Pilot Solar Thermal Power Plant Station in Southwest Louisiana

Terrence Chambers[1], Jonathan R Raush[1], G.H. Massiha[2]
[1] Departement of Mechanical, College of Engineering, University of Louisiana at Lafayette, Lafayette, LA 70504, USA
[2] Department of Industrial Technology, University of Louisiana at Lafayette, Lafayette, LA 70504, USA

Article Info

Article history:

Received Nov 30, 2012
Revised Jan 28, 2013
Accepted Feb 10, 2013

Keyword:

Alternative energy
Feasibility study
Fifth keyword
Power Plant
Solar Thermal

ABSTRACT

Solar thermal plants are basically power plants that generate electricity from high-temperature heat. The difference between them and conventional power plants is that instead of deriving energy from gas, coal or oil, the sun provides the energy that drives the turbines. In this paper we will give a brief demonstration of solar thermal power and different system designs of solar thermal power plants. Then we will see the feasibility of implementing solar power plants in Louisiana which currently depends mostly on its conventional power plants which use traditional fuels such as gas, oil, and coal. This study was a part of a proposal that was funded by the US the Department of Energy to construct solar thermal plant near Lafayette, Louisiana. The power plant is currently under the construction and it will be completed by Summer of 2013.

Corresponding Author:

Dr. G.H. Massiha,
Department of Industrial Technology,
University of Louisiana at Lafayette,
Lafayette, LA 70504, USA.
Email: Massiha@louisiana.edu

1. INTRODUCTION

Energy flows from many sources and exists in a variety of interchangeable forms, and drives all systems. It is fundamental to the quality of our lives and today, we find ourselves totally dependent on an abundant and uninterrupted supply of energy for living and working. It is undoubtedly the key ingredient in all sectors of modern economies.

Fossil fuels and nuclear technologies which have been the main source of global energy production since the beginning of the 1970's, have left behind a legacy of thousands of coal, natural gas, and oil fired power plants spread across the world. The carbon gas emissions and non-degradable nuclear waste produced by these plants have caused dangerous environmental problems such as the greenhouse effect which led to the depletion of ozone followed by global warming and climate change. These energy production methods are non-sustainable. So let's look forward to sustainable energy production methods utilizing renewable energy sources that are clean, cheap and 'green'.

Solar energy is radiant energy produced by the Sun. Each day more solar energy hits the Earth than the total energy that all the inhabitants of the planet would consume in 27 years. Today, people use the sun's energy for lots of things. Solar energy can be converted to thermal (or heat) energy and used to heat water for use in homes, buildings, or swimming pools and to heat spaces inside greenhouses, homes, and other buildings.

Clean energy from the sun can replace power sources that pollute the environment. The few emissions of greenhouse gases or air pollutants generated by solar energy technologies occur mostly during the manufacturing process. A 100-megawatt solar thermal electric power plant, over its 20-year life, will avoid more than 3 million tons of carbon dioxide (CO2) emissions when compared with the conventional fossil fuel-powered electric plants available today according to Future Timeline (2011). Solar energy can be converted to electricity in two ways. The first is Photovoltaic (PV devices) or “solar cells” which change sunlight directly into electricity. PV systems are often used in remote locations that are not connected to the electric grid. They are also used to power watches, calculators, and lighted road signs etc. The second one is Solar Thermal Power Plants which indirectly generate electricity when the heat from solar thermal collectors is used to heat a fluid which produces steam that is expanded through a turbine to drive an electrical generator. This paper mainly discusses solar thermal power and various solar thermal power plant technologies. Then we will examine the relevant data with regard to the feasibility of these plants in Southwest Louisiana.

2. SOLAR THERMAL POWER

Solar thermal power uses direct sunlight, so it must be sited in regions with high direct solar radiation. Suitable sites should offer at least 2,000 kilowatt hours (kWh) of electricity per m^2 of sunlight annually, while the best sites offer more than 2,500kWh/m^2 according to National Renewable Energy Lab (NREL) web site (2011). Typical locations, where the climate and vegetation do not offer high levels of atmospheric humidity, include steppes, bush, savannahs, semi-deserts and true deserts, ideally located within ±40 degrees of latitude. Among the most promising areas of the world are therefore the South-Western United States, Central and South America, Africa, the Middle East, the Mediterranean countries of Europe, Iran, Pakistan and the desert regions of India, the former Soviet Union, China and Australia. In many regions of the world, one square kilometer of land is enough to generate as much as 100-200 Gigawatt-hours (GWh) of solar electricity per year using solar thermal technology. This is equivalent to the annual production of a 50 MW conventional coal or gas-fired power plant. Over the total life cycle of a solar thermal power system, its output would be equivalent to the energy contained in 16 million barrels of oil. Worldwide, the exploitation of less than 1% of the total solar thermal potential would be enough to meet the recommendations of the United Nations’ Intergovernmental Panel on Climate Change (IPCC) for the long-term stabilization of the climate and) and Union of Concerned Scientists (2011).

Over 700 megawatts of solar thermal electric systems were deployed. The market for these systems exceeded 5,000 megawatts by 2010 according to NREL energy analysis, enough to serve the residential needs of 7 million people which will save the energy equivalent of 46 million barrels of oil per year. Moreover Solar thermal power plants create two and one-half times as many skilled, high paying jobs as do conventinal power plants that use fossil fuels.

Producing electricity from the energy in the sun’s rays is a relatively straightforward process. Direct solar radiation can be concentrated and collected by a range of Concentrating Solar Power (CSP) technologies to provide medium to high temperature heat. This heat is then used to operate a conventional power cycle, for example through a steam or gas turbine. Solar heat collected during the day can also be stored in liquid, solid or phase changing media like molten salts, ceramics, concrete, or in the future, phase changing salt mixtures. At night, it can be extracted from the storage medium to run the power generation plant. Current CSP technologies include parabolic trough power plants, solar power towers and parabolic dish engines.

Solar energy has enormous potential as a supplement or alternative to fossil fuels for serving energy markets in the Unites States and many third world nations as it reported in many references such as Elizabeth Bast and Srinivas Krishnaswamy (2011). In the near term, solar energy can reduce demand for natural gas used by utilities to generate electricity. The goal is for the cost of solar energy to be competitive with fossil fuels. It is projected that by 2020, the intermediate load electricity will be 10 to 16 cents/kWh, Price of Oil (2011. Solar must be at or below the cost of fossil fuels if it is going to play a major role in the market.

2.1 Suitable Places in USA

As described before, suitable sites should offer at least 2,000 kilowatt hours (kWh) of electricity per m^2 (kWh/m^2/day) of sunlight annually; that means they should offer at least 5.5-6.0 kWh of electricity per day per m^2 area [2,000 / 365 = 5.5]. One good source of optimal solar home design is provided by Peter Gevorkian (2008) in Solar Power in Building Design. Figure1 show the solar radiation across the United States of America. From this it is known that southwestern states are good for solar thermal power production. They are Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah. State of Louisiana falls under next best category with 4.5-5.0 kWh/m^2/day.

U.S Department of Energy has done a study on southwestern states shown is Reports to Congress (2007) and found that they have suitable lands capable of producing 6800GW. The details of their study are as follows.

Table 1: Solar Capacity in Southwestern States

Site	State	Land Area (m^2)	Capacity (GW)	Generation (GWh)
1	AZ	19,279	2,467,663	5,836,517
2	CA	6,853	877,204	2,074,763
3	CO	2,124	271,903	643,105
4	NV	5,589	715,438	1,692,154
5	NM	15,156	1,939,970	4,588,417
6	TX	1,162	148,729	351,774
7	UT	3,564	456,147	1,078,879
8	Total	53,727	6,877,055	16,265,611

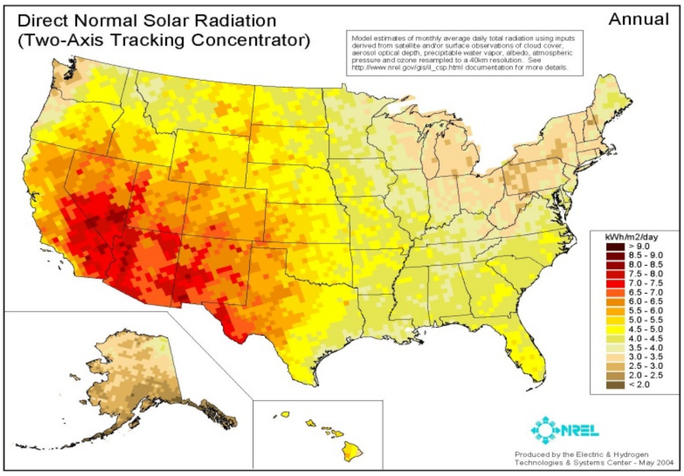

Figure 1. Direct Normal Solar Radiation on U.S.A. in kWh/m2/day, Produced by NREL (2011)

These numbers were based on a Geographic Information Systems analysis to identify candidate areas in the Southwest. Several filters were used to determine which land was suitable for CSP plants:

• Only lands with an average daily solar resource of 6.75 kWh/m^2 or above
• 500 contiguous acres of land minimum
• Land with 1 percent or less slope
• Excluded designated urban areas, national parks, national preserves, wilderness areas, wildlife refuges, or water.

2.2 Parabolic Trough

Parabolic trough-shaped mirror reflectors (Figure 2) are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough focal line. In these tubes a thermal transfer fluid is circulated, such as synthetic thermal oil heated to as much as 400°C by the concentrated sun's rays. This oil is then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator. Of the various solar thermal power plant technologies, only parabolic trough technology has yet achieved market maturity. A typical photograph of solar field of a parabolic trough power plant is given in Figure 2, Renewable Energy World (2011).

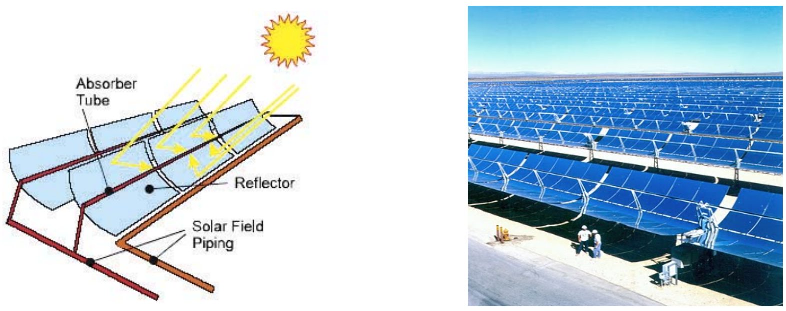

Figure 2. Parabolic Trough CSP System and Parabolic Trough System at Arizona

2.3 Cost Components in Constructing a Solar Trough Plant

The major cost contributors in direct cost of a parabolic trough solar plant with thermal storage are the solar collector field (53%), thermal storage system (23%), and power block (14%), as shown in Figure 4. The major component costs in the solar field are illustrated in Figure5. The key cost elements in the solar field are the receiver (20%), the mirrors (19%), and the concentrator structure (29%) according to studies done by Sargent & Lundy LLC Consulting Group for NREL (2003).

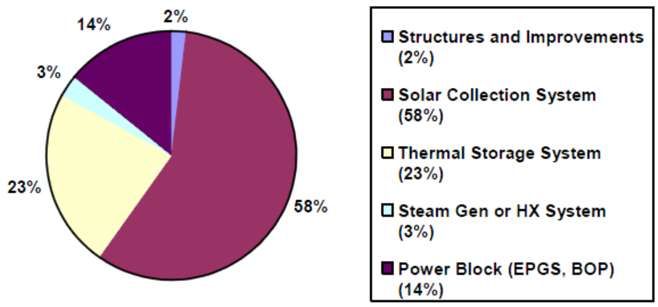

Figure 3. Major Cost Categories for Parabolic Trough Plant 2004 Near-Term Case: 100 MWe, NREL (2011)

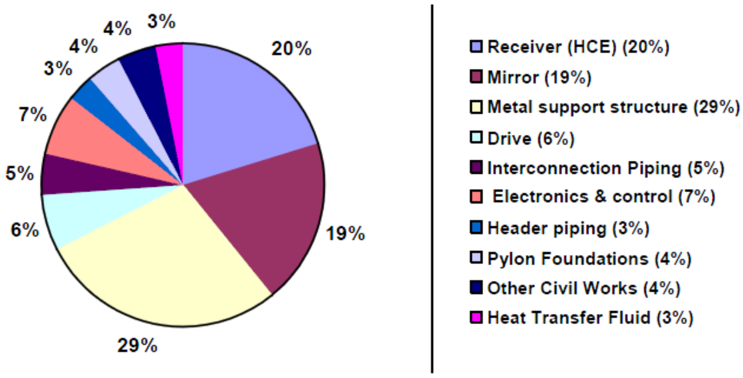

Figure 4. Solar Field Component Cost Breakdown for Parabolic Trough Plant 2004 Near-Term Case: 100 MWe, 12 hours TES, 2.5 Solar Multiple, NREL (2011)

The table given below lists some solar trough power plants in USA and their details. All were constructed by Solargenix & ACCIONA Energy.

Table 2 List of Solar Trough Power Plants and their details in USA, NREL (2011)

Site	Plant Name	Capacity (MW)	Solar Field Area(m^2)	Total Area(m^2)	Location	Investment ($million)	Year of Operation
1	SEGS IX	80	483,960	1,690,000	Harper Lake, CA	275.2	1991
2	SEGS VIII	80	464,340	1,620,000	Harper Lake, CA	231.2	1990
3	Nevada Solar One	64	357,200		Boulder City, NV	266	2007
4	SEGS VII	30	194,280	680,000	Kramer Junction, CA	116.1	1989
5	SEGS VI	30	188,000	660,000	Kramer Junction, CA	116.1	1989
6	SEGS V	30	250,500	870,000	Kramer Junction, CA	123.9	1988
7	SEGS IV	30	230,300	800,000	Kramer Junction, CA	111.9	1987
8	SEGS III	30	230,300	800,000	Kramer Junction, CA	108	1987
9	SEGS II	30	190,338	670,000	Daggett, CA	96	1986
10	SEGS I	13.8	82,960	290,000	Daggett, CA	61.9	1985
11	APS Saguaro	1	10,340	101,171	Saguaro, AZ	5	2006

2.4 Central Receivers

Central receivers, or power towers, consist of a central tower surrounded by a large array of mirrors or heliostats as shown in Figure 5, Department of Energy (2011). The heliostats are flat mirrors that track the sun on two axes (east to west and up and down). The heliostats reflect the sun’s rays onto the central receiver. The sun’s energy is transferred to a fluid: water, air, liquid metal and molten salt have been used. This fluid is then pumped to a heat exchanger or directly to a turbine generator.

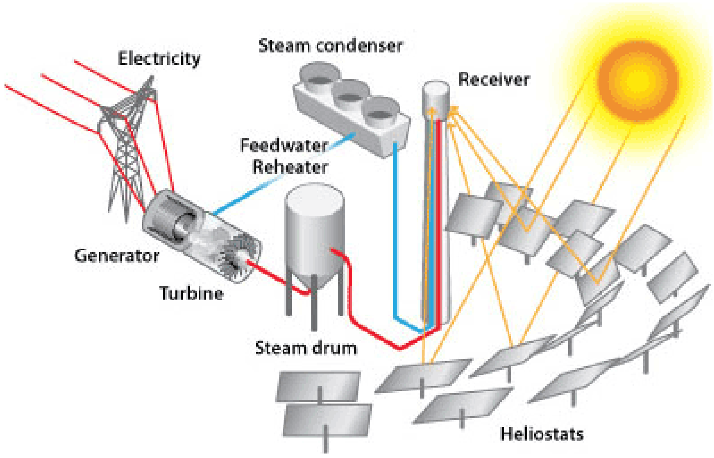

Figure 5. Central Receiver system

3. COST COMPONENT IN PLANTS

The cost components in constructing the Central Receiver Power Plant are as shown in the above Figure 6. The solar field, electric power block, and receiver encompass approximately 74% of the total direct cost. The major cost component is the heliostat field, which encompasses 43% of total cost. The next three categories are electric power block, 13%; receiver, 18%; and balance-of-plant, 6%, NREL (2011).

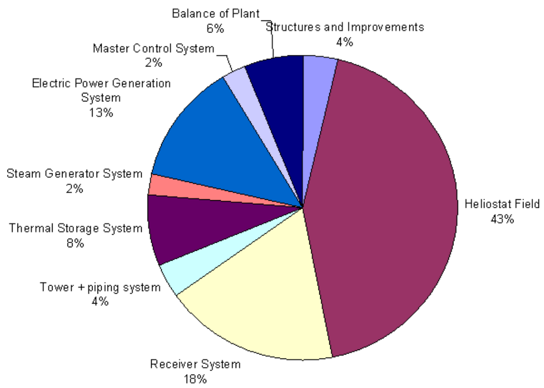

Figure 6. Major Cost Categories for Central Receiver Plant 2004 Near Term

Table 3: List of Central Receivers Plants and their Details Around the World

Site	Plant Name	Capacity (MW)	Solar Field Area (m^2)	Total Area (m^2)	Location	Investment ($millions)	Year of Operation	Constructed By
1	Solar One	10	72,500		Daggett, California		1982-1986	Department of Energy
2	Solar Two	10	82,750		Daggett, California	48.5	1994-1999	Department of Energy
3	Solar Tres	17	285,200	1,423,100	Ecija, Spain			GEMASOLAR
4	PS10 Solar Power Tower	11	75,000	600,000	Seville, Spain	44.43	2007	Solucar

3.1 Cost Reduction Techniques

Due to the high capital investments, the overall unit cost of electrical energy produced by solar thermal energy is high compared to electrical energy produced by conventional methods. A lot of research work is going on to reduce this cost. The unit energy cost can be reduced by some techniques described below.

1. Reducing the component and system costs by improved design and manufacturing techniques.
2. Improving the plant efficiency
3. Increasing the number of full load hours by the installation of thermal storage.

4. Reducing the operation and maintenance costs by extended operation, increased operating life, and reduced maintenance requirements.

3.2 Necessity in Louisiana

The state of Louisiana mainly depends on the conventional methods to produce electrical energy. The total Louisiana's electrical power industry net generation by energy source for year 2006 is given below according to Louisiana Department of Natural Resources (2007).

Table 4: Louisiana Electric Energy Generation Profile

Energy Source	**Generated Energy (GWh)**
Coal	24,379
Petroleum	1,851
Natural Gas	40,499
Other Gases	2,342
Nuclear	16,735
Renewable	3,744
Other	1,370
Total	90,922

Renewable energy source	**Generated Energy(GWh)**
Geo-thermal	0
Hydro conventional	713
Solar	0
Wind	0
Wood/Wood waste	2,950
MSW Biogenic/Landfill Gas	0
Other biomass	81
Total	3,744

From this it is can be seen that only 4% of total energy is produced by renewable energy sources and there is no usage of solar power. Every state must increase its renewable energy capacity for the future. Comparing to southwestern states, Louisiana has less opportunity to use solar power. The average electrical energy that can be produced by solar trough and solar tower technology in some cities is calculated based on the average solar radiation in those cities. The below table shows this information and all the numbers are in $kWh/m^2/day$.

Table 5: Solar Capacity in Some Cities of Louisiana, NREL (2011)

City	Average Solar Radiation	Electrical energy by Solar Trough systems	Electrical energy by Solar Tower systems
Lake Charles	4.93	0.986	1.133
New Orleans	4.92	0.984	1.131
Shreveport	4.63	0.926	1.065

These numbers show that the state of Louisiana also has the considerable capability to produce electrical energy from solar energy. These values will improve with technology improvements. So this is the right time for Louisiana to think about the solar power. The plant installation for University of Louisiana at Lafayette project is under way on five acres of land that was donated to the university by the City of Crowley (north of Lafayette), Louisiana.

3.3 Assessment of Levelized Energy Cost for Trough and Tower Technologies

With the present technology Louisiana is suitable for small solar thermal power plants. Sargent & Lundy LLC Consulting Group (2003) developed cost models estimating the levelized energy costs for both solar trough and central receiver plants for the future for NREL.

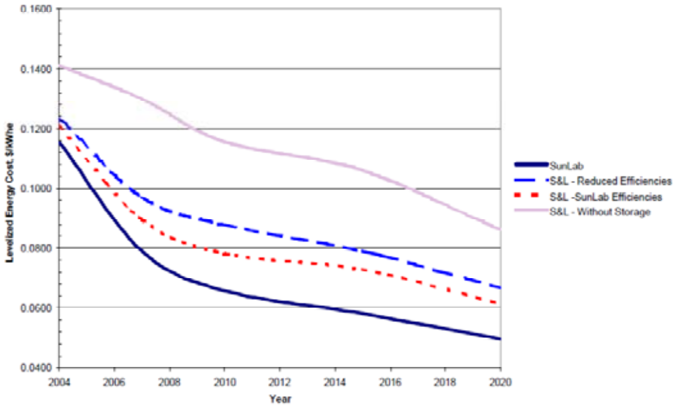

Figure 7. Trough Levelized Energy Cost

From the above graphs we can see that CSP technology is a proven technology for energy production as there is a potential market for CSP technology. Even though CSP technology is currently more expensive than the conventional fossil-fueled technology, significant cost reductions are achievable assuming reasonable deployment of CSP technologies.

4. CONSTRUCTION PHASE

US Department of Energy funded the proposal for construction of a small solar thermal power plant in January of 2011. The power plant will be located north of Lafayette, Louisiana and the construction started July 2012. The UL project is expected to create or retain 2.29 full-time equivalent jobs, produce 171,806 kWh of energy annually, and provide a learning environment for students majoring in technology and engineering.

The University of Louisiana and CLECO Power LLC (Energy Company located in south central Louisiana) are collaborating on the construction of this pilot scale solar thermal power plant from the beginning. This power plant will be capable of producing 20 kW electricity supplied to the grid. This plant will be first of its kind in Louisiana and provide valuable research by investigating the feasibility of solar thermal power in Louisiana.

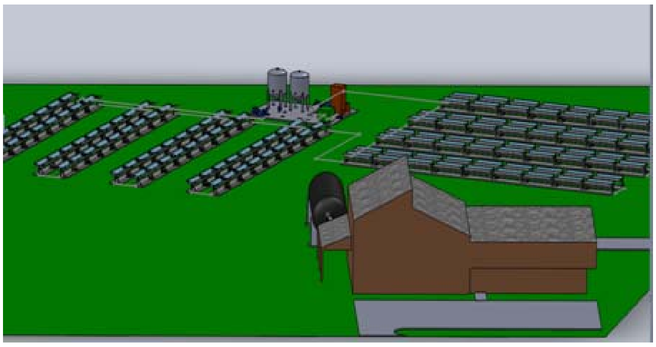

Figure 8. UL Lafayette Solar Power farm plant in Lafayette, Louisiana

Figure 9. UL Lafayette Solar Power Construction in its early stage, Nov 2012.

5. CONCLUSION

The aim of this paper is to demonstrate the two main technologies that can convert solar energy into thermal energy and then into electrical energy. Solar thermal power plants are needed in order to meet the growing demand of electricity, to take care of the shrinking fossil resources and to reduce the CO_2 emissions. Many developing countries are trying to use their abundant natural energy – solar radiation - in order to reduce their reliance on fossil fuels. Louisiana which is a developing state mainly depends on conventional plants for its electricity. As there is always an increase in need of energy, it is the best time for the state of Louisiana to look forward for the solar thermal energy as it is suitable and has considerable resources for constructing solar plants. At present, the solar levelized energy cost is relatively high compared to conventional electrical power generation methods. This will be reduced in the future by technology improvements and mass production.

REFERENCES

[1] Energy Works. 2011. solar-wind-nature-energy.com/solar_thermal.html.
[2] Department of Energy. 2011. http://www.eere.energy.gov/basics/renewable_energy/.
[3] Direct Normal Solar Radiation image from http://ocw.mit.edu/NR/rdonlyres/Mechanical-Engineering/2-626Fall-2008/3AC7D468-4E86-488D-8453-00F28136297/0/lecture1.pdf.
[4] Elizabeth Bast and Srinivas Krishnaswamy. 2011. Access to Energy for the Poor: The Clean Energy Option, http://priceofoil.org/wp-content/uploads/2011/06/Access-to-Energy-for-the-Poor-June-2011
[5] Future Timeline. 2011. http://www.futuretimeline.net/21stcentury/2020-2029.htm
[6] Louisiana renewable electricity profile. 2007 edition. http://dnr.louisiana.gov/assets/docs/energy/electricity/electric_generation_20071228.pdf
[7] National Renewable Energy Lab. 2011. http://www.nrel.gov/learning/.
[8] Renewable Energy World, Parabolic Trough System at Arizona, image from http://www.renewableenergyworld.com-/rea/news/article/2004/03/first-solar-trough-plant-since-1990-underway-10800.
[9] Peter Gevorkian. *Solar Power in Building Design, The engineer's complete design resource*, 2008.
[10] Price of Oil. 2011. http://priceofoil.org
[11] Report to congress on "Assessment of potential impact of concentrating solar power for electricity generation", (EPACT 2005 – SECTION 934(C)), U.S. Department of Energy, 2007.
[12] Sargent & Lundy LLC Consulting Group for National Renewable Energy Laboratory. *Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts*, 2003. http://www.nrel.gov/docs/fy04osti/34440.pdf

BIOGRAPHIES OF AUTHORS

Dr. Terrence L. Chambers serves as Associate Dean of Engineering at the University of Louisiana at Lafayette. His research interests include engineering optimization, artificial intelligence, virtual reality, and alternative energy. He is the author of numerous papers, and has been awarded roughly three million dollars in externally funded research grants.

Jonathan Raush, M.S. MCHE, is a Research Scientist in the Department of Mechanical Engineering in the University of Louisiana at Lafayette College of Engineering. His primary responsibilities include oversight of the construction and operation of the pilot scale Solar Thermal Power Plant being developed at the CLECO Alternative Energy Center. His research interests include Alternative Energy Conversion, Thermodynamics, Cogeneration, Heat Transfer, Fluid Mechanics, Fuel Cells, , and Mechanical Failure Analysis.

G. H. Massiha, Ph.D., is a Louisiana Board of Region Professor of Engineering. His areas of research interest are alternative energy, robotics, and automation manufacturing.