Final Project Report

Project Title:

SOLAR ENERGY PAINTS LAREDO GREEN

Principal Investigator: Dr. Tongdan Jin,

Department of Math and Physical Sciences,

Texas A&M International University (TAMIU)

Laredo, Texas, USA

Sponsor: A.R. Sanchez, Jr. School of Business, TAMIU

Project Duration: June 1, 2008 to August 31, 2008

Report Date: August 31, 2008

Table of Contents

Acknowledgment

The Principal Investigator (Tongdan Jin) would like to thank the following faculty, staff, and students who contribute or support to the projects either directly and indirectly between June 1 2008 and August 31, 2008. Their assistances and/or supports make the timely accomplishment of this project possible. They are listed in the alphabetical order based on the first name.

- Ms. Amy Palacios, Data and Information Specialist, A.R. Sanchez, Jr. School of Business, TAMIU, Texas, USA.
- Dr. Andres E. Rivas-Chavez, Assistant Professor of A.R. Sanchez, Jr. School of Business, TAMIU, Texas, USA.
- Dr. Haibo Wang, Assistant Professor of A.R. Sanchez, Jr. School of Business, TAMIU, Texas, USA.
- Dr. Jack So, Professor and Dean of A.R. Sanchez, Jr. School of Business, TAMIU, Texas, USA.
- Ms. Jianing He, Ph.D. student in School of Business Administration, South China University of Technology, Guangdong, China. (currently is a visiting graduate student in TAMIU).
- Ms. Jiefang Li, Ph.D. student in School of Business Administration, South China University of Technology, Guangdong, China. (currently is a visiting graduate student in TAMIU).
- Ms. Laura Coco, Student Service Administrator, Texas Intensive English Program, Austin, Texas, USA.

Abstract

The goal of the project is to study the benefits and implementation cost of the solar energy in Laredo area. Solar energy provides an alternative, yet sustainable, energy resource to the increasing demand of energy in Laredo and its surroundings. The research intends to provide a proactive measure to resolve the potential energy issue in the near future by leveraging renewable energy technology.

To achieve the project goal, the following tasks have been accomplished: (1) collect and analyze data to estimate the average sunny days, daytime hours, and temperature profiles in Laredo and its surrounding areas; (2) develop financial model to estimate the cost per unit watt given the current solar technology; (3) carry out surveys and identify the public options on the use and implementation of solar technology in Laredo; (4) provide constructive roadmap toward the implementation of solar energy for both the energy investors and the consumers for next ten years.

Our research found that the implementation of solar energy in Laredo is geographically and climatically feasible. Located in the south part of the Texas, Laredo is among the few cities in the U.S. receiving about 300 sunny days in a year. Meanwhile, the daytime is extremely long in the summer time from 7:00am to 8:00pm. Even in the winter, the daytime still spans from 7:00am to 6:00pm. The average temperature in the summer is above 90 degree Fahrenheit and it is around 50 to 60 degrees even in the winter time. The unique weather profile favors the adoption of the solar energy technology in Laredo.

If the local government and solar energy industries are able to provide reasonable incentives, Laredo is ready to be one of the leading cities to implement renewable energy, especially solar cells, in the US and around the world.

Finally the use of solar technology also open ample opportunities for local engineering students from TAMIU who are interested in further exploring the innovative energy technology and making local communities greener and cleaner.

Chapter 1 Laredo Weather and Energy Distribution

1.1 The Weather Profile in Laredo

Laredo, a city with population of 230,000, is located at border between the Southern Texas and Mexico. It has a unique blend of American & Mexican cultures. This cultural fusion is reflected in every aspect of life in Laredo, be its food, dance, or language.

The latitude of Laredo is 27.506N. The longitude is -99.507W. See Figure 1. This determines the weather in Laredo is semi-arid with more than 300 sunny days annually.

Figure 1. The Location of Laredo

Based on the information from Astronomical Applications Department of the U.S. Naval Observatory [1], the average daylight hours in Laredo are 11.9 hours per day. Even in December and January, the daily light hours are 10.3 hours. The daily light hours in June and July could reach 13.5 hours. Figure 2 presents the monthly daylight hours from January to December.

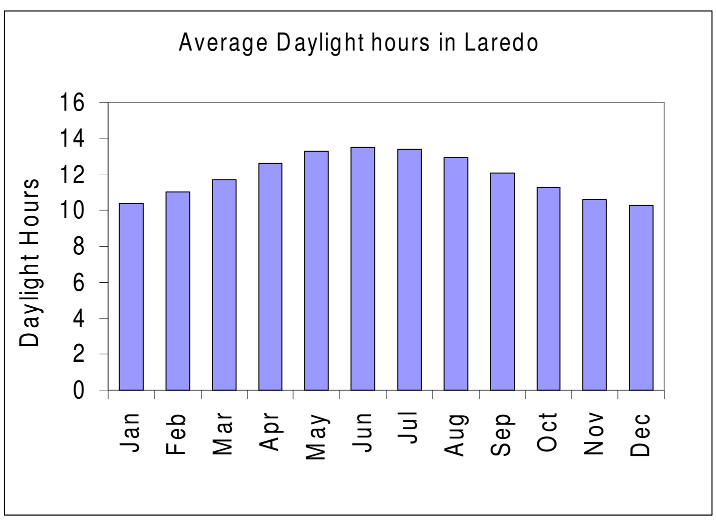


Figure 2: Average Daylight Hours in Laredo

According to the data from the National Weather Service Forecast Office [2], the average temperature in Laredo varies from 60 degrees in Fahrenheit to 90 degrees as shown in Figure 3. The average temperature for the whole year is 78 degrees. The maximum temperature varies from 70 degrees in January to 102 degrees in June. The average sunny days are 320 per year [3], which counts for 88% day times during the entire year. Given these favorable weather conditions, Laredo is an ideal city to develop and implement solar energy technology.

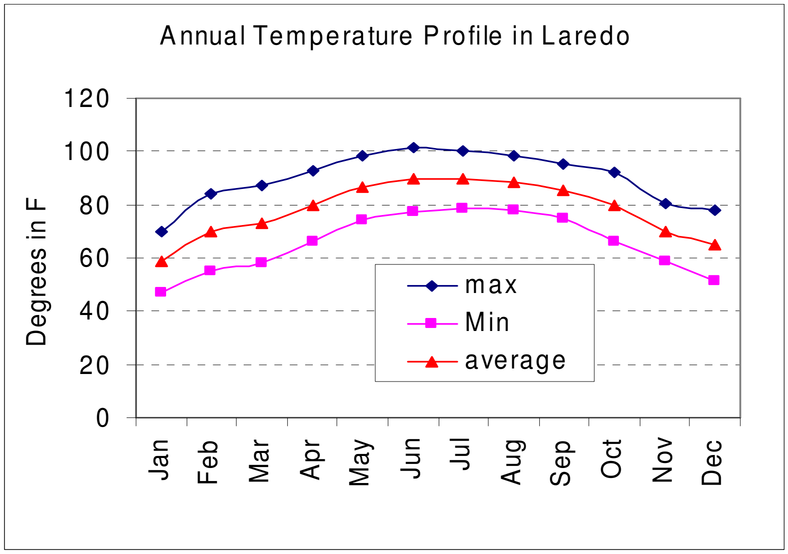


Figure 3: The temperature profile in Laredo

1.2 The Challenge of the Energy

The gasoline price increases dramatically over last three years by almost doubling the rate [4]. Figure 4 shows the U.S. all grades all formulations retail gasoline price between 1993 through June 2008 (the price continues to increase since June 2008). The price is relatively stable with very small increase between year 1993 and 2003. Starting from 2004, the gasoline price soars toward $4.00 per gallon as of June 2008. The straight line is a prediction line assuming the annual price increase by 5%-the typical inflation rate. Based on the prediction, the gasoline price in 2008 is supposed to be $2.23/gallon, yet the actual retail price exceeded $4.08 as of June 17, 2008. This is 84% higher than the prediction price after considering the inflation factor. That means the gasoline price is influenced by the fluctuation of many factors rather than inflation. This results in the uncertainty and risk to apply gasoline as a major energy source in the future. Therefore developing static and low cost alternative energy is reasonable and necessary.

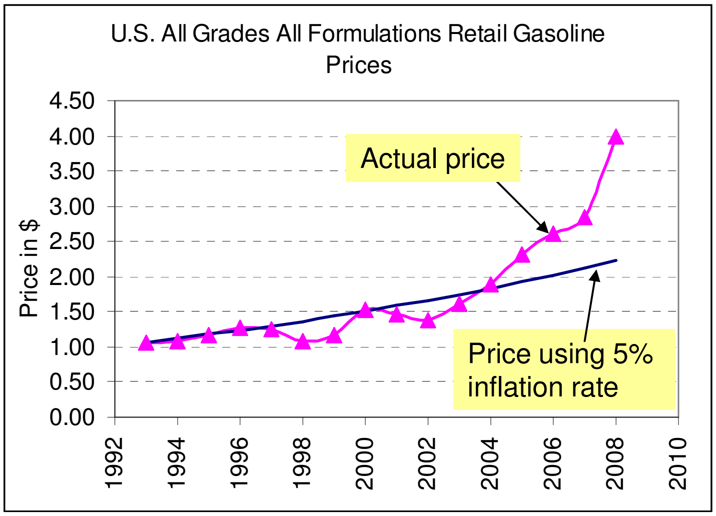


Figure 4: US gasoline retail price since 1993

Facing the ever-increasing demand of the energy, renewable energy emerged as energy alternatives to fill the gap between the energy supply and the demand. Renewable energy is a kind of energy produced from natural resources—such as sunlight, wind, tides and geothermal heat—which are renewable (naturally replenished). Renewable energy technologies range from solar power, wind mill, hydroelectricity/micro hydro, biomass, and biofuels for transportation [5].

From 2003 through 2007, the average annual growth rate of renewable energy consumption was 3 percent, compared with just 1 percent increase in total energy consumption. Again, bio-fuels and wind were largely responsible for the increase, with 5-year average annual growth rate of 25% and 29%, respectively. Yet renewable energy still constitutes a very small percentage of the entire energy pool in the US. Figure 5 shows the distribution of the energy productions by different sources for 2007. Petroleum represents 40%. Natural gas and coal are 23% and 22% respectively. The total renewable energy counts only for 7% of the national annual energy consumption. Among the renewable energy, biomass and hydroelectric together consists of nearly 90%, and the solar energy represents only 1% of the renewable energy—almost too small to be mentioned. For information, please refer to [6].

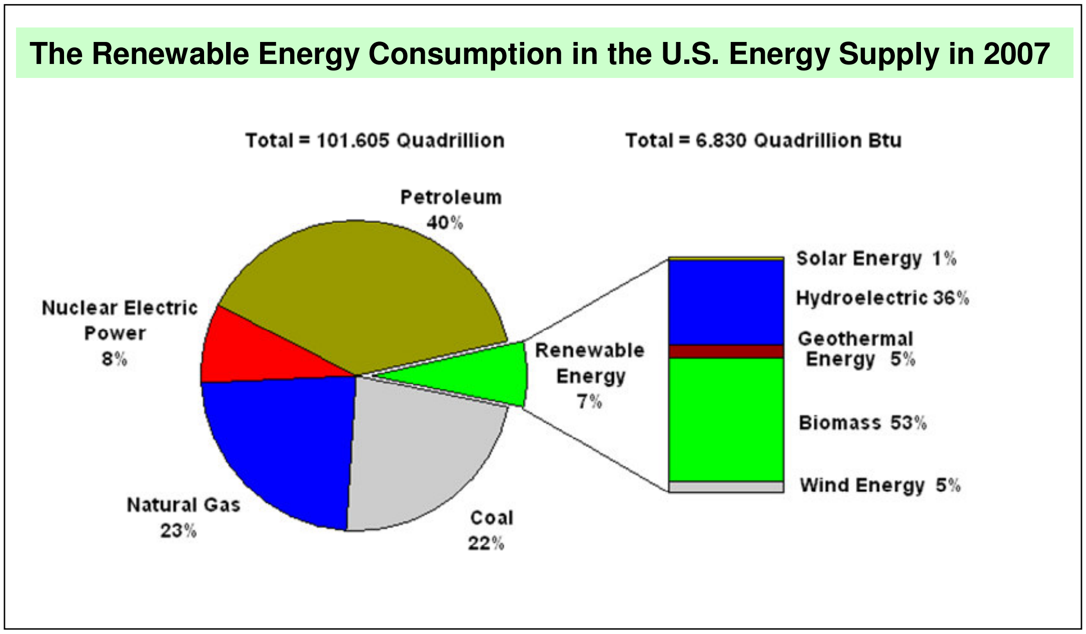


Figure 5: The Renewable Energy in the U.S. in 2007

In the U.S., many states have taken the initiatives to implement the renewable energy technologies over last ten years [7]. Figure 6 lists the ten leading states in deploying and harnessing the renewable energy in 2007. Washing, Californian, and Oregon are top three players in the renewable energy area with annual production of 170.5 Mega KWh totally. Texas is positioned in 5th following the New York. The annual production in Texas is 10 Mega KWhr. One KWh electricity approximately can make your home TV to operate for 5-10 hours. A typical American household consumes 200 to 300 KWh per month.

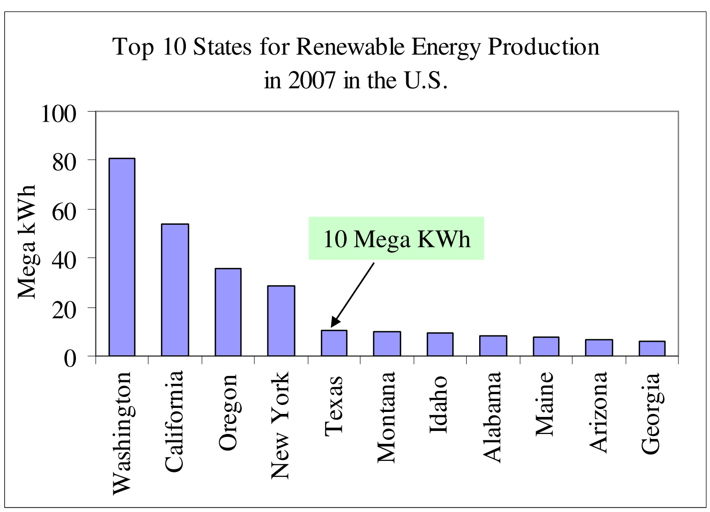


Figure 6: Top Ten States for Renewable Energy Production

References

[1] Astronomical Applications Department of the U.S. Naval Observatory, http://aa.usno.navy.mil/data/docs/RS_OneYear.php

[2] Laredo Climate Archive, http://www.srh.noaa.gov/crp/climate/lrdf-6.html

[3] Office of Graduate Studies, http://www.tamiu.edu/gradschool/environment.shtml

[4] Energy Information Administration, http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm

[5] Renewable Energy, from http://en.wikipedia.org/wiki/Renewable_energy

[6] Renewable Energy Consumption and Electricity Preliminary 2007 Statistics, http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html

[7] Total Renewable Net Generation by Energy Source and State, http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table6.html

Chapter 2 Worldwide Energy: Past and Present

2.1 Energy in Early Human History

Sun is the first energy source for human being. Man began to control the fire around 1 million BC [1]. Later man began to harness the wind power for milling and transportation around 5000 years ago. Around 1200 BC, in Polynesia, people learned to use this wind energy as a propulsive force for their boats by using a sail [2].

About five thousand years ago, magnetic energy was discovered in China. Magnetic force pulled iron objects and it also provided useful information for navigators since it always points to North because of the Earth's magnetic field [3, 4].

2.2 The Energy used During the Industrial Revolution

During the 19th century, the Industrial Revolution started in England and quickly spread to Europe, North America and other parts of the world. The industrial revolution dramatically shaped the life of human being and also profoundly changed the utilization of the energy as of today. Fossil fuels such as coal, petroleum, and natural gases began to be used extensively after the industrial revolution.

A. Use of coal

Around 1000 BC, the Chinese found coal and started using it as a fuel. When Marco Polo returned to Italy after an exploration to China in the 13th century, he introduced coal to the Western world after returning to his home in Italy [5].

In the 17th century, England started producing coal of its own and supplying it to other countries. The U.S. began to dig coal in 1748 as the first documented mining activity [6]. Later coal was used in steam machine, and drove the birth of the world's first electric generator in 1880 [7].

B. Use of oil

By the end of 1800s, a new form of fuel was catching on: petroleum. The first oil well was drilled in that region by Edwin Drake in 1859 [8]. Nowadays, oil becomes one of the most important energies that powers airplanes, ships, and automobiles etc.

C. The discovery of electricity

The word electricity originated from "elektron", the Greek word for amber [9]. Otto von Guericke invented the first static electric generator in 1675, while the first current generator was made by Alosio Galvani in 1780. Thomas Edison added lighting in 1880, which was soon followed by working electric motors and electric heating in the 20th century. In today's technology era, various electronic devices embedded with software programs are generating another wave of information revolution that impacts our live from all aspects.

2.3 The Increased Demand of Energy

According to The International Energy Agency, world will need almost 60% more energy in 2030 than in 2002, and fossil fuels will still play the major role in the next 20 years. It is estimated that current reserves will only be able to provide for about 40 years. Pessimistic people predict that oil production will decline within 15 years, while others claim that there is no need to worry about oil for the next 100 years, yet the rising prices are likely to push the world towards alternative energy sources such as solar and wind powers eventfully.

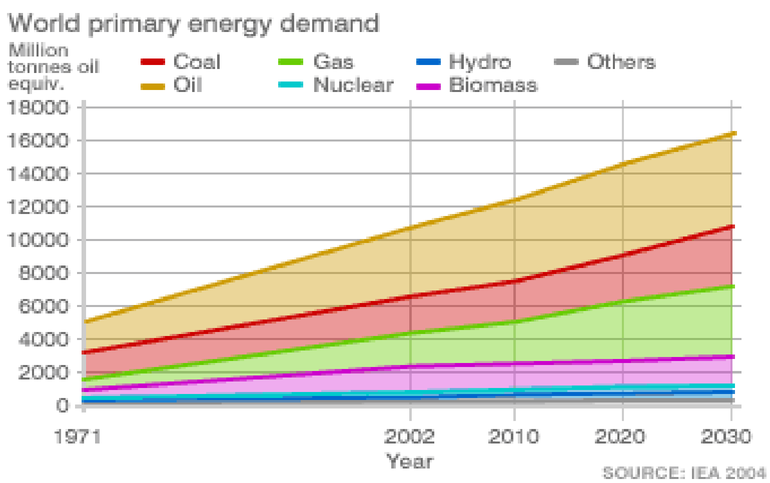


Figure 7 The Energy Demands and Forecast [9]

Meanwhile, as developing countries like China and India move toward industrialization, global energy demand is forecasted to increase by 60% in the next three decades according to the International Energy Agency. Fossil fuels such as oil and coal will continue to dominate, estimated to account for 85% of new demand [10].

2.4 The Global Warming Effects

Global warming manifests as the increase in the temperature of the atmosphere near the Earth's surface, which drives the changes in global climate patterns. It often refers to the warming that results from the increased emissions of greenhouse gases (e.g. CO_2) from human activities.

The greenhouse effect is the rise in temperature that the Earth experiences because certain gases in the atmosphere (e.g. water vapor, carbon dioxide, nitrous oxide, and methane) trap energy from the sun without releasing back to the space. Heat would escape back into space and Earth's average temperature would be about 60ºF colder if these gases do not exist in the air. Therefore these gases are referred to as greenhouse gases. Figure 8 graphically illustrate the principle of the greenhouse effects [11].

(1) Solar radiation passes through the clear atmosphere.

(2) Most radiation is absorbed by the Earth's surface and warms it.

(3) Some solar radiation is reflected by the Earth and the atmosphere.

(4) Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.

(5) Infrared radiation is emitted from the Earth's surface.

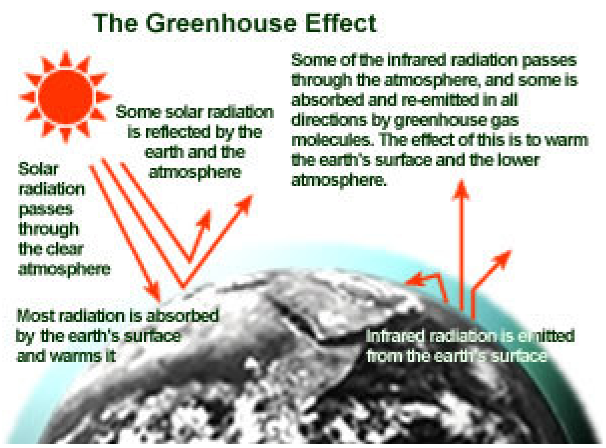


Figure 8. The principle of the greenhouse effects [11]

If greenhouse gases continue to increase due to the burning of fossil fuels, the average temperature at the Earth's surface could increase from 3.2 to 7.2ºF by the end of the 21st century. Scientists have convinced data to show that human activities are changing the composition of the atmosphere, and hence increase the temperature of the atmosphere over the last 100 years. [12]

2.5 The Time for Renewable Energy

Some scientists were already becoming concerned about the exhaust from combustion of the fossil fuel. They started developing natural energy sources including solar energy, hydroelectric energy, and geothermal energy. What is now thought of as renewable energy has been used by man for more than 5000 years. Today's interest in the renewable energy seems to be the new applications and harness of the old technology, rather than “re-invent of the wheel”. What are really new in today’s renewable energy is the integration of manufacturing technology and nanotechnology into the production of energy. Solar cells, wind power, and biofuels are all benefitted from the advancement of interdisciplinary technology [13].

References

[1] Energy Matters: Energy through History, http://library.thinkquest.org/20331/history/

[2] Energy Matters: Energy through History, http://library.thinkquest.org/20331/history/

[3] Energy Matters: Energy through History, http://library.thinkquest.org/20331/history/

[4] History of Energy, Elementary Energy Infobook, Page 9

[5] Energy Matters: Energy through History, http://library.thinkquest.org/20331/history/

[6] History of Coal Use, http://www.bydesign.com/fossilfuels/links/html/coal/coal_history.html

[7] A Short History of Energy, http://www.ucsusa.org/clean_energy/fossil_fuels/a-short-history-of-energy.html

[8] History of Oil Use, http://www.bydesign.com/fossilfuels/links/html/oil/oil_history.html

[9] Energy: Meeting soaring demand, http://news.bbc.co.uk/1/hi/sci/tech/3995135.stm

[10] Soaring Demand:World Primary energy demand, http://news.bbc.co.uk/2/shared/spl/hi/pop_ups/04/sci_nat_global_energy_crisis/html/1.stm

[11] Green House Effect, http:// epa.gov/climatechange/kids/greenhouse.html

[12] U.S. Environmental Protection Agency, http://www.epa.gov/climatechange/basicinfo.html

[13] Energy Kid’s Page, http://www.eia.doe.gov/kids/energyfacts/index.html

Chapter 3 Era of Renewable Energy

3.1 What is Renewable Energy?

Renewable energy is a kind of energy produced from natural resources—such as sunlight, wind, tides and geothermal heat—which are renewable (naturally replenished). Renewable energy technologies range from solar power, wind mill, hydroelectricity/micro hydro, biomass, and biofuels for transportation.

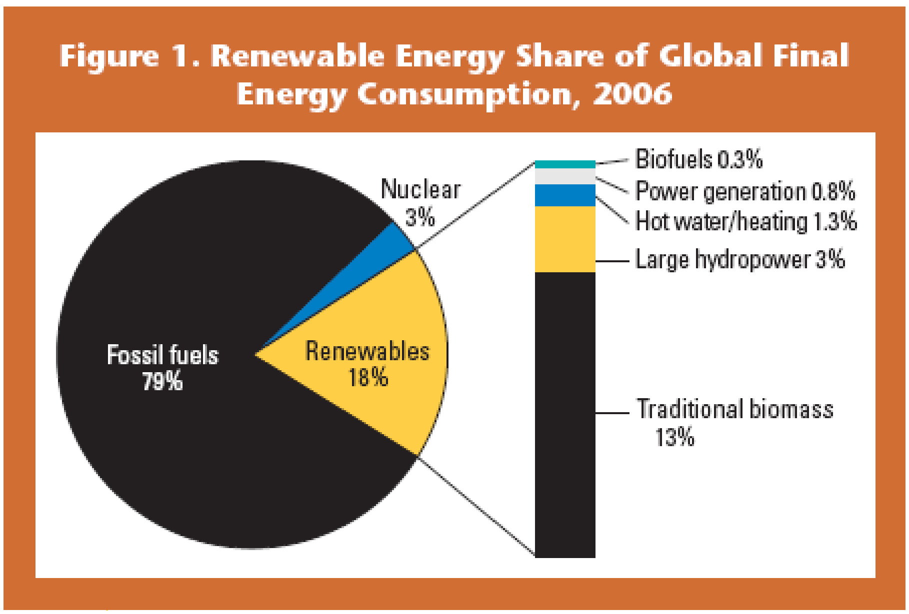


Figure 9 Energy Production Distribution Pool in the Word for 2006

Notice that Figure 9 （which is given by Renewables 2007 Global Status Report, Paris: REN21 Secretariat and Washington, DC: Worldwatch Institute, Page. 9）and Figure 5 (which is given by . the Energy Production Distribution Pool in the US). An interesting observation is the renewable energy counts for 18% of contribution world-wide, yet it is only 8% in the US energy pool. Therefore, as a leading economy entity in the world, the U.S. has great potential in developing and applying renewable energy.

3.2 Nations Leading the Renewable Energy

Based on existing capacity of renewable energy in 2006, China, Germany, USA, Spain, and India are the top five nations. New capacities continue to be added into these five nations together with other countries world-wide (see Table 1). New capacities include wind power, solar PV (photovoltaic), solar hot water, ethanol production, and biodiesel production.

Table 1 Summary of Leading Nations in Renewable Energy

Top Five Countries	#1	#2	#3	#4	#5
Annual amounts for 2006					
New capacity investment	Germany	China	United States	Spain	Japan
Wind power added	United States	Germany	India	Spain	China
Solar PV added (grid-tied)	Germany	Japan	United States	Spain	South Korea
Solar hot water added	China	Germany	Turkey	India	Austria
Ethanol production	United States	Brazil	China	Germany	Spain
Biodiesel production	Germany	United States	France	Italy	Czech Republic
Existing capacity as of 2006					
Renewables power capacity	China	Germany	United States	Spain	India
Small hydro	China	Japan	United States	Italy	Brazil
Wind power	Germany	Spain/United States		India	Denmark
Biomass power	United States	Brazil	Philippines	Germany/Sweden/Finland	
Geothermal power	United States	Philippines	Mexico	Indonesia/Italy	
Solar PV (grid-connected)	Germany	Japan	United States	Spain	Netherlands/Italy
Solar hot water	China	Turkey	Germany	Japan	Israel

Source: Renewables 2007 Global Status Report, Paris: REN21 Secretariat and Washington, DC:Worldwatch Institute, Page. 8.

3.3 The Profile of Major Renewable Energies

In the following sections, the outline of renewable energy, including wind power, solar energy, biomass, geothermal energy, hydraulic power, are presented. The advantages and disadvantages of each energy in the perspectives of technology and cost are compared in turn.

A. Wind power

	Technology	Cost	Potential expansion in the next 10 years
Advantage	1. Wind energy is ample, renewable and clean. 2. Modern technology can capture wind efficiently. 3. Wind turbines are available in a range of sizes so that they could be widely distributed.	1. It is one of the lowest-price renewable energy available today, costing between 4 - 8 cents per KWh.	1. Since 1995, global wind-generating capacity has increased nearly fivefold. 2. Electricity production from wind leapt by 31% in 2007. 3. Good wind areas, which cover 6% of the U.S. land area, have the potential to supply more than one and a half times the current electricity consumption of the United States.
Disadvantage	1. The strength of the wind is not constant, predictable or storable. Therefore, one cannot depend completely on wind in areas needed a large amount of energy. 2. Wind turbines indirectly produce noise pollution, up to the level as a family car traveling at 70 mph. 3. The power of wind energy is limited. The largest single turbine available today can only provide enough electricity for 475 homes.	1. Higher initial investment than fossil-fueled generators. 2. A large number of turbines have to be built to generate a proper amount of wind energy.	

References

[1] V. Ryan, 2005, Advantages and Disadvantages of Wind power, http://www.technologystudent.com/energy1/wind8.htm

[2] Roy D'Silva, 2007, Advantages and Disadvantages of Wind Energy, http://www.buzzle.com/articles/advantages-disadvantages-wind-energy.html

[3] Guardian Unlimited, Wind Power Use Grows by 30%, Guardian Newspapers, 2008, http://www.buzzle.com/editorials/1-10-2002-9149.asp

[4] U.S. Department of Energy. Advantages and Disadvantages of Wind Energy. http://www1.eere.energy.gov/windandhydro/wind_ad.html

[5] U.S. Department of Energy. Wind Energy Resource Potential. http://www1.eere.energy.gov/windandhydro/wind_potential.html

[6] U.S. Annual Wind Power Resource and Wind Power Classes - Contiguous U.S. States.http://www1.eere.energy.gov/windandhydro/wind_potential.html

B. Solar energy

	Technology	Cost	Potential expansion in the next 10 years
Advantage	1. It is easily available, sustainable and clean. 2. It is widely used in heat, electricity, transportation, and other innumerable photochemical processes. 3. It can work independently and be easily expandable as most solar panels can be added according to requirement.	1. There are no incurring costs. once the initial costing is taken care of, it is virtually maintenance free.	As energy shortages are becoming common day-by-day, solar energy is thus becoming more price-competitive.
Disadvantage	1. The solar cells can only produce DC, thus the conversion from DC to AC incurs a loss of about 4-12%. 2. Solar electricity and heat are not available at night and also may not be accessible in case of bad weather conditions. 3. Solar panels require a large area for installation in order to achieve a good level of efficiency. 4. It can be influenced by the presence of water vapor, pollution etc. in the air, which may cause complexities.	1. The initial cost is very high, usually due to the high-cost semiconductor materials. 2. Solar electricity is presently costlier than the electricity given by other sources.	

References

[1] Jayashree Pakhare, 2007, Advantages and Disadvantages of Solar Energy, http://www.buzzle.com/articles/advantages-and-disadvantages-of-solar-energy.html

[2] Anita Van Wyk, Solar Energy Advantages Disadvantages, http://ezinearticles.com/?Solar-Energy-Advantages-Disadvantages&id=50178

[3] Learn about the Many Advantages of Solar energy, http://www.alternate-energy-sources.com/advantages-of-solar-energy.html

[4] Solar Energy Avantages & Disadvantages, http://www.solarenergyadvantages.org/solar_energy_advantages.html

C. Biomass

	Technology	Cost	Potential expansion in the next 10 years
Advantage	1. Low greenhouse gas emission, commonly available 2. Proven technology 3. It uses waste products 4. Biogases can be used in high-efficiency combined cycle plants	1. It uses low-cost waste products	Biomass use for power generation is not projected to increase substantially by 2020 because of the cost of biomass relative to the costs of other fuels and the higher capital costs relative to those for coal- or natural-gas-fired capacity.
Disadvantage	1. Current production methods would require enormous amounts of land to replace all gasoline and diesel. 2. It could contribute a great deal to global warming and particulate pollution if directly burned. 3. On a small scale there is most likely a net loss of energy as energy must be put in to grow the plant mass	1. Relatively expensive, both in terms of producing the biomass and converting it to alcohols. 2. It is generally not economical to transport biomass fuels over long distances.	

References:

[1] What Is The Advantage Of Biomass Energy? http://www.alternate-energy-sources.com/advantage-of-biomass-energy.html

[2] The Advantage and Disadvantage of Biomass. http://library.thinkquest.org/20331/types/biomass/advant.html

[3] Energy Information Administration, official Energy Statistics from the U. S. Government. Biomass for Electricity Generation, http://www.eia.doe.gov/oiaf/analysispaper/biomass/

D. Geothermal energy

<table>
<tr><th></th><th>Technology</th><th>Cost</th><th>Potential expansion in the next 10 years</th></tr>
<tr><td>Advantage</td><td>1. It runs continuously day and night with an uptime typically exceeding 95%.
2. Geothermal power stations are relatively small, and have little impact on the environment.</td><td>1. Once a geothermal power station is implemented, the energy produced from the station is practically free.</td><td rowspan="2">1. The potential of geothermal energy production in the Western U.S. is significant.
2. The largest barriers are not technical, but geographical. Geothermal resources are not found everywhere, the thermal fluids can only be produced where the reservoirs are.</td></tr>
<tr><td>Disadvantage</td><td>1. Geothermal heat is extracted from deep within the earths surface which results in disadvantage concerning finding a suitable build location.
2. Some geothermal stations have created geological instability, even causing earthquakes strong enough to damage buildings.
3. It extracts small amounts of minerals such as sulfur.</td><td>1. The initial cost of design and installation is high. .
2. Open-loop systems require a large supply of clean water in order to be cost effective.</td></tr>
</table>

References:

[1] Energy development, http://en.wikipedia.org/wiki/Energy_development
[2] Geothermal Advantages & Disadvantages, http://tristate.apogee.net/geo/gdfdgad.asp
[3] Jane C. S. Long, Lisa Shevenell. The Potential of Geothermal Energy http://64.233.167.104/search?q=cache:76gy7igZvigJ:www.unr.edu/geothermal/MicroDocs/GeothermaltestimonyJCSL.doc+Geotherma+Potential+expansion&hl=zh-CN&ct=clnk&cd=6&gl=us

E. Hydraulic power

	Technology	Cost	Potential expansion in the next 10 years
Advantage	1. Electricity can be produced at a constant rate. 2. It is storable and available as needed. 3. Dams are designed to last many decades.	1. Large dams can become tourist attractions which would make up a little initial cost.	1. Hydropower's share of the nation's generation is predicted to decline through 2020 to about 6% from about 10% today. The decline is due to environmental issues, regulatory complexity, and energy economics. 2. Energy analysts expect almost no new hydropower capacity to be added through 2020.
Disadvantage	1. Hydropower plants can be impacted by drought. 2. The building of large dams can cause serious geological damage, or even earthquakes 3. Hydropower plants can cause low dissolved oxygen levels in the water. Maintaining minimum flows of water downstream of a hydropower installation is critical for the survival of riparian habitats.	1. Dams are extremely expensive to build and must be built to a very high standard. 2. It takes many decades to be profitable. 3. New hydropower facilities impact the local environment including humans, flora, fauna, local cultures and historical sites, which values are higher than electricity generation.	

References

[1] V. Ryan, 2005, Advantages and Disadvantages of Hydropower.http://www.technologystudent.com/energy1/hydr2.htm

[2] U.S. Department of Energy. Hydropower Resource Potential. http://www1.eere.energy.gov/windandhydro/hydro_potential.html

[3] U.S. Department of Energy. Advantages and Disadvantages of Hydropower. http://www1.eere.energy.gov/windandhydro/hydro_ad.htm

Chapter 4 Successful Applications of Solar Cell Technology

4. 1. Outlines

Solar power, especially the Photovoltaic (PV), can be widely used in commercial as well as residential area for individual consumers, farmer, business and telecommunication. With the costs and prices declined, solar power is more and more competitive as a source of peak power. The U.S. is the leading solar energy application country after Germany and Japan.

What is Photovoltaic? Photovoltaic technology is to apply semiconducting material to convert the sunlight directly into electricity. It is affected by the Earth's atmosphere and atmospheric conditions relative to the sun. In most of U.S. region, the solar energy is abundant for PV devices. PV Applications act in the perspectives of technology and costs as a current technology.

4.2 Commercial Power Applications

A 500KW PV system was installed to generate electricity to meet the summer peak demand in Pacific Gas and Electric Company's (PG&E) Kerman substation in California in 1993. The complementary solar power generator helps to avoid the shorten life of the expensive transformer of power grid and satisfy the seasonal increasing electrical demand. The value of the Kerman substation is measuring for the possibility of another use of PV utility system.

PV powered lighting systems are widely used throughout the U.S. for its reliable technology and low cost. (information from Robert Foster)

Technology	Cost
1. Operate at 12 or 24 volts DC with recycle battery. 2. Fluorescent or sodium lamps are recommended for their high efficiency.	1. Cheaper than grid lighting. 2. The price ranges from $600-$1,500, depending on the size.

4.3 Residential Power

PV powered home in Massachusetts launched an all-solar home since 1980. The 4.5 KW PV array generates more electricity for household use in summer so that the excess one is sold to the utility. In winter, the family has to buy some from the utility. The south wall of the house is built by all glass to absorb sunlight. The PV modules are 40 square in the south-facing roof. It converts DC electricity to AC power for household use.

Another residential solar electricity application is in Florida. The Chases enjoyed their holidays in a remote home. Comparing the cost of $15,000 to extend a utility line to their home, they preferred to install PV system in the modern 185 square meter home. The PV-power system could meet the need of TV, washing machine, microwave, oven and so on with DC as well as AC by inverter. The Chases put the battery and control in the central spot to save the length of wire. This application shows that PV can be considered as a convenient, yet cost-effective power alternative for residential homes where regular wires do not reach.

Here is another good application of PV technology in Mexico. It will cost $3.2 million for a line extension from the nearest utility line 110KM away, the village of Xcalak in Mexico added a PV modules to the existing hybrid power system, which includes 6 wind turbines, 234 PV modules, 3 batteries, a 40-KW inverter to convert DC to AC, a diesel generator and a complex control system.

Technology	Cost
1. PV system can provide power for refrigerator, lights, TV, and other common household appliances. 2. It is important for users to install quality equipments. Most of the 40, 000 PV home lighting systems installed before 1998 were out of use because the poor balance of systems hardware.	1. In Texas, a residence lived more than one mile away from the electric grid can install a PV system which is cheaper than extending the electric grid. 2. A 2KW PV array, meeting the energy needs of a family, costs about $15,000.

4.4 Water Pumping

Water Pumping is one of the most attractive applications for PV power for it is reliable technologies and required no maintenance. Thousands of agricultural PV water pumping is in use today through Texas and around the nation.

Oliver Romey, a rancher in South Dakoda, decided to install the PV-powered water pumping, due to the high cost ($ 18,000) of extending the nearest power line which is 1.5 miles away from his farm in 1990. 1.6 KW electricity is generated by the solar array. The system pumps 30 gallons per minute from a 43-feet-deep well and then carries it 5.5

miles through a pipeline to meet the demand of 150 head of cattle. The models can be extended if water demand increase.
The comparison of technology and cost of PV powered water pumping is shown as follows:

Technology	Cost
1. AC and DC motors with centrifugal or displacement pumps are in the PV pumping systems. 2. The power is less than 2 horsepower in size. It is excellent for medium scale pumping needs 3. Well installed quality ones can continuously service over 20 years	1. The cost ranges from $1,500-$20,000.

4.5. Telecommunications

Isolated mountaintops and remote area are ideal to use PV powered telecommunication systems. Sprint Communications invested a PV-powered electric generator in a remote signal station in the mountains of northern Nevada. The PV array complements the propane generators at the Sand Pass station. The backup PV-powered electricity generator reduced the maintenance cost for station's fuel significantly.

4.6 Gate Openers

Technology is mature and commercial products are available for gate openers powered by solar energy.

Technology	Cost
1. The PV powered gate could release a gate latch. Open a gate and close the gate with wireless remote control. 2. The size and the weight could up to 16 feet and 250 pounds, respectively. 3. The batteries could be charged only a few watts.	1. A set of PV powered gate system with a PV module and transmitter is about $700.

4.7 Electric Fences

Technology	Cost
1. A 6 or 12 volt gel cell batteries could be used for day and night operation without maintenance. 2. A unit could produce safe power spikes ranging from 8, 000-12, 000 volt. The fence could be 25-30 miles.	1. The cost ranges from $150-$300.

4.8. Water Tank Deicers

PV power is applied to melt ice for livestock tanks in the north plain of Texas. The PV module provides power to generate the movement of the air bubble so as to melt the tank's ice. The cost for the deice water tank including PV module, compressor and mounting pole is $450. (The information above is from Robert Foster)

4.9 Evaporative Cooling

Solar powers offer a variety of sizes and models of Evaporative Coolers designed for off-grid consumers and commercial applications (mainly buildings running on 12, 24, or 48 volt battery banks). DC-powered evaporative coolers consume half as much power as regular AC coolers. These units are not typical evaporate coolers in which they do not run on conventional power grid electricity (AC).

Technology	Cost
1. PV evaporative cooling systems are appropriate in the dry area, such as west Texas. 2. Battery storage is necessary when cooler operation is desired at night.	1. The price ranges from $500 to $1, 500, depending on the size.

4.10 Consumer Electronics

Solar powered personal electronics are widely used in watches, cell phones, calculators, and cameras.

4.11 Electric Utility Applications

Utility market is the potential future increasing application for PV technology. The project “Million Solar Roofs Initiative (MSRI)”, which means putting solar thermal and PV systems to 1 million US residential roofs by the year of 2010, is promoted by the White House and Department of Energy. (the information above is from Robert Foster)

Both the Austin Utility and Central and Southwest Services are members of the Utility Photovoltaic Group (UPVG). These areas build examples of city utility. In Austin, 20KW experimental array was installed in 1992. A 300KW PV array by Decker Lake was built later in order to evaluate the possibility of PV. Central and Southwest Services is another utility organization. It installed over 300KW PV connected to the electric grid. (the information above is from Robert Foster)

4.12 Incentives for Solar Energy Application

The special policies of Germany, Japan and California proved that polices boosted the market growth and technology development in solar energy.

In Germany, “feed-in tariff” is offered to the solar power producers about 50 Euro cents for every KWh fed into the utility grid. The policy guaranteed the price would be reduced by 5% each year and the policy will continue for 20 years. [from #1, Solar Energy Industries Association]

In Japan, the 70,000 Roofs Program subsidizes the initial 50% cash for a 3-4 KW grid connected residential systems by the government. The installation of solar systems have boosted from 500 to 100,000 dramatically. [from #1, Solar Energy Industries Association]

The Emerging Renewables Buy-Down Program (similar to rebate) guaranteed a capital subsidy of $3 per watt of solar power installation. Rebate levels are reduced by 20 cents per watt every six months. This proved a success so that the California Solar Energy Industries Association (CalSEIA) proposed an extension of the program for the sale increase of the global market from 2015 to 2024. [from #1, Solar Energy Industries Association]

4.13 Conclusions

Solar energy, especially PV, has successful operation and application to satisfy the remote electricity demand. The government policy will direct the popularity and further development in more and more cities in the future.

References

[1] Solar Energy Industries Association (SEIA). Our Solar Future: The U. S. Photovoltaics Industry Roadmap Through 2030 and beyond. http://www.seia.org/roadmap.pdf

[2] Energy Information Administration. Solar Photovoltaic. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarphotv/solarpv.html

[3] U.S. Department of Energy. Utility Applications Case Study: Power for a Utility Substation in California. http://www1.eere.energy.gov/solar/cs_ca_substation.html

[4] U.S. Department of Energy. Grid-Connected PV Case Study: PV Power for an Energy-Efficient Home in Massachusetts. http://www1.eere.energy.gov/solar/cs_ma_eehome.html

[5] U.S. Department of Energy. Remote Homes Case Study: PV Power for a Modern Home in Florida. http://www1.eere.energy.gov/solar/cs_fl_modern_home.html

[6] U.S. Department of Energy. Remote Villages Case Study: Village PV Power in Mexico. http://www1.eere.energy.gov/solar/cs_mexico_village.html

[7] Robert Foster. Photovoltaic Markets and Applications. http://www.epsea.org/pv.html

[8] U.S. Department of Energy. Water Pumping Case Study: PV-Powered Water for Cattle in South Dakota. http://www1.eere.energy.gov/solar/cs_sd_cattle_water.html

[9] U.S. Department of Energy. Communications Case Study: A PV-Powered Telephone Signal Booster in Nevada. http://www1.eere.energy.gov/solar/cs_nv_signal_booster.html

[10] Texas Solar for Schools. http://www.seco.cpa.state.tx.us/re_solarschools.htm

[11] Renewable Energy Education. http://www.seco.cpa.state.tx.us/re_education.htm

[12] Watts on Schools, http://www.wattsonschools.com/sites/laredo_texas.htm

[13] Ashley Richards. 39th place starts debate. http://www.ldfonline.org/shownews.asp?newsid=86

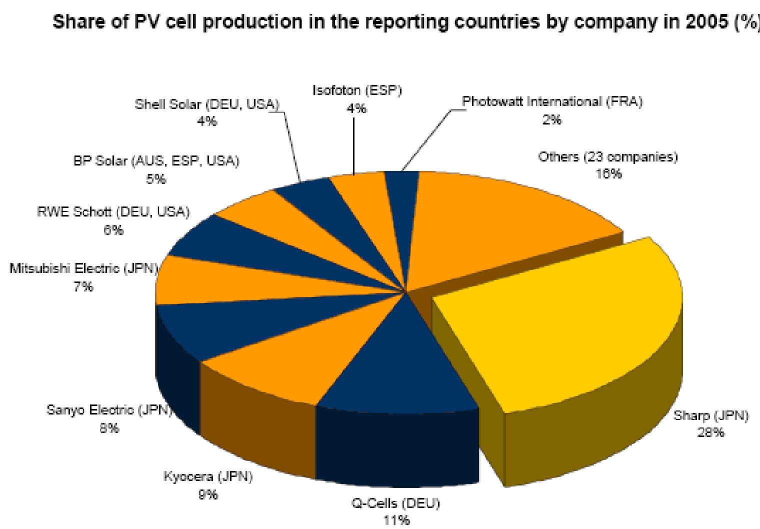
[14] Solar Powered Reverse Osmosis. http://www.southwestpv.com/Catalog/PDF/Water_RO_Laredo.pdf

[15] Solar Energy Laboratory Research. http://www.me.utexas.edu/~solarlab/Research.html

Chapter 5 Technological Know-How of Solar Energy

5.1 Leading Manufacturers for Solar Cells

The latest top three solar cell or panel manufacturers are Sharp Solar, Q-Cells, Suntech Power Corporation. Major manufacturers of solar equipments include Shell Solar, BP Solar, GE Solar, Kyocera Solar and Mistubishi Electric.



Major plays in the PV cell production

Source: Solar Photovoltaic market, cost and trends in EU. Oct 2006.
http://eneken.ieej.or.jp/en/data/pdf/368.pdf

Sharp Solar, a Japanese company, is the largest manufacturer of solar cells worldwide with nearly as much generating capacity as the next three largest manufacturers combined. (information from http://www.evo.com/). The company is the pioneer in solar manufacturing industry. The milestones include: beginning research in 1959, mass production in 1963, designing and producing residential solar panel in the mid-1990s. (information from http://solar.calfinder.com/, as above)

Headquartered in Germany, Q-Cells, the PV manufacturer, surpassed Sharp and emerged as the leader producer of solar cells in Feb. 2008. Q-Cells was founded in 1999. The company has focused on silicon cells. Its quick ascent to the top is likely due to the acquisition of adequate amount of silicon during the recent silicon shortage. (information from http://solar.calfinder.com/, as above)

Suntech Power Corporation is another young and leading solar cell company that jumped to the third position in 2008. Founded in 2001, the company focuses on silicon-based solar cells. Suntech is diversifying within the solar industry and began thin film cell production last year. (information from http://solar.calfinder.com/, as above)

First Solar is a US and worldwide leader in thin film technology. The main reason why U.S. left behind in manufacturing is that the countries like Germany, Japan and China have more aggressive government support in solar industry. (information from http://solar.calfinder.com/, as above)

The following table, which ranks photovoltaic suppliers by manufacturing volume as well as noting the type of cells: Crystalline or thin-film. Any manufacturer that has a [1] under "Cell technology" also manufactures thin-film, although crystalline is its primary technology.

Company	Country of origin	Cell technology	Capacity 2008 (MWs)
Sharp Electronics	Japan	Crystalline[1]	870
Q-Cells	Germany	Crystalline[1]	834
Suntech Power Holdings Ltd.	China	Crystalline[1]	590
First Solar	USA	Thin-film	484
SolarWorld	Germany	Crystalline	460
Sanyo	Japan	Crystalline	365
BP Solar	UK	Crystalline	480
Kyocera	Japan	Crystalline	300
Motech Industries Inc.	Taiwan	Crystalline	330
Solarfun Power Holdings	China	Crystalline	360
SunPower Corp.	USA	Crystalline	414
Gintech Energy Corporation	Taiwan	Crystalline	300
E-TON SOLAR TECH	Taiwan	Crystalline	320
Yingli Green Energy	China	Crystalline	400
CEEG Nanjing PV Tech Co.Ltd.	China	Crystalline	390
China Sunergy Co. Ltd	China	Crystalline	320
Mitsubishi	Japan	Crystalline[1]	280
Ersol Solar Energy AG	Germany	Crystalline	220
Jing Ao Solar Co Ltd.	China	Crystalline	175
Moser Baer Photovoltaic	India	Crystalline[1]	120
Total (in MW)			8012
Total for Top 10			5073

5.2 Major Technologies Used in Solar Cells

Solar cell or photovoltaic (PV) cell is a device that converts solar energy into electricity by photovoltaic effect. Solar cells are often encapsulated in a solar module. The module has a sheet of glass on the front in order to allow light pass and protect the semiconductor wafers from harsh weather or other unfriendly condition. The module is assembled in series or parallel to connect a solar array. Notice that the dominating Solar Cell Technology: C-Si and TF (thin-film).The following summarizes the key elements of solar cell technology.

- The semiconductor. It absorbs and converts light into electron-hole pairs.
- The semiconductor junction. It separates the photo-generated carriers, that is, electrons and holes.
- The contacts on the front and back of the cell. It directs the current to flow to the external circuit.

The main categories of solar cell technology defined by the choice of the semiconductor include crystalline silicon (C-Si) in the wafer form and thin film (or TF) of other materials. C-Si solar cell dominates the solar cell market. Its market share is up to 90%, as contrast to that of TF solar cell, which is only about 10%.

C-Si solar cells consists two categories of technology. The first is monocrystalline, which is made by slicing wafers from a high purity single crystal. The second is multicrystalline, which is produced by sawing a cast block of silicon into bars and then further transforms into wafers. Multicrystalline is the main technology trend.

According to the materials used, the TF solar cell technology is divided into several kinds according to the material. The first is amorphous silicon (a-Si). The material is a different form of silicon. The second is cadmium telluride (CdTe). The third is copper indium (gallium) diselenide (CIS or CIGS). CdTe and CIS are called polycrystalline materials. The a-Si is the most well developed TF solar cell technology. However, the market share of TF solar cell is as low as only 10%. In 2007, the market share of CdTe, TF silicon and CIGS in the total solar cell market is 4.7%, 5.2%, and 0.5%, respectively.

Table 1 The Comparison of c-Si Solar Cell and TF Solar Cell

Items		c-Si solar cell	TF solar cell
Technology	Merit	1. Yield stable and good efficiencies (11-16%) 2. The main technology of solar cell Each c-Si cell generates about 0.5V. 3. The cells are sealed under toughened and high transmission glass to resist weather change.	1. The selected materials are strong light absorbers. 2. Only need to be about 1 micron thick. 3. Many TF technologies demonstrate best cell efficiencies above 13%. The stable efficiencies probably are at least 10%.
	Draw-back	1. The single junction silicon devices are approaching the theoretical limiting efficiency of 33%. 2. Poor absorber of light. 3. Require considerable thickness (several hundred microns) of material.	1. Technologies dilemmas: (1) Better stability requires using thinner layers. However, this reduces light absorption efficiency. (2) Lower cost material leads to reducing energy conversion efficiency. 2. The technology is complex and the commercialization proved difficult.
Cost	Merit	It can be warranted for up to 25 years, without a significant decrease in efficiency.	1. TF technology reduces the amount of light absorbing material in solar cell. This leads to the low cost of TF solar cell. 2. TF are potentially cheaper than c-Si because of the lower material cost and larger substrate size.
	Draw-back	High cost of c-Si wafer which makes up 40-50% of a finished module cost.	1. The time span of commercialization process proved long. It is at least twenty years to experience from lab research to the early manufacturing. 2. Some TF materials degrade the efficiencies up to 15-35%, comparing to the initial values.

Information digested and concluded from:

(1) Solar Cell Technologies. http://www.solarbuzz.com/technologies.htm

(2) Solar cell. http://en.wikipedia.org/wiki/Solar_cell

5.3 Potential Technological Obstacles to Overcome

5.3.1 Energy conversion efficiency

Energy conversion efficiency (ECE) is one of the major obstacles of solar cell to overcome. For the last two decades, researchers have devoted to break the 40% efficiency barrier on solar cell devices. In 1994, National Renewable Energy laboratory of Department of Energy (DOE) broke the 30% barrier. In 2006, the 40% efficiency was broken by a concentrator solar cell produced by Boeing-Spectrolab.

The 40.7% solar cell was developed by using a multi-junction structure which could capture more solar spectrum. Almost all of today's solar cell modules do not concentrate sunlight but use the natural producing sunlight, which achieves an efficiency of 12-18%. This breakthrough established a new milestone in solar-to-electricity application and promised solar cell to be the cost-effective solar electricity. The installation cost was $3 per watt and the producing electricity cost was 8-10 cents per KWh. However, there is a long pathway to translate this accomplishment into the marketplace.

Concentrator is another technology that shows higher absorption efficiency than flat plate PV arrays. It uses mirror or lenses to focus light on to the designed cells. Concentrator systems require direct sunlight and will not operate under cloudy conditions. To adapt to the sunlight height through seasons, two-axis tracking is sometimes used.

5.3.2 Material Choose

Alternative material is another focus of solar cell technology in order to lower the manufacturing cost. The 40.7% efficient solar cell mentioned above was achieved by using a new class of metamorphic semiconductor materials, which allowed much greater freedom in multi-junction cell design for optimal conversion. Dr. Richard R. King, principal investigator of the high efficiency solar cell research also pointed out that this excellent performance of these materials hinted at higher efficiency in future solar cells.
As discussed above, TF technology reduces the cost of light absorbing material in solar cell. However, this technology encounters dilemmas: (1) better stability requires the use of thinner layers. However, this reduces light absorption efficiency. (2) lower cost material leads to reducing energy conversion efficiency.

The high cost production process has attracted some alternative PV technology development. Nanotechnology is a new generation of solar power technology that includes organic and inorganic solar cells derived from nanocrystals that can convert sunlight into electricity at a fraction of the cost of silicon solar cells. For example, "spray on solar cells" are a nano-based plastic that is able to capture solar energy even in cloudy days. Electrochemical PV cells are a low-cost technology that uses a dye-sensitizer to absorb the light and create electron-hole pairs in a nanocrystalline titanium dioxide semiconductor layer. Current research aims at the conversion rate of 30-60% as well as low material cost. However, the two major issues for organic solar cells to commercially compete with silicon solar cells are: (1) the present efficiency of organic solar cells is only around 6%, comparing to 20% for the commercialized silicon cells; (2) organic solar cells suffer from huge degradation effects over time due to the environmental effects such as water, oxygen or UV rays. Therefore, increasing the efficiency and the lifetime are two big issues for organic solar cell commercialization.

5.3.3 Installation Placement

The third obstacle to overcome is the large area that rigs the concentrated cells. Should the giant collections of cells be placed in the residential areas where citizens might complain of their unsightliness, or in remote areas that could potentially harm the wildlife? This is another technology hurdle to overcome before solar cells proliferate in large scale.

5.4 Why the PV Cost is so High?

Price has long been a major obstacle to widespread the usage of solar cells. Although there are several solar cell technologies, silicon-based solar cell has made up more than 95% of the solar cell market today. Why the manufacturing cost of solar cell is so high? First of all, it lies in the complex production process. Silicon-based solar cells are made from a refined, highly purified silicon crystal which involves hundreds of processes.

Secondly, another factor to cause the price to increase is the shortage of silicon, which has long been the stable material of dominative solar cell technology. This factor has effected from 2005 after a long increase of the overall cell price. Solar power cost about $4 a watt in the early 2000s, but silicon shortages, which began in 2005, have pushed up prices to more than $4.80 per watt. The shortage has been severe enough to drive silicon prices to more than 10 time normal levels. (Same source of the former reference.)

References

[1] http://www.ecobusinesslinks.com/solar_energy_solar_power_panels.htm#2.%20 PV%20Manufacturers
[2] Sharp Solar. http://solar.sharpusa.com/solar/home/0,2462,,00.html
[3] Q-Cells. http://www.q-cells.com/en/index.html
[4] Suntech Power Corporation. http://www.suntech-power.com/
[5] BP Solar. http://www.shell.com/home/Framework?siteId=shellsolar&FC2=/shellsolar/html/iwgen/leftnavs/zzz_lhn1_0_0.html&FC3=/shellsolar/html/iwgen/welcome.html
[6] GE Solar. http://www.gepower.com/prod_serv/products/solar/en/index.htm
[7] Kyocera Solar. http://www.kyocerasolar.com/
[8] Mistubishi Electric. http://global.mitsubishielectric.com/bu/solar/index.html

Chapter 6 Emerging Technologies of Solar Cells

6.1 The Principle of Silicon-Based Solar Cell

The silicon-based dominated the solar market with more than 90%. It benefits from the high conversion efficiency and reliability in the current market. In this section, the principle of silicon-based solar cell is introduced and the forecast of solar cell technologies are reviewed.

6.1.1 Manufacturing Process of Solar Modules

The raw material of solar cell is silicon particles. They are melted and re-cast to high-purified cubes. Then the cast silicon is stabilized and cut into blocks, called "ingots". Next, the blocks are sliced into thin wafers. There are two kinds of wafers, one is p-type and the other is n-type silicon, which are the important parts of solar cell. When the p-n layers are synthesized together, an electrode is formed, which is called solar cell. The manufacturing process of solar cell is shown in Fig. 1 from ref. [1].

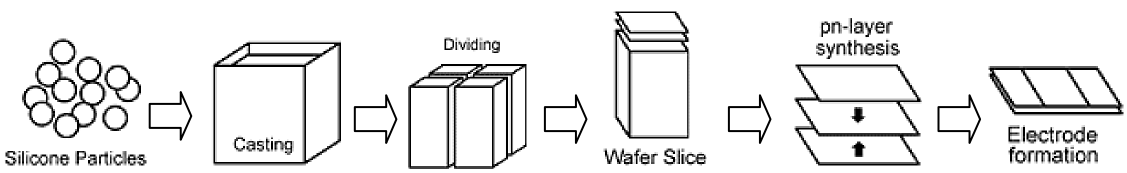


Figure 1 The Manufacturing Process of Solar Cell
Source: Principle of Solar Cell.
http://global.kyocera.com/prdct/solar/spirit/about_solar/cell.html

6.1.2 The Structure of Solar Cell

Solar cells are made of semiconductors which are similar to integrated circuits for electronic equipment. In Figure 2, it shows the typical structure of solar cell. [[2]] At the top of the contact structure, there are widely-spaced thin metal strips, called fingers, which allow light to pass through. Next to fingers, it is covered with ARC, the anti-reflection coating, a thin layer of dielectric material which is used to minimize light reflection. The solar cell is encapsulated by upper ARC and Back contact. Inside these covers is the heart of solar cell. This part which generates current is called p-n junction. It is made up of n-type emitter, junction and p-type base.

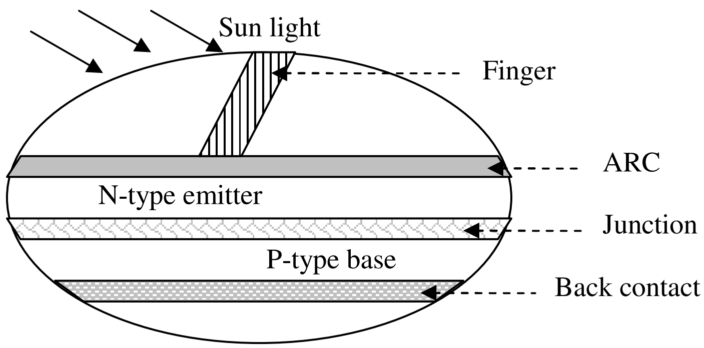


Figure 2 The Structure of Solar Cel l
Source: http://www.soton.ac.uk/~solar/intro/tech6.htm

6.1.3 The Working Principle of Solar Cell

Solar cells are essentially semiconductor junction. The junction separates the silicon wafer with opposite charge. On the one side of the junction, it is the negative type emitter, called n-type emitter. On the other side of the junction, it is the positive type base, called p-type base. The p-n junction is shown in Figure 3. [[3]] The junction acts as a diode to let the electron can only flow from p-side to the n-side and let the holes flow from n-side to p-side.

Sunlight radiation causes electrons (negative) and electron holes (positive) in the junction to separate from their atoms. The generated electrons from the p-type base begin to move toward the n-type emitter. So do the electrons holes in the n-type emitter. These movements are shown in the Figure 3. As the movement of electron and electron holes accumulate, voltage is generated. When lead wire connects the n-type layer and the p-type layer together, electricity is generated.

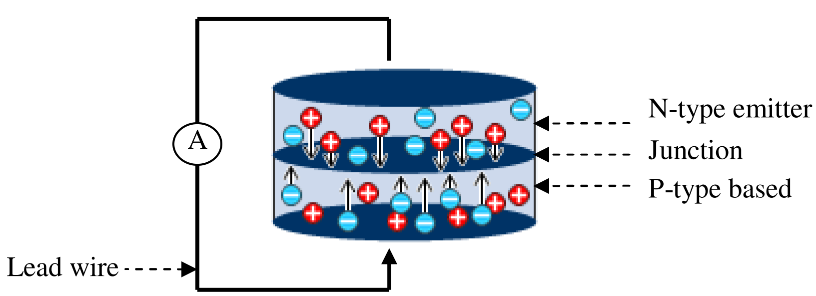


Figure 3 The Working Principle of Solar Cell
Source: http://sharp-world.com/solar/generation/structure.html (with revisions)

However, the single solar cell generates only small amounts of electricity, a series of solar cells are connected together in order to generate enough voltage for use. The series of solar cells, encapsulated with tempered glass and other coaters in order to protect the cells, called solar modules. The typical solar module structure is shown in Figure 4. [1]

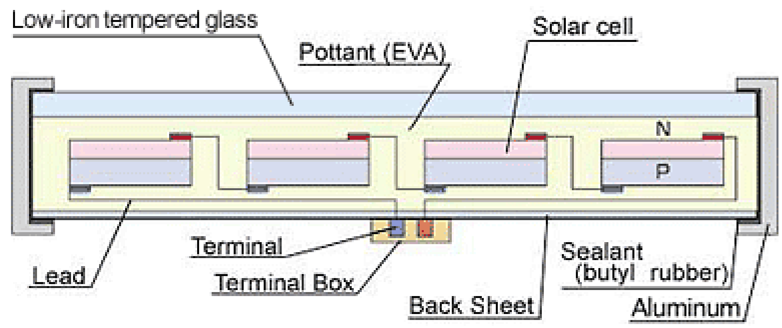


Figure 4 Solar Module Structure

Source: http://global.kyocera.com/prdct/solar/spirit/about_solar/module.html

6.2 Efficiency Losses in Solar Cell

In the process of converting sunlight to electricity, the losses of energy mainly come from: (1) thermalization loss; (2) recombination loss. [4, 5]

(1) Thermalization Efficiency

Each semiconductor is restricted to converting only a part of solar spectrum. [6]As mentioned above, the conversion from solar energy to electricity begins with photon generating hole-electron pair. When the energy of the photons is below the band gap of absorber material, they can not be separated into hole-electron pair. Therefore, only a fraction of photons above the band gap can be converted to useful output. The solar spectrum conversion rate can be increased with multiple band gap absorber materials. [5]

(2) Recombination Loss

Some of the electron-hole pair passed through the surface of the solar cell may give up its energy and become an atom within the solar cell without reaching the surface. This process is called recombination. This also reduces the efficiency of solar energy conversion. [5]

What is more, a certain amount of solar energy is transformed into heat of junction or other encapsulated material of the solar cell, rather than electrical energy.

Basically, solar cells made of silicon or other combination of materials is suited only for specific range of spectrum. [7] Therefore, there is a natural efficiency limit of solar energy. Figure 5 below shows the theoretical maximum efficiency levels of various solar cells at standard conditions.

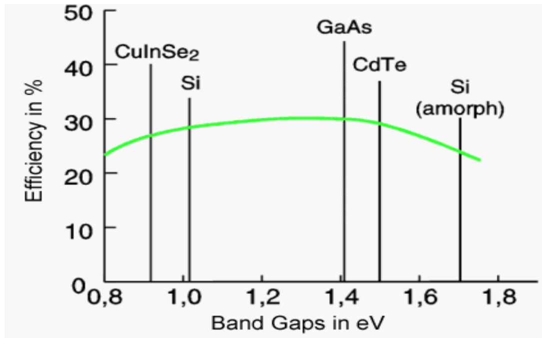


Figure 5 Theoretical Limit of solar cell with different material combination
Source: http://www.solarserver.de/wissen/photovoltaik-e.html

6.3 The Comparison of Different Kinds of Solar Cell

The most popular type of solar cell currently in use is crystal silicon. The silicon-based solar cell can be classified to several types, as shown in Figure 6.

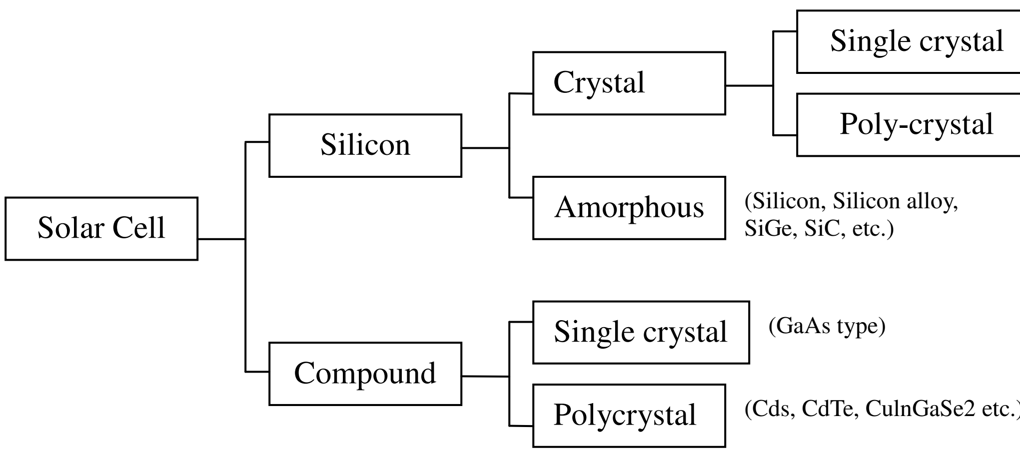


Figure 6 Classification of Silicon-Based Solar Cell
Source: http://sharp-world.com/solar/generation/structure.html

The features of different types of silicon-based solar cell are compared in Table 1. Basically, monocrystalline silicon is most attractive concerning both efficiency and cost, due to the highest requirement of silicon purify technology. Amorphous silicon is cost-efficient but low in energy conversion efficiency. The energy conversion efficiency and cost of polycrystalline silicon are both between the monocrystalline and amorphous silicon.

Table 1 Silicon-Based Solar Cell Features

Material	Conversion efficiency	Relia bility	Cost	Characteristics	Main Applications
Single crystal	High	High	High	Proven usage record	Space terrestrial
Polycrystal silicon	Middle	High	Middle	Suitable for high volume production	Terrestrial
Amorphous	Low	Low	Low	Operates comparatively well under fluorescent light	Consumer use, terrestrial
Single-crystal compound	High	High	High	Heavy, cracks easily	Space
Polycrystal compound	Low	Low	Low	Uses few resources but some types contain pollutants	Consumer use, terrestrial

Source: http://sharp-world.com/solar/generation/structure.html (with some revisions)

6.4 Conclusion

Basically, the fundamental of solar cell technology is stable because the p-n junction structure of solar cell is not challenged by the emerging technology. The trend of the solar cell technology focuses on the new material alternative to silicon as well as new structure to increase the absorption rate of sunlight, such as concentrator and nanoparticles. The themes of technology development of solar are conversion efficiency and cost, which seems to be opposite in current technology. That is why the cost-competitive technology is difficult to pave the way to mass-production. In the coming five to ten years, silicon-based solar cell is still the dominated in the solar market with its attractive efficiency and reliability and the release of silicon shortage.

References

[1] Manufacturing Solar Modules. http://global.kyocera.com/prdct/solar/spirit/about_solar/module.htm

[2] How Solar Cells Work. http://www.soton.ac.uk/~solar/intro/tech6.htm

[3] Principles of a Solar Power Generation System. http://sharp-world.com/solar/generation/structure.html

[4] Yogesh Wakchature. Solar Cells. p. 15. www.nd.edu/~gsnider/EE698A/Yogesh_Solar_cells.ppt

[5] Solar Cell. http://en.wikipedia.org/wiki/Solar_cell

[6] Light Absorption by a Semiconductor. http://www.soton.ac.uk/~solar/intro/tech5.htm

[7] Photovoltaics: Solar Electricity and Solar Cells in Theory and Practice http://www.solarserver.de/wissen/photovoltaik-e.html

Chapter 7 Roadmap to Cost Reduction of Solar Cells

7.1 The Cost Factors of Solar Electric System

A PV system consists of an array of modules generating DC electricity, an inverter that converts from DC to AC, and sometimes battery storage back up with charge controller. [1]

The cost of a solar electric system will be decided by factors including the size of the system, the PV system rating, and the incentive or tax credits.

7.1.1 The Size of the System

The size of the PV system may be the most significant factor that influences the total cost. As PV systems get larger, the cost per watt is lower. Following is the list of average cost of PV system according to different sizes.

Table 1 The Average Cost of PV System in Different Sizes

System size (Watt)	Installation cost ($)	Cost (cent/watt)	Tips
75	900	12	Single-PV-panel system
2000	16,000-20,000	8-10	Meet nearly all the needs of a very energy-efficient family
5000	30,000-40,000	6-8	Completely meet the energy needs of many conventional homes

Source: 1. FAQ's about Residential Grid-Tied Solar Electricity.
http://www.solarexpert.com/grid-tie/FAQs.html
2. U.S. Department of Energy. A Consumer's Guide: You're your Power from the Sun.
http://www.nrel.gov/docs/fy04osti/35297.pdf

7.1.2 The PV System Rating

The PV system just designed to offset when the total electrical needs is not enough, because the cost to accomplish a 100% system may be prohibitive. Some utilities use tiered rates which mean the more energy you use the higher is the cost per kWh. Therefore, the most economically feasible size is usually between 50-75% of your annual household needs. [1]

7.1.3 The Incentives or Tax Credits

Many states in the U.S. offer incentive for installing PV systems.

A. Net Metering Law

The storage battery in the PV system is used to ride out utility blackouts. However, because the battery adds significantly expense to the system while providing no payback, weekly maintenance and need replacing every five to ten years, most city dwellers are opting for a "grid-tie" system. The "Net Metering Law" make the PV system becomes more economical. [1]

Customers who own PV systems can benefit from Net Metering Law. The "Net Metering Law" allows the users "sell" the PV-produced electricity to the utility at the same price which he/she purchases electricity from the power grid, up to the amount he/she would have used, rather than at the much lower whole sale price for selling electricity to utility before. [2]

B. Property and Sales Tax

Tax incentives include a sales tax exemption on the PV system purchase, a property tax exemption or state personal income-tax credits, all of which provide an economic benefit to lower the high capital cost of PV system. [2]

C. Buy-Down

The U.S. Department of Energy has been involved in a program called TEAM-UP, or Technology Experience to Accelerate Markets in Utility Photovoltaics. In this program, suppliers buy-downs and consumers rebates range between $2-4 per watt.

For more information on the incentive of the PV system, here is the link of National Database of State Incentives for Renewable Energy (DSIRE): www.dsireusa.org.

7.1.4 Other Factors

The cost of a PV system also considers the lifetime of the system, the lifetime of each component (including replacement cost where necessary), the operational and maintenance cost and the financial cost. [3]

7.2 The Average Electricity Cost for a Regular Household

According to report on the Electricity Consumption by End Use in U.S. Households in 2001 from Energy Information Administration, the annual electricity consumption per household is 10,656 kWh. In Laredo, the Space Heating, which adds up to around 4,000 kWh/year, is not fit for use. Subtracting this consumption, the average household electricity consumption in Laredo is 6,600 kWh. [4]

The annual electricity cost in Laredo is almost 850 dollars. The calculating process is shown below:

(Annual electricity consumption) × (Price of Residential Electricity per Unit)

= 6,600 × 0.1286

= 848.76

7.3 Investment Payback

7.3.1 The Electricity Bill Saving

From the information of US Department of Energy, a method to calculate the saving for a Net-Metered PV system is introduced.

(1) Determine the system's size in Kilowatts (kW) which is the value of the "**kW of PV**" in the equation below. A reasonable range is from 1-5 kW.
(2) Based on your geographic location, select the energy production factor from the map below for the "**kWh/kW-year**" input for the equation.

Energy from the PV system:
kWh/year = (**kW of PV**) × (**kWh/kW-year**)

(3) Calculate the saving by the following equation.

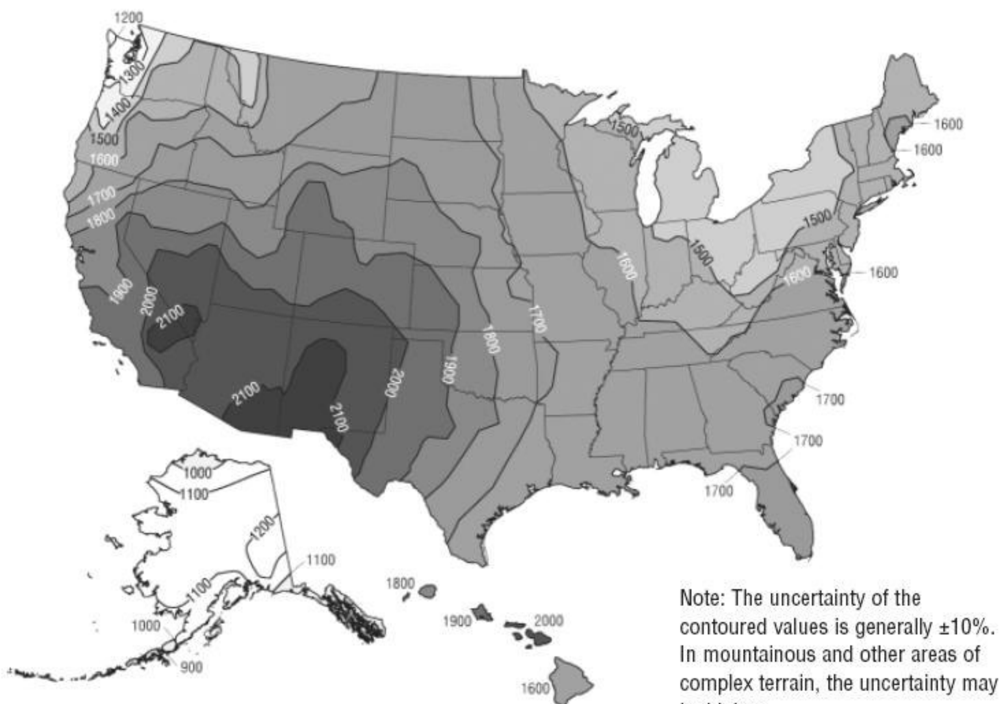
Energy bills savings
$/year saved = (**kWh/year**) × (**Residential Rate**) / 100

The residential rate in the above equation is the average retail residential rate for energy from utilities in cents per kWh. It is shown in your utility bill. Here in the equation, the unit of the residential rate should be $/kWh. For example, the residential rate in Laredo is 0.1286 $ /watt. [5]

Now here is an example of annual electricity bill savings form PV system of a family in Laredo. The electricity bill saving can be calculated as follows:

(1) Energy from the PV system
kWh/year = 5 × 1800 = 9,000 kW/ year

(2) Energy bills saving per year
$/year saved = 9,000 × 0.1286 = 1157.4
So, the annual saving from 5 kW PV system in Laredo is 1157.4 dollars.



Source: U.S. Department of Energy. A Consumer's Guide:You're your Power from the Sun. http://www.nrel.gov/docs/fy04osti/35297.pdf

7.3.2 The Investment Payback Period

Assuming after installing the solar PV system, the maintenance is free and the electricity is freely come from solar cell, the payback period can be calculated by two methods:

A. Not Concerning the Interest Rate

Payback Period = (Installation Cost) / (Energy Bills Saving)

Supposed the installation cost of a 2 kW PV system (for a very energy-efficient family) and 5 kW PV system (Completely meet the energy needs of many conventional homes) is 18,000 and 35,000, respectively. Therefore the payback period is shown in the table below.

Table 2 Payback Period not Concerning the Interest Rate

kW of PV	kWh/kW-year	kW/year	residential rate	$/year saved	installation cost ($)	payback period (year)
2	1800	3600	0.1286	462.96	18000	38.88
5	1800	9000	0.1286	1157.4	35000	30.24

The payback period for a 2 kW and 5kW PV system is up to 38 years and 30 years, respectively. However, the life span of a solar system is only around 20 years. Therefore, if there are no tax credits or other rebate policy, it is not economic to apply solar system in Laredo currently.

B. Taking the interest rate into account.

$$PV = A\frac{1-(1+r)^{-t}}{r}$$

PV: principal value
A: annual saving
r: interest rate
t: payback period

According the equation above, we could get the sensitivity analysis of the interest rate and the payback period below.

Table 3 Sensitivity Analysis of the Interest Rate and the Payback Period

Interest rate	0.5%	1%	1.5%	2%	critical value of interest rate
2 kW PV system	43.34	49.48	58.78	75.91	2.57%
5 kW PV system	32.87	36.19	40.60	46.88	3.31%

It is shown in Table 3 that the payback period increases dramatically with the increase of interest rate. The critical value of interest rate for the 2 kW PV system and 5 kW PV system is 2.57% and 3.31%, respectively. However, according to the statistics of Board of Governors of the Federal Reserve System, the average annual federal fund rate in recent 10 years is 3.78%.[6] And 3.78% is above the critical values of the interest rate. Therefore, the PV system is impossible to receive the principle investment at the interest rate of 3.78%.

7.4 The Cost Reduction Trend in the Next Two Decades

The residential solar electricity cost is around 30-40 cents per watt. [7] According to the report of Solar Photovoltaic market, cost and trends in EU, the PV electricity vision will be (1)cost be at 0.05-0.12 Euro/kWh; (2) flat plate modules up to 25% efficiency, (3)system lifetimes of 40 years, (4)energy payback times <1 year for all technologies in 2030. [3]That means a bright technology future for the PV system.

7.5 Conclusion

The cost influence factors as well as the calculation method of electricity bill saving of PV system are analyzed in this section. However, from the examples on the payback period of household PV system, we could conclude that it is not economic for dwellers to apply PV system by themselves for residential electricity currently. As we can see that there are incentive policies supported by government, the PV system will be much more attractive. What is more, with the technology advance and the cost reduction, the PV system will provide a significant part of the world’s electricity supply in the coming two decades.

References

[1] FAQ's about Residential Grid-Tied Solar Electricity. http://www.solarexpert.com/grid-tie/FAQs.html

[2] U.S. Department of Energy. A Consumer’s Guide: You’re your Power from the Sun. http://www.nrel.gov/docs/fy04osti/35297.pdf

[3] Solar Photovoltaic market, cost and trends in EU. Oct 2006. http://eneken.ieej.or.jp/en/data/pdf/368.pdf

[4] Energy Information Administration. Electricity Consumption by End Use in U.S. Households in 2001. http://www.eia.doe.gov/emeu/reps/enduse/er01_us_tab1.html

[5] Energy Information Administration. Residential Electricity Prices: A Consumer’s Guide. http://www.eia.doe.gov/bookshelf/brochures/rep/

[6] Board of Governors of the Federal Reserve System. Historical Data. http://www.federalreserve.gov/releases/H15/data.htm

[7] Solar Electricity Prices: Solarbuzz Consultancy Reports. http://www.solarbuzz.com/solarprices.htm

Chapter 8 Solar Technology in Laredo-Present and Future

Laredo is an ideal place to promote solar energy application due to the long daytime and many clear days all year round. The solar energy and surface meteorology is shown that Laredo has abundant solar energy.

Table 8.1 Laredo Solar Statistics through the Year

Variable	Jan	Feb	Mar	Api	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Insolation, kWh/m²/day	2.89	3.57	4.57	5.44	5.95	6.40	6.64	6.07	5.11	4.21	3.19	2.72
Clearness, 0 - 1	0.47	0.48	0.51	0.53	0.54	0.57	0.60	0.58	0.54	0.53	0.49	0.47
Temperature, °C	11.58	14.12	17.33	20.93	23.44	25.36	26.07	26.20	24.25	21.16	16.04	12.09
Wind speed, m/s	4.98	5.02	5.20	4.99	4.58	4.42	4.58	4.49	4.49	4.58	4.94	4.83
Precipitation, mm	20	27	10	30	57	44	22	46	75	42	25	20
Wet days, d	4.5	3.8	2.5	3.5	4.8	3.3	2.4	3.8	5.2	3.6	3.5	4.2

Source: http://www.gaisma.com/en/location/laredo-texas.html

8.1 Solar in Texas Schools

SECO (State Energy Conservation Office) has carried out the Texas Solar for Schools Program since 2001. This program has funded 31 small-scale solar energy systems ranging from 1KW to 3KW to schools in Texas. These systems has not only saved money on electric bills but also promoted the renewable energy education.

In Martin High School in Laredo, it began to use a 4KW photovoltaic system to generate power since 1999. For more information, please direct to the following links.

Watts on Schools. http://www.wattsonschools.com/sites/laredo_texas.htm
Texas Solar for Schools. http://www.seco.cpa.state.tx.us/re_solarschools.htm
Renewable Energy Education. http://www.seco.cpa.state.tx.us/re_education.htm

8.2 Local Solar System Companies

Sunbelt Solar is a solar and wind system solution provider for household and industry in Laredo. Its services include modular solar panel system, grid tied photovoltaic solution, stand alone solar system and so on. For more information, please visit the following link

http://www.sunbeltsolar.com/

8.3. Solar Energy in Public Accommodation

It was said from Laredo Development Foundation that the Environmental Services of Laredo applied for a $200,000 grant through the Department of Energy so that Laredo could launch a solar energy plan including energizing park lights or water faucets through solar energy.

Ashley Richards. 39th place starts debate.
http://www.ldfonline.org/shownews.asp?newsid=86

The Texas State Energy Conservation Office's (SECO) Renewable Energy Demonstration for Texas colonial commissioned a project which was the first solar powered RO system for municipal water in Laredo in 2003. The projected was finished by Southwest Photovoltaic System, Inc, which is a Premier Distributor for BP Solar. You may also visit the following webpage.

Solar Powered Reverse Osmosis.
http://www.southwestpv.com/Catalog/PDF/Water_RO_Laredo.pdf

8.4 Solar Energy Laboratory Research

The University of Texas at Austin conducted a project to collect the solar radiation resource for Texas. The project is supported by the State Energy Conservation Office (SECO). There are two types of solar monitoring stations instruments to obtain total solar radiation data, class I and class II. Laredo (KGNS television station) is the class II instrument sites

A software package, Texas Renewable Energy Evaluation Software (TREES), funded by SECO provided a tool to compare the economics of solar photovoltaic and wind generated electricity against conventional energy sources.

Solar Energy Laboratory Research. http://www.me.utexas.edu/~solarlab/Research.html

8.5 Summary

Initiatives have been taken to promote the applications and use of solar technology in Laredo areas. Local public schools have implemented pilot systems for educational purpose. The wide adoption of the solar technology in Laredo can not be accepted without the supports from government, industry, and community people. Given the geographical advantages in terms of sunny hours, Laredo is ready to be one of the leading cities to implement renewable energy, especially solar cells, in the US and around the world.

Chapter 9 Survey Report on the Laredo Solar Technology

The project team designed a questionnaire on the Solar System Acquaintance. In the early of August, the pretest was implemented in a mathematic class of TAMIU. The pilot surveys were sent out to 18 students. 17 questionnaires were got back. All of the questionnaires are valid.

In the late of August, the revised questionnaires containing 14 items were sent out to another group of student in TAMIU. 45 respondents answered the survey. All of the questionnaires are valid.

The questionnaire contained 14 items. The content consists of five parts:

(1) the knowledge of solar energy;

(2) the electricity cost in Laredo;

(3) the preference of solar energy implementation;

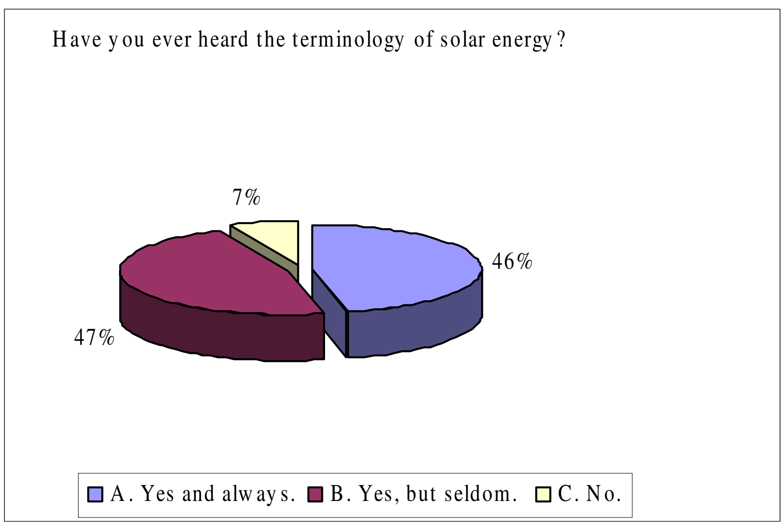
(4) the popularity of solar energy;

(5) the willingness of installing solar power system.

The results of the survey are shown below.

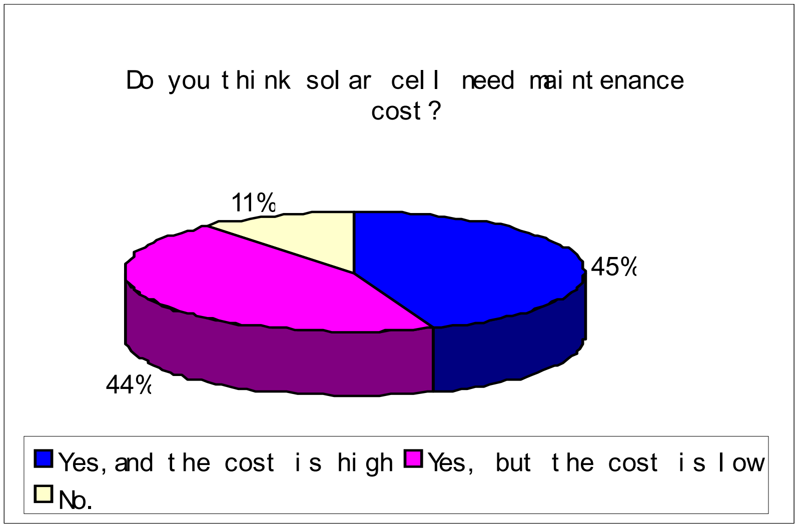
8.1 The Knowledge of Solar Energy

Q1. The acquaintance of the concept



On the question "Have you ever heard the terminology of solar energy?" almost 50% respondents chose "yes and always", and almost the same "yes but seldom". Only 7% respondents have never heard the term of solar energy. Therefore, solar energy is not a strange concept to most of consumers.

Q2 Maintenance cost

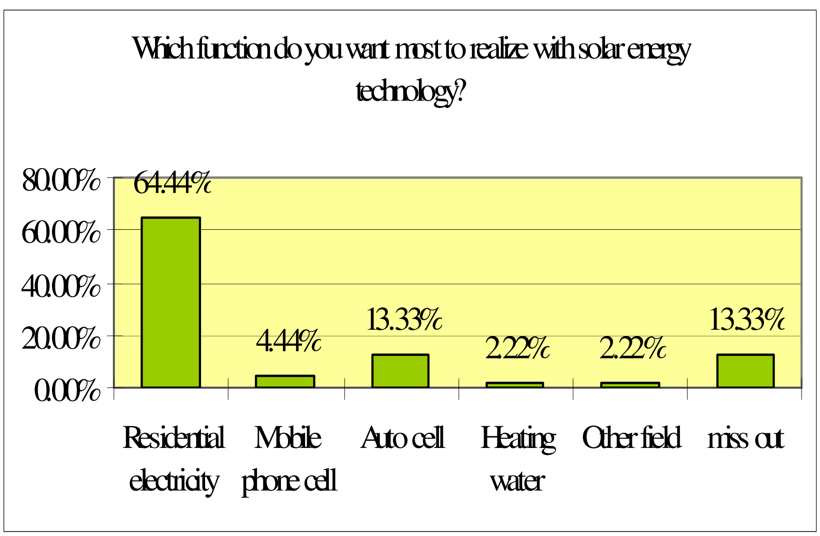


Up to 45% of respondents believed that solar cell needs high maintenance costs. Actually, solar cell almost needs very low maintenance cost.

From the result of these two questions, it can deduce that most of the respondents have a concept of solar energy. However, the acquaintance on this field is limited.

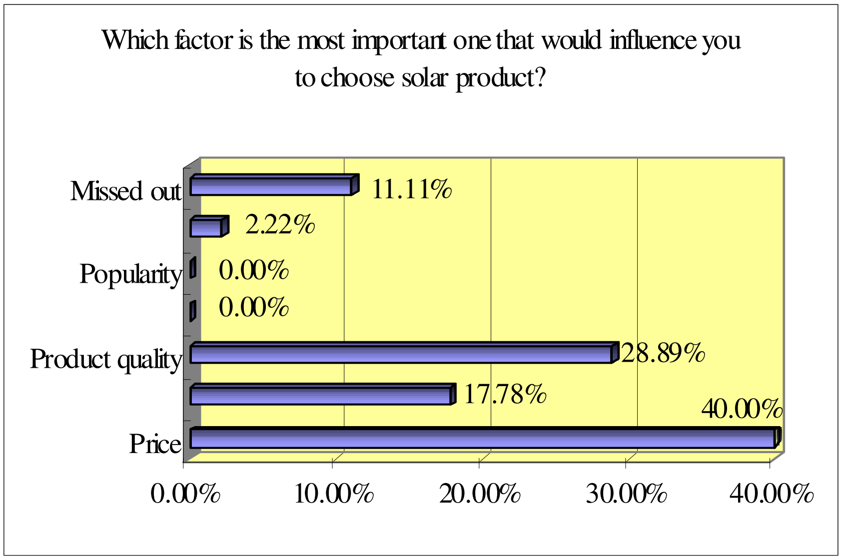
8.2 The Preference of Solar Technology

Q1 Favorite function of solar energy technology



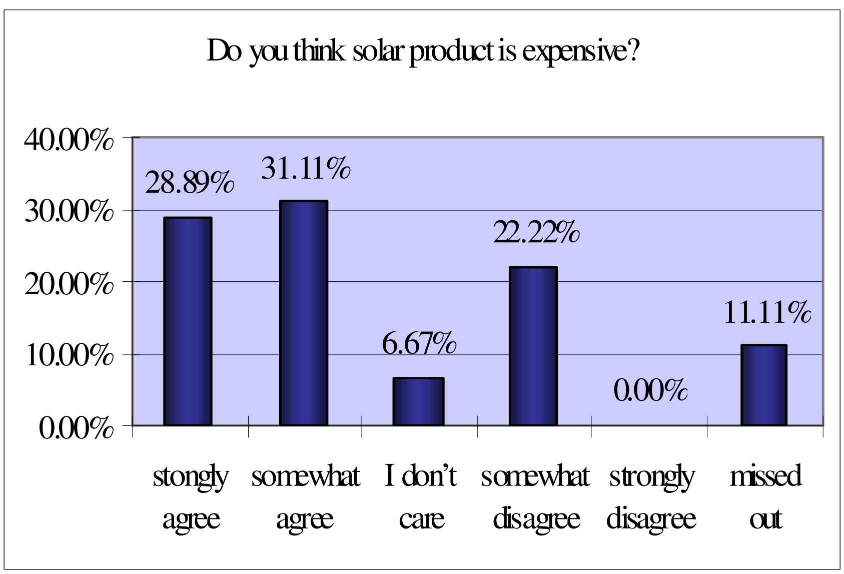
On the application of solar energy technology, residential electricity was the favorite. Almost 2/3 of the respondents chose this item. This result is the same as pilot test. We could conclude reasonable that residential electricity will be popular in residential solar application.

Q2 Which factor is the most important one that would influence you to choose solar product?



On the factor that influence purchase of solar product, price is the dominate factor. It attracts 40% of the respondents. Product quality is the secondary important factor, the percentage is almost 30%. Safety is another influencing factor. However, the product brand and popularity of the product have no influence on purchase decision.

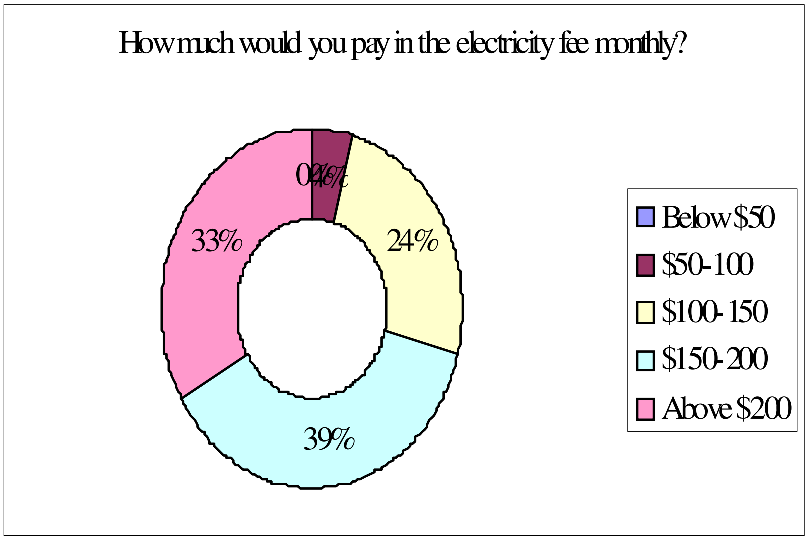
Q3. The price sensitivity



The opinions on the price of solar product were diversity. Almost 60% respondents agreed that solar product was expensive, whereas over 20% respondents thought that it was not expensive. Therefore, the price is still a sensitive factor to purchase decision of solar energy.

9.3 The Electricity Cost in Laredo

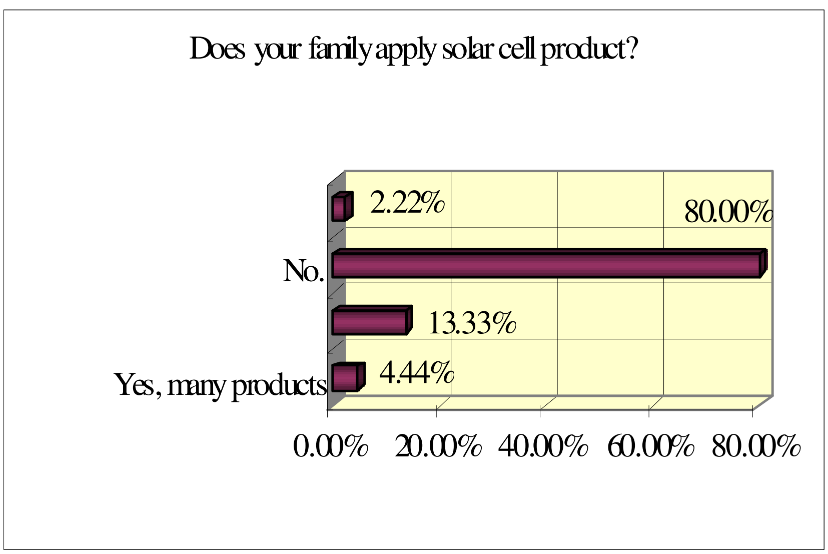
Q1 Monthly electricity fee



33% of the respondents thought that their monthly electricity fees were over $200. The proportion of monthly fee range from $150-200 is almost 40%. In other words, more that 70% of the respondents pay more than $150 utility fee monthly.

9.4 The Popularity of Solar Energy

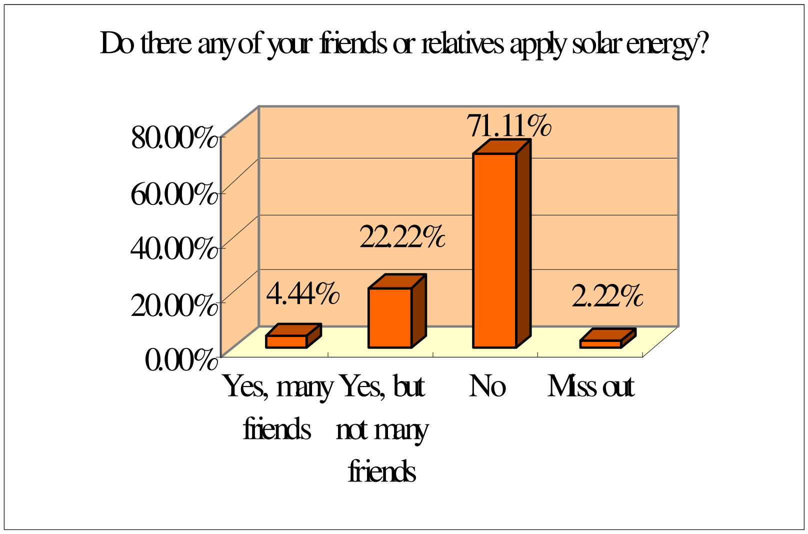
Q1 Solar cell product popularity in family



Up to four fifth of the respondents said that there was no solar product in their family. Only 5.88% family used solar product.

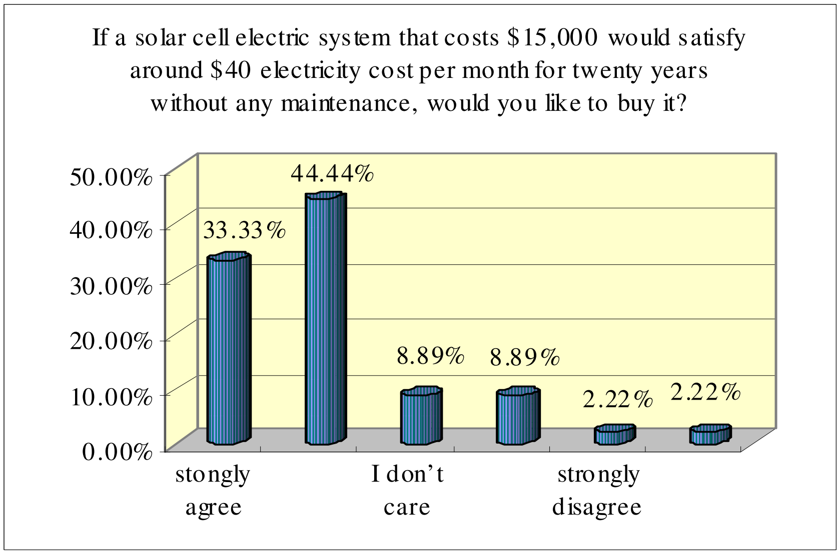
Q2 Solar energy popularity among respondents' friends and relatives

The proportion of solar energy application in respondents' friends and relatives was also low. Up to 70% of the respondents say no.



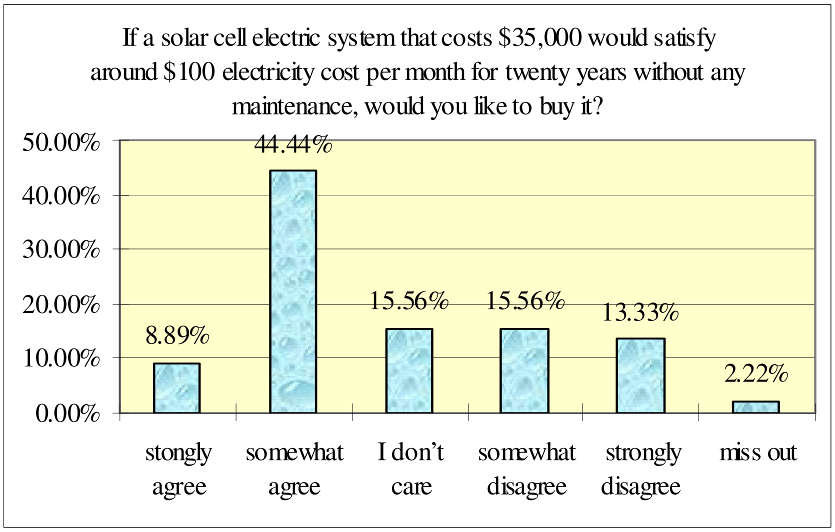
9.5 The Willingness of Installing Solar Power System

Q1 The willingness to install 2kw solar power system



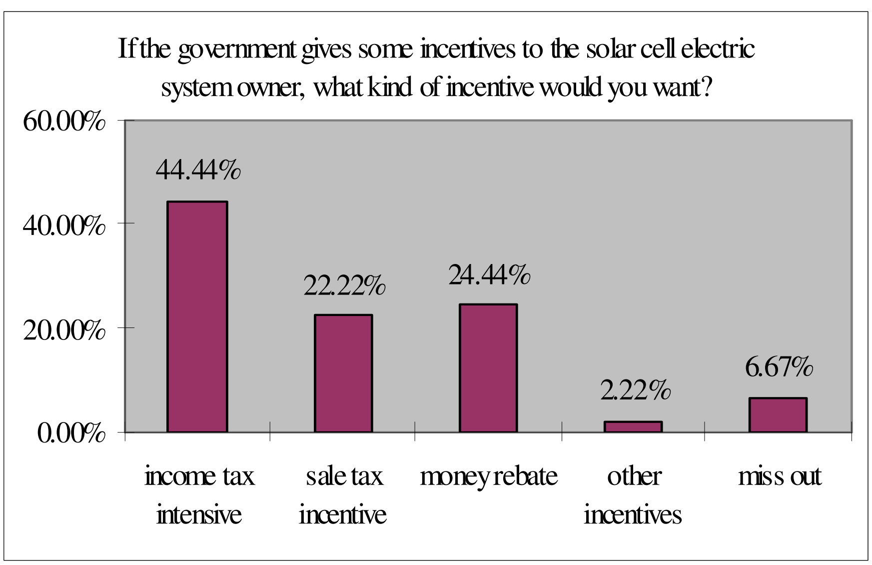
Suppose a solar cell electric system that costs $15,000 would satisfy $40 monthly electricity cost for twenty years without any maintenance, up to 75% of respondents have an attempt to buy it. That means the 2kW solar power system sounds a good deal to them. The result is almost the same as pilot test.

Q2 The willingness to install 5kw solar power system



Comparing the high value of 2kW solar power system, the likelihood to use 5kW solar power system is relative lower. However, up to 50% of respondents would like to use it. The reason may be the high price because the price is a sensitive factor for respondents as we discussed above.

Q3 The choice for incentive to solar cell electric system



On the incentive to the solar cell electric system, 40% of respondents chose income tax incentive and 20% would rather sale tax incentive. As the price is the sensitive factor to solar product purchase, more than 90% of the respondents prefer incentives.

9. 6 Conclusions

From the result of the survey, we conclude some solar energy implementation in Laredo family.

- The respondents get to know the term of solar energy. However, they had not much acquaintance on solar energy.
- The popularity of solar energy is very low. Over 70% of the respondents' family and friends do not apply solar product.
- The function of solar technology they want to use most is residential electricity.
- Price is a sensitive factor to choose solar product,. Therefore, more than 90% of the respondents welcome different kinds of incentives.
- Solar energy can only be the associate energy supply in the family to the most. More than 70% of monthly electricity costs of the responds are more than $150. However, the 5KW solar power system, which seems expensive to most respondents could just cover $100 electricity fee. Therefore, solar energy could not alternate the original electricity supply source at the present stage.

Appendix: The Survey Questionnaire

Survey of TAMIU Research Project "Solar Paints Laredo Green"
(The survey is anonymous)

1 Have you ever heard the terminology of solar energy? (   )
A. Yes, and always. B. Yes, but seldom. C No

2 Which field do you think that solar energy can be applied in? (more than one answer is permitted) (   )
A. Commercial power supply, B. Agriculture water pumping, C. Space energy supply, D. Heating water, E. Residential power supply, F. Other field, please illustrate_______ .

3 Which function do you want most to realize with solar energy technology in your daily life? (   )
A. Residential electricity, B. Mobile phone cell, C. Auto cell, D. Heating water, E. Other field, _______ .

4 Which factor is the most important one that would influence you to choose solar product? (   )
A. Price, B. Safety, C. Product quality, D. Product brand, E. Popularity, F. Other factors, _________.

5 Do you think solar product is expensive? (   )
A. Strongly agree, B. Somewhat agree, C. I don't care, D. Somewhat disagree, E. Strong disagree, F. N/A

6 Do you think solar cell need maintenance cost? (   )
A. Yes, and the cost is high. B. Yes, but the cost is low. C. No

7 How much do you pay for the electricity fee monthly in your family? (   )
A. Below $50 B. $50-100 C. $100-150 D. $150-200 E. above $200

8 What are the percentages of the electricity cost in the following appliances in your family? (make an estimation)
A. Air-conditioning (   ) % B.Fridge (   ) %
C. Heating (   ) % D.Light (   ) %
E. Others (   ) %

9 Are there any your friends or relatives apply solar energy? (   )
A. Yes, and many friends B. Yes, but not many friends C. No.

10 Does your family apply solar product? (   )
A. Yes, and many products
B. Yes, but not many products
C. No.

11.Which kind of solar technology does your family apply? (more than one answer is permitted) (   )
A. Residential electricity, B. Solar cell, C. Auto cell, D. Heating water, E. Other field, please illustrate____ .

12 If a solar cell electric system that cost **$15, 000** would satisfy around **$ 40** electricity cost per month for twenty years without any maintenance, would you like to buy it? (   )
A. Strongly agree B. Somewhat agree C. I can not make a decision
D. Somewhat disagree E. Strong disagree

13 If a solar cell electric system that cost **$35, 000** would satisfy around **$ 100** electricity per mouth for twenty years without any maintenance, would you like to buy it? (   )
A. Strongly agree B. Somewhat agree C. I can not make a decision
D. Somewhat disagree E. Strong disagree

14 If the government gives some incentives to the solar cell electric system owner, what kind of incentive would you want? (   )
A. Income Tax incentive, B. Sale tax incentive, C. Money rebate, D. Other incentive, please illustrate