, approximately 16 percent of the volume of gas delivered to a residential costumer may have been wasted through leakage within the household, which caused headaches or worse if enough gas collected in the house. Other improvements in efficiency saved the energy of the homemaker as well. Many burners during the 1920's were set to 3 instead of 2 ounces of pressure and were not adjusted to use the proper gas and oxygen mixture. This caused gas to burn with a 6.5 inch high yellow flame instead of a 4 inch high blue flame, scorching the side of pots, taking 15% more gas to boil a pot of water, and taking the homemaker several minutes to scrub each burned pot (Herbert, 1992, p. 2).

## E.3 Effects of Natural Gas in the Environment

Natural gas is the cleanest of all fossil fuels (Oppenheimer, 1989, p. 22). Its production involves minimal disturbances to the surrounding environment. Natural gas can play an important role in reducing ground level ozone (smog), acid rain, and the greenhouse effect (global warning) (Oppenheimer, 1989, p. 22).

## E.4 History of Natural Gas

During the 1940's the reliance on wood and coal had many costs for households in addition to the dollar cost of the fuel. There were labor costs associated in some instances with gathering the fuel and in most instances with feeding furnaces, fireplaces and stoves. There were also heath costs associated with by-product particulates created both inside and outside the house. This changed in circumstances made natural gas furnace and water heaters increasingly attractive during the war years. The number of workers employed by businesses increased as did the average number of houses per day. Less time was available to household members to perform chores around the house. Value of leisure time increased as money incomes increased, and the number of hours available for daily leisure declined. Hence, the value of lost opportunities for leisure or the opportunity cost of maintaining a wood or coal appliance in the household increased (Herbert, 1992, p. 2).

# Appendix F: Information about Biomass

Biomass is a renewable source of energy that captures solar energy and carbon from $CO_2$ in growing biomass and converts it to alternate fuels such as biofuels or synfuels. It could also be used directly as a source of thermal energy (Klass, 1998, p. 32). Biomass is collected for feed, fiber, and construction materials. Any wastes that are produced from processing can be directly converted into synthetic organic fuels, which means that biomass can be used for direct heating applications. According to Klass, energy can also be produced by harvesting biomass that has high energy-hydrocarbons in them naturally. A rubber tree is an example of biomass that contains these hydrocarbons (Klass, 1998, p. 31).

Animal waste is another form of biomass. Methane can be drawn from farm animal and human waste. Landfills also create large amounts of methane that can be used to supply cheap heating gas (Fay, 2002, p.148).

Energy can be processed by biomass in five ways. According to Fay and Golomb, the first is by combustion which is directly burning woody plants and grasses. The second is via gasification. Biomass can be converted to a gaseous fuel made of $H_2$ and CO that is combustible in boilers and furnaces. The third, pyrolysis, is thermal decomposition that produces a combination of combustible solid, liquid, and gas products. The fourth process, fermentation, produces ethanol, which is blended with gasoline for use in motor vehicles. The final process is anaerobic digestion. In this process, a gaseous mixture of $CO_2$ and $CH_4$ is formed and can be upgraded to form more desirable forms of energy (Fay, 2002, p.150).

## *F.1 Efficiency of Biomass*

A biomass plant requires 270-750 acres per megawatt (Berinstein, 2001). When biomass is processed to a form that can be used as a replacement for fossil fuels it loses some of its heating values and produces a cost of conversion (Fay, 2002). Therefore to compete with fossil fuels, low cost forms of biomass fuels must be produced. Also, most forms of biomass must be stored which will increase the yearly cost (Fay, 2002).

## *F.2 Environmental Impacts of Biomass*

There are many environmental impacts associated with the use of biomass. They are very similar to the effects of agriculture. The impacts include the consumption of manufactured fertilizers and spreading of pesticides and herbicides. Soil erosion is also a large problem when the harvesting of biomass is involved. Irrigation water must be used to supply biomass with water. Biomass also can destroy the natural ecosystem by the formation of farmland to produce biomass. The worst impact of biomass is that the air emissions produced from combustion can be comparable to those of fossil fuels (Fay, 2002, p.151).