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START Report 2/98

START Mission to Brazil

May 5-9, 1997

Final Report by Patricia Cordeiro

MINISTÉRIO DE MINAS E ENERGIA

CEPEL ELETROBRÁS SYSTEM

Weizmann Institute of Science מכון ויצמן למדע

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IEA SolarPACES START Mission to Brazil

May 5-9,1997

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-ACO4-94AL85000.

Preface

Since 1977, the SolarPACES community has pursued a focused program of RD&D in the field of solar thermal power. The systematic development of three plant types (trough, tower and dish) has led to the brink of their commercialization, which is now possible in a power range from a few kilowatts to hundreds of megawatts. Plants can function in grid-connected, stand-alone or remote applications and are suitable for hybrid operation, particularly with natural gas. They are applicable in all regions of the globe having high direct normal solar insolation, including large areas of Africa, Australia, China, India, the Mediterranean, the Middle East, the Southwestern United States and Central and South America.

In October, 1995, the concept of the START Mission (START stands for Solar Thermal Analysis, Review and Training) was developed. The goal of these Missions is to help nations in the above mentioned regions develop a rational approach to the deployment of solar thermal electric systems within their country.

Each Mission means the concentrated joint effort of an international team of SolarPACES experts and representatives from their respective country, and may include:

- analyses of appropriate solar thermal power technologies
- review of specific sites for solar thermal power projects
- review of the terms of reference for detailed feasibility and implementation studies
- development of a concept of financial engineering based on the applicable law
- identification of potential funding sources and options for specific projects
- comparison of power generation costs in the country.

The START Missions are one way in which SolarPACES member countries are presently undertaking to fulfill their strategic objective of reducing the financial, political, commercial and institutional hurdles to market development of solar thermal technologies. These efforts are jointly sponsored by members designated by the governments of ***Australia, Brazil, Egypt, France, Germany, Israel, Mexico, Russia, Spain, Switzerland,*** *the* ***United Kingdom*** and the ***United States of America***, with membership in SolarPACES presently under discussion in several other countries.

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ACRONYMS

ANEEL	National Agency for Electrical Energy
BNDES	Brazilian Economic and Social Development Bank
CC	Combined Cycle
CEMIG	Minas Gerais Electric Energy Company
CEPEL	Electric Energy Research Center
CEPISA	Piauí Electric Energy Company
CERJ	Rio de Janeiro Electric Energy Company
CESP	São Paulo Electric Energy Company
CHESF	São Francisco Hydroelectric Company
CPC	Compound Parabolic Concentrator
CPFL	São Paulo Light and Power Company
DIAPR	Directly Irradiated Annular Pressurized Receiver
DLR	German Aerospace Research Center
DNAEE	Brazilian National Department of Water and Electrical Energy
ELECTROPAULO	São Paulo Electric Energy Company
ELETRONORTE	North Brazil Electric Energy Company
ELETROSUL	South Brazil Electric Energy Company
EPGS	Electric Power Generating System
FLHIP	Frustum-Like High-Pressure
FURNAS	Furnas Electric Energy Company
GEF	Global Environmental Facility
GNP	Gross National Product
IADB	Inter-American Development Bank
IADB SMSE	Inter-American Development Bank Sustainable Markets for Sustainable Energy
IEA	International Energy Agency
IPP	Independent Power Producers
ISCCS	Integrated Solar Combined Cycle System
MDA	McDonnell Douglas Corporation, USA
MME	Brazilian Ministry of Mines and Energy
O&M	Operation and Maintenance
OECD	Organization for Economic Cooperation and Development

PDF	Program Development Fund
PRODEEM	Brazilian Energy Development Program for States and Communities
PV	Photovoltiacs
R&D	Research and Development
RD&D	Research, Design and Development
SBP	Schlaich, Bergermann and Partner (Germany)
SCOT	Solar Concentration Off-Tower
SCOT/CC	Solar Concentration Off-Tower Combined Cycle
SEGS	Solar Electric Generating System
SolarPACES	Solar Power and Chemical Energy Systems
START	Solar Thermal Analysis, Review and Training
STE	Solar Thermal Energy
SunLAB	Partnership between Sandia National Laboratories (SNL) and National Research Energy Laboratory (NREL)
UNDP	United Nations Development Program
WB GEF	World Bank Global Environment Facility
WIS	Weizmann Institute of Science (Israel)

START MISSION EXECUTIVE SUMMARY

Mission Background

Brazil START Mission Purpose

Brazil first entered into contact with the International Energy Agency, Solar Power and Chemical Energy Systems (IEA/SolarPACES) in 1995 and, sponsored by the Ministry of Mines and Energy (MME), became a SolarPACES member in 1996. The ministry anticipated cooperation with other SolarPACES members interested in demonstrating and developing power towers, dish systems and parabolic troughs and requested a START Mission to Brazil. A full review of the need for new energy in Brazil and the changes in technology would contribute to the identification of possible implementation of solar thermal electric generation in Brazil. The purpose of the mission was to brief Brazilian research centers, electric utilities, and the energy ministry regarding the techno-economic status of solar thermal technologies and to explore the possibility of building solar thermal power plants in Brazil.

Brazil START Mission Activities

During the week of May 5th, 1997, a START team composed of IEA/SolarPACES representatives from the US, Germany, Spain and Israel visited Brazil. The host of the mission was the Brazilian Centro de Pesquisas de Energia Elétrica (CEPEL), an institution similar to the USA's Electric Power Research Institute, located in Rio de Janeiro.

The START team visited two proposed solar sites, reviewed the associated insolation data, and performed a first-cut systems analysis based on this data. CEPEL organized an International Solar Thermal Workshop to take place during the START Mission, which included START Team presentations on technology, economics, proposed plants, and the analyses of Brazilian meteorological data and possible solar sites. Brazilian researchers and officials presented information on energy demand, financing, private and government markets, and past studies of solar thermal development. The team met with Companhia Energética de Minas Gerais (CEMIG), the electric company of the state of Minas Gerais, to exchange information on energy resources and options, and also demonstrated various software tools to researchers at CEPEL's laboratories in Rio de Janeiro.

Mission Findings

Electric Power Production

The current installed capacity of 55.5GW, 93% of which is hydroelectric, is increasingly being complemented by thermal plants. Thermal plants have historically only been used in Brazil for isolated areas, and for supplement during dry hydrologic periods or during supply problems caused by transmission constraints. Recently, growing environmental concerns regarding the untapped hydro potential, including the Amazon River Basin, have made hydroelectric power plant locations more difficult to obtain.

The MME governs Brazil's energy policy and all development of energy resources. The current regulatory agency is the National Agency for Electrical Energy (ANEEL). Centrais Elétricas Brasileiras S.A. (ELETROBRÁS), partly owned by the federal government, is the central utility that finances and oversees programs for building and operating power systems. ELETROBRÁS has been the major shareholder in all the power generating companies. ELETRONORTE, CHESF, FURNAS, and ELETROSUL supply distributor facilities and several large industrial consumers. There are also local government utilities engaged in distribution.

Brazil enacted legislation in 1995 allowing the sale of government-owned electric generation assets. New construction under The 1995/2004 Expansion Plan calls for self-production and independent power production exclusively.

Currently, 20 million Brazilians lack electric service. It is expected that the demand for electricity in Brazil will double in the next 10-12 years and expansion required through 2006 could total 26-45GW, a 4-6% annual growth.

Solar Thermal Resource

Brazil has extensive, semi-arid regions receiving direct normal insolation on the order of 6kWh/m^2 daily. The greatest radiation potential is in the São Francisco River Basin and the Sobradinho area in the Northeast. Potential sites in Brazil are close to the equator and this has an optical advantage.

Immense land areas are available for solar thermal applications. Januária and Itacarambi (two START Team sites visited) have excellent topographic conditions, grid access, cooling water, road access, low wind speeds, and moderate ambient temperatures with little daily variation. These sites receive annual solar direct radiation between 1800 and 2300 kWh/m^{2}a and can easily accommodate large-scale solar power plants.

Brazil has monitored global radiation for the past twenty years and began monitoring direct normal radiation, a value necessary for studying solar concentrating technologies, in the past ten years. Studies have also produced correlations between the two values in order to benefit from the extensive global radiation databases available.

Solar Thermal Project Options

CEPEL and others have identified off-grid villages, irrigation loads, and grid-connected power for cities as the market for solar thermal power plants in Brazil. Plants would optimally be located along the São Francisco River and in the Northeast. The size of proposed plants are from 10s of kW to approximately 100MW. Trough, tower, and dish solar thermal technologies could be deployed.

With over 80 plant-years of experience, parabolic troughs are the most mature solar thermal technology for large grid-connected systems. Performance continues to improve while annual operation and maintenance costs are dropping. From 1990 to 1991 CEMIG studied the possibility of building an 80MW solar trough power plant and estimated that the cost of energy would be US$114/MWh, compared to US$50/MWh for hydroelectric and US$75/MWh for conventional thermal plants. The investment cost for solar included US$70-million in taxes and US$46-million in interest during construction. Current tax policy does not provide subsidies or tax-equity provisions for solar thermal generation, but rather heavily penalizes solar thermal power projects in comparison to hydro and fossil generation.

Several dish-Stirling prototypes have been successfully operated in a number of countries, but large-scale deployment of dish-Stirling has not yet occurred. The 25kW systems that have been tested convert sunlight to electricity at a net efficiency of slightly under 30%. Assuming an annual production rate of a few thousand units per year, projections for levelized energy cost of a 25kWe dish-Stirling system range from US$90-130/MWh. Dishes with 8-10kWe ratings have also been developed. Currently, next generation systems are undergoing research and development in the USA and Europe. CHESF, in the northeast regions of Brazil, has expressed interest in installing a 1MW dish-Stirling power plant.

Power towers have been field tested around the world in the last 15 years, but are commercially less mature than parabolic trough systems. Solar Two, a 10MW power tower based on molten salt technology, is currently completing start up in California, USA. A 1MW power tower based on volumetric air technology is currently being tested in Almeria, Spain. These types of power towers, scaled to 100-200MW, are expected to be competitive with coal-fired power plants. A small tower concept based on beam-down optics is currently being developed in Israel. A prototype to be built in the next few years is expected to compete with smaller fossil-electric technologies in the 1-30MW size range. Brazil has expressed interest in building a small power tower plant to demonstrate the essential elements of the technology.

For the START Mission, a comparison study was made between Solar Two, a solar thermal site located in Barstow, California, USA, and a site based on Solar-Two-type tower technologies located in Itacarambi, Minas Gerais, Brazil. It was concluded that to receive the same results in Brazil as in the USA, a larger solar field and thermal storage system would be required to achieve the same annual capacity factor. Electricity costs for a plant in Brazil would be approximately 12% higher than a plant in the USA.

Mission Summary

Conclusions

An aggressive expansion program is underway throughout Brazil, which calls for doubling the installed electric generating capacity by the year 2010. Cheap expansion with hydro and fossil resources is nearly exhausted and consequently there is currently huge potential for new resources to enter into the market.

Brazil has a tremendous solar resource and good opportunities for the application of solar thermal electric systems. The semi-arid region of Brazil's Northeast and the São Francisco River basin have the best conditions for deployment of solar troughs, towers and dishes. Within the expansion and rural electrification programs

Recommendations

The START Team recommends that Brazil continue pursuing the application of solar thermal electric technology, specifically focusing on furthering the following: technology development and evaluation; resource and market studies; and policy making in the financial, regulatory, and energy planning areas. Technology development should both utilize proven systems for immediate electricity generation, and establish research and development facilities to build the national technology base. Calculation of cost of energy for the technology should be standardized for a consistent comparison of dishes, towers and troughs.

Unique solar thermal applications such as solar-biomass combination schemes should be investigated, as well as considering the widespread impact to be made by using the solar resource for producing electricity and allowing then the hydro resource to be used for irrigation rather than electricity. Brazil should be encouraged to continue its assessment of the solar resource and to thoroughly identify the potential for off-grid and grid-connected insertion of solar thermal electric power.

Regulatory, financial and energy planning policies should be reviewed during the expansion and restructuring process. Distortions in taxation, compensation, financial risks and sustainability should be filtered out by new policies so that the technology's availability, efficiency, requirements and benefits can finally be compared to other power generation technologies.

START MISSION DETAILED REPORT

1. START Mission Background

1.1 Introduction

Solar Thermal Analysis, Review and Training (START) Missions were initiated by the IEA/SolarPACES Executive Committee in 1995. SolarPACES, established under a different name in 1977 as a cooperative solar thermal technology development program, is an implementing agreement of the Renewable Energy Technologies under the IEA Committee on Energy Research and Technology. The objective of SolarPACES is cooperative research, development, demonstrations and exchange of information and technical personnel regarding solar power and chemical energy systems.

START Missions contribute to the SolarPACES vision of facilitating international cooperation, beginning with member countries, in the successful development of widespread deployment of solar thermal technologies to meet individual national energy diversity goals and overall global environmental restoration goals. START Missions provide a team of independent experts for technical and economic information exchange, identification of potential funding sources, discussion of terms of reference for feasibility studies, comparison of power generation costs, and review of potential project sites.

Prior to a START Mission, the potential host country must have investigated national solar thermal potential, technology capacity, industrial resources, and implications for the national energy plan. To date, IEA/SolarPACES has sent START Missions to Egypt, Jordan, and Brazil in a continuing effort to move forward with appropriate applications of solar thermal electric systems.

1.2 Brazil’s Readiness for Mission

Brazil first entered into a contact with IEA/SolarPACES in 1995 and, sponsored by the MME, became a SolarPACES member in 1996. The ministry anticipated cooperation with other SolarPACES members interested in demonstrating and developing prototypes of power towers, dish systems and parabolic troughs and requested a START Mission to Brazil. CEPEL became the designated coordinator for Brazil’s SolarPACES participation, and organized and hosted the mission held in May of 1997. The purpose of the mission was to brief Brazilian research centers, electric utilities, and the energy ministry regarding the techno-economic status of solar thermal technologies and to explore the possibility of building a large solar thermal power plant in Brazil. Activities planned for the mission were to include an international workshop on solar thermal electric generation, site visits and analysis of insolation data for two locations in the state of Minas Gerais, and a working session with one of the large electric companies in Brazil.

The START Mission, at Brazil's request, would highlight power tower systems. Thermal storage capabilities and economies of scale provided by towers were known to be important issues for the feasibility of solar thermal electric in Brazil. A previous study sponsored by the German government regarding an 80MW trough-type solar electric generating station in Brazil had demonstrated that solar thermal was still more expensive than hydro and fossil alternatives for grid-connected systems. A full review of the need for new energy and the changes in technology since the previous consideration would contribute to the identification of possible implementation of this technology in Brazil. Conclusions from the START Mission would also help define Brazil's participation in the working groups of IEA/SolarPACES.

1.3 START Mission to Brazil

During the week of May 5th, 1997, a START Team composed of IEA/SolarPACES representatives from the US, Germany, Spain and Israel visited Brazil. The host of the mission was CEPEL, an institution similar to USA's Electric Power Research Institute located in Rio de Janeiro. The purpose of the team's visit was to brief research centers, electric utilities, and the energy ministry regarding the techno-economic status of solar thermal technologies and to explore the possibility of building a solar thermal power plant.

The START Team visited two proposed solar sites, reviewed the associated insolation data, and performed a first-cut systems analysis based on this data. CEPEL organized an International Solar Thermal Workshop to take place during the START Mission, which included START Team presentations on technology, economics, proposed plants, and the analyses of Brazilian meteorological data, and possible solar sites. Brazilian researchers and officials presented information on energy demand, financing, private and government markets, and past studies of solar thermal development. The team met with CEMIG (the electric company of the state of Minas Gerais who historically has expressed the greatest interest among Brazilian utilities in developing solar thermal electric power) to exchange information on energy resources and options and demonstrated various software tools to researchers at CEPEL's laboratories in Rio de Janeiro.

2. START Mission Events

The START Mission began with a working session with the electric company of the state of Minas Gerais (CEMIG), which had historically expressed the greatest interest among Brazilian utilities in developing solar thermal electric power. Next, the START Mission Team visited two of the sites previously proposed for solar thermal power plants, followed by the presentation of a two-day international workshop on the technical and economic status of solar thermal electric systems. The team's last day in Rio de Janeiro was spent touring CEPEL's Ilha de Fundão facilities and presenting solar software tools to interested researchers and students gathered at CEPEL. Each of the software packages which had been used for the START Mission's simulations and analyses were demonstrated to the assembled group.

2.1 CEMIG Working Meeting

The START Team traveled to Belo Horizonte, with Evandro Camelo representing CEPEL, on May 5, 1997, for a working meeting with the electric company of Minas Gerais, CEMIG. CEMIG, whose power plants and transmission lines are sown in Figure 2.1, is the company that cosponsored the study of a trough project in the Northeast of Brazil with Pilkington and had set up weather monitoring stations at various possible solar plant sites.

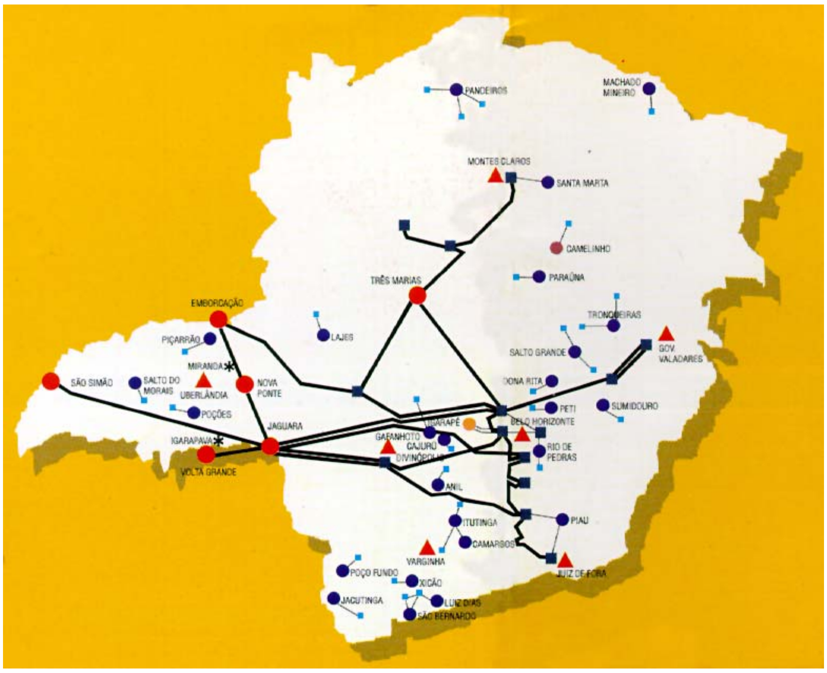


Figure 2.1 CEMIG Power Plants and Transmission Lines

CEMIG directors and engineers described the situation within the state of Minas Gerais, which currently has an installed capacity of 4.9 GW, with 4.8 GW from hydro-electric power plants. Privatization of Brazilian electric power distribution and natural gas transport was initiated in February

1995 changing the institutional format of the electric sector. Since enactment of the Concession's Law, CEMIG no longer has a strong say in the expansion planning carried out by the DNAEE. Now, CEMIG is required to bid competitively to build new plants, but will have the opportunity to bid on plants throughout the country.

Prior to the privatization of the electric sector, CEMIG's expansion plans through the year 2015 included 7GW of new hydro capacity and 730MW of new thermo-electric plants. Due to the costs associated with relocating homes and entire towns to acquire the best locations in the interior of Brazil for new dams, hydropower expansion is not as attractive as it once was. Future expansion will likely be with thermal, wherever it is cheaper than hydro, and some new thermal plants will be utilized for base loads. Thermal plants will complement Brazil's vast hydro capacity in that reservoirs can be filled while using thermal generation. A possible future strategy for leveraging the use of thermo-electric generating stations is to build plants along the coast to avoid the cost of transporting fuel to the interior. Power lines already in place to transport hydro power to the coast could instead be used to dispatch energy to the growing number of electricity consumers in the interior, allowing reservoirs at the hydro plants to store energy for peak use.

CEMIG's business approach to electric power supply systems planning and development was then addressed. The key business factors included the cost of energy, the energy outlook, customer base, and competition with oil and coal imports. First, cost studies have shown that the cost of energy, for example thermoelectric generation using fuel oil transported 600km to northern Minas Gerais, is approximately US$75/MWh. In comparison, the cost of energy for hydroelectric has been approximately US$50/MWh. CEMIG has studied the solar expansion option and believes the cost of energy for an 80MW solar trough power plant would be approximately US$114/MWh, a large portion of which was due to import taxes on the plant equipment. In fact, the tax policy on power investments and equipment imports heavily penalize solar thermal power projects. The SEGS (Solar Electric Generating System) study conducted shows that the project would have cost US$286-million plus an additional US$120-million in taxes. Brazil has historically subsidized the cost of fossil-fired electric generation but currently has no subsidies or tax-equity provisions for solar thermal generation. However, Brazilian legislation and exemptions regarding import taxes are modified frequently and should be thoroughly re-investigated.

Next came a discussion on the energy outlook, the customer base, and the availability of fossil fuels. Electric energy consumption in the state of Minas Gerais grew 8% in 1996 and 3-4% through April of 1997. CEMIG's strategy under the newly privatized system is to maintain the company's current clients and to increase the customer base by 3% per year. The mix of new hydro and thermal plants will soon be affected by new competition in the restructured economy from oil and coal imports. Since Brazilian coal is 50% ash (a poor grade for thermal electric generation), Brazil's ability to import coal will improve the economics of coal plants. Likewise, since PETROBRÁS, the Brazilian oil company, sees more profit in the higher viscosity oil products than in fuel oil, the ability to import oil may also drive down the cost of traditional thermo-electric generation.

A debate on the difficulties of implementing solar thermal in Brazil then took place. Whereas it may have once been acceptable and even desirable for CEMIG to invest in more expensive energy solutions as part of the larger picture concerning the environment and sustainability, CEMIG must now win cost-competitive bids to maintain and grow its power generation base. Solar thermal electric generation will compete with thermal from oil and coal and will succeed only if it becomes cheaper than fossil-fired electric generation. In the eyes of certain CEMIG directors, widespread acceptance of solar thermal will require brutal, dramatic advancements in the technology. However, in certain areas of Brazil, such as in the state of Ceará, the growth in energy demand and the cost of energy are critically high. Such situations, which are not necessarily rare in Brazil, may benefit tremendously from the use of solar thermal electric generating systems.

2.2 Visits to Proposed Solar Sites

Immense land areas are available in Brazil for the implementation of extensive solar thermal power systems. An exhaustive site survey was done in 1990 and 1991 by Flagsol with ELETRONORTE, CHESF, and CEMIG and included the screening of dozens of site locations. As preferred sites, the Januária area was pre-selected for CEMIG and Sobradinho for CHESF. The START Team visited Januária and Itacarambi, two of the sites located in northern Minas Gerais for which insolation data were collected from 1991 to 1994. The Januária site is part of the Pedras de Maria Biological Reserve and both sites are located along the São Francisco River basin, which receives some of the better solar radiation in the country. Accompanying the team on the site visits were Evandro Camelo of CEPEL, Carlos Alvarenga of CEMIG, and Wilfried Grasse of SolarPACES.

Both sites were known to have excellent topographic conditions, grid access, cooling water, and now road access. Low wind speeds and moderate ambient temperatures with little daily variation in the region would ease the aging of solar fields. Typical shrubs and vegetation for cattle minimize dust development. Radiation measurements indicated annual solar direct radiation in a range between 1800-2300kWh/m²a. The Flagsol study found that such areas can accommodate over 400MW of solar power plants.

The team actually found both sites to be covered with thick, coarse vegetation (apparently due to recent heavy rainfalls and not indicative of year-round precipitation levels). Though these sites are not situated in the most arid regions of Brazil, they were chosen as the best areas in CEMIG's supply region, having high growth rates and relatively good insolation for a solar expansion option. Other criteria for site selection in the previous feasibility studies had included availability of water, fuel, land, and infrastructure.

During the trips to these sites, the pre-feasibility studies conducted by CEPEL and Flagsol for CEMIG were related to the team. The studies were based on a composite of direct, normal radiation measured from 1990 forward, and on global radiation measured in previous years. The first feasibility study for a SEGS plant near the town of Januária was conducted in 1990 and concluded that a SEGS plant was not yet competitive. Later, a study was conducted to examine the feasibility of an Integrated Solar Combined Cycle System (ISCCS) plant which would operate at higher efficiencies and result in a more promising prospect for power generation in the Brazilian electric sector. In the end, such a plant was still less competitive than other options, and CEMIG has not moved forward with the project. However, it is certainly the impression of the START Team that CEMIG is making a keen effort to stay in touch with any technology advancements that could change the economics of solar thermal electric generation.

2.3 International Workshop on Solar Thermal Electric Generation

During the first day of this international workshop, members of the START Team presented the current status and advanced concepts of trough, tower and dish technology. In particular, the technologies and projects that are of current and future interest with the SolarPACES countries were discussed, including the following:

1. Solar Two and follow-on 30-100MWe project (USA)
2. TSA and follow-on PHOEBUS project (Germany)
3. DIAPR and follow-on SCOT project (Israel)
4. Dual system project (Israel/Brazil)

The current status and development plans for each of these power tower technologies are described later in this report.

Next, Amilcar Gonçalves from ELETROBRÁS reported on the present and future electric energy demand in Brazil. As of 1996 Brazil's installed capacity of 63.5GW was 93% hydroelectric. Brazil has an estimated 247GW of hydroelectric potential, 40% of which lies in the Amazon Basin. Typically, transmission lines cover great distances from source to load, since the water resources are mainly located in the interior and the vast majority of the population is along the coast. The hydroelectric generation is now increasingly being complemented by thermal plants, as environmental sensitivities regarding the Amazon are heightened and prime locations for hydro-power projects become more difficult to obtain. The country also has resources of coal, uranium, gas, oil, and sugar cane bagasse. Over 60% of Brazil's entire energy consumption is already renewable (this includes the use of bagasse, hydro-power, and gasohol for automobiles).

Nationally, expansion required through 2006 could total 26-45GW, equaling approximately 4-6% annual growth. The 1996 economic indicators were as follows:

per capita GNP (1995 dollars)	US$4,648
per capita electric energy consumption	1.74MWh
total electric energy consumption *	276TWh

* includes self producers and interruptible energy

Deraldo Cortez of the MME described the development of the Brazilian energy sector and the recent course of privatization of the utilities and reorganization of the market. The legal framework, conditions and regulations for Independent Power Producers (IPP) are now under full discussion within the various governmental bodies. The Concessions Law, passed in February 1995, allowed Brazil to begin selling off government-owned electric generation assets. The Public Service Law, enacted in July 1995, specifically addresses the right of independent power producers to produce and sell electricity. The MME is awarding concessions for new power plant development through the year 2004 through a program of solicitations. New construction under The 1995/2004 Expansion Plan will be for self-production and independent power production. An independent consultant has been hired to help implement the IPP policy that was established in July 1995.

In certain regions of Brazil the demand for electricity has grown faster than the country's economy and will double in the next 10-12 years. The national household service rate has increased from 48-92% in the last 25 years, yet some 20 million Brazilians still lack electric service. Deraldo Cortez discussed the PRODEEM program, whose objective is to promote the supply of energy to communities that are far away from conventional systems using renewable and technically feasible energy sources that are economically viable, commercially possible, politically acceptable, and environmentally sound.

James Bolivar of Companhia Energética do Piaui (CEPISA) summarized the demand for electric energy in the northeast region of Brazil. In brief, the Northeast has a large potential for economic growth, and is currently growing faster than the country as a whole. The demand for electricity has grown even faster than the economy, and indicators show that the consumption will double in 10-12 years. The generation of electricity is concentrated, and despite the concentration of consumption in some centers of production, servicing the loads in remote parts of the country will require extensive transmission lines. The planned hydroelectric systems will not satisfy the future demand, therefore new sources of electric generation must be sought. Ambient conditions of the northeast favor exploitation of solar energy. Thus solar thermal electric generation should be considered as soon as possible to augment the electric generation of the Northeast in cooperation with CHESF and to supply decentralized power to localized loads in conjunction with transmission line extensions. The state of Piaui meets all the requirements for a solar thermal electric generating plant.

During the second day of the workshop the START Team presented the principal factors of risks and benefits of solar thermal energy and reduction of costs associated with investments in solar thermal technology. Also presented were the perspectives of various financial institutions regarding solar thermal electric systems and an evaluation of the insolation data from Januária and Itacarambi, including a first-cut systems analysis based on this data.

The final session was closed by Deraldo Cortez, who stated that the conclusions from the START Mission will help define Brazil's participation in the SolarPACES Program of Work. Results of the pre-feasibility study of central power towers in Brazil will be of great value to IEA/SolarPACES as well as representing an important contribution to the identification of possible implementation of this technology in Brazil. Brazil plans to build cooperation with members of IEA/SolarPACES who are interested in demonstrating and developing prototypes of power towers, dish systems and parabolic troughs. Brazil has a fantastic market to be developed and in a large number of cases where there is no conventional energy, solar thermal electric technology is already very competitive.

As the next step, CEPEL plans to initiate a study of all solar thermal technologies to determine the most appropriate for application within Brazil. The results of this study will frame the project that will be proposed to the Global Environmental Facility (GEF).

2.4 Insolation Studies

Brazil has extensive, semi-arid regions receiving on the order of 6 kWh/m^2 of daily direct normal insolation. Although these regions show less radiation than Mojave Desert or North African sites, their location close to the equator reduces cosine losses, equalizes the daily operation and partly offsets the radiation difference. Satellite data (see Figure 2.2) compiled by SunLAB confirmed that the São Francisco River basin and the Sobradinho area of the Northeast have the most promising radiation potential in Brazil.

CEPEL has been collecting global radiation data in Brazil since 1979 and CEMIG has monitored a state-wide insolation measurement network since 1983, including some direct and diffuse data as well as the more common global radiation. CEPEL, CHESF and the Federal University of Pernambuco

(UFPe) are currently working to complete a solarimetric radiation map for Brazil.

An exhaustive solar plant site survey had been carried out from 1990 to 1991 by Flachglas Solartechnik (Flagsol) together with ELETRONORTE, CHESF and CEMIG including the screening of dozens of site locations. As preferred sites, the Januária area in Minas Gerais was pre-selected for CEMIG and the Sobradinho area for CHESF. The radiation measurements carried out from 1990 to 1993 at selected sites in the concession areas of CEMIG, CHESF and ELETRONORTE indicated annual normal direct radiation levels between 1750 and 2300 kWh/m^2a.

Prior to the START Mission, the team analyzed the solar data for two sites, Januária and Itacarambi, both in the state of Minas Gerais. The data was collected by CEMIG from April, 1990 to April 1993 for Januária, and March 1990 to November 1993 for Itacarambi. Januária is located at longitude 44º 22' W, latitude 15º 40' S, and an elevation of 500m above sea level, and nearby Itacarambi is at longitude 44º 08' W, latitude 16º 33' S, and the same elevation. Each station measured the three components of solar insolation as well as other meteorological data. Direct normal insolation was measured with an Eppley Normal Incidence Pyrheliometer (NIP), the global horizontal insolation with a Kipp and Zonen CM11 Solarimeter, and diffuse with a Kipp and Zonen CM11/CM121 Solarimeter.

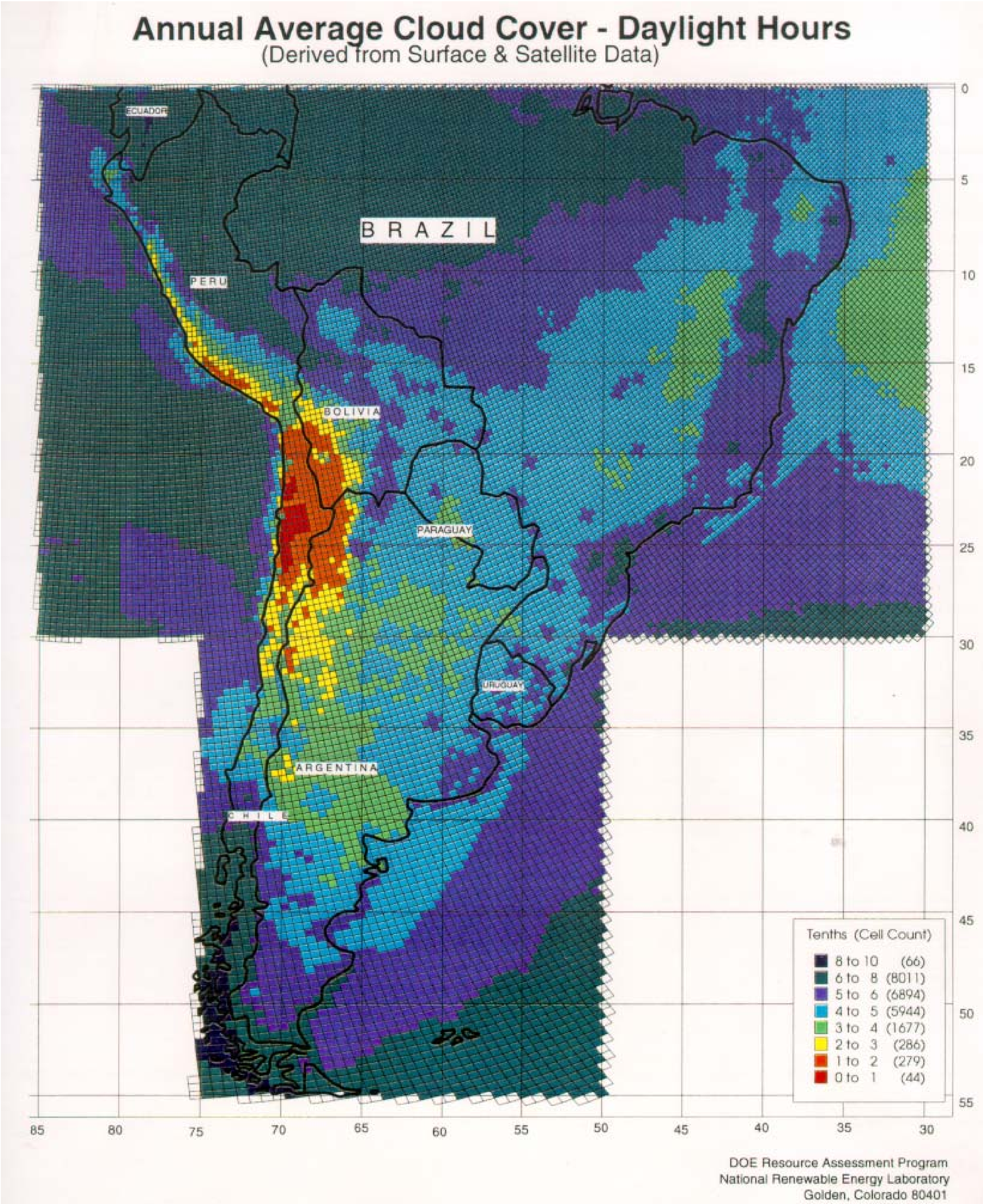


Figure 2.2 SunLAB cloud cover satellite data

This database had previously been used in updating the performance evaluations of solar trough plant feasibility studies conducted in 1990 and 1991. Data for Itacarambi in 1993 showed an annual direct normal insolation of 2315 kWh/m²a. The performance evaluations showed this level of insolation resulting in guaranteed annual energy credits of 123 GWh/yr from the solar portion of the plant alone.

Six files of data were available from each site, namely, hourly record files and statistical record files of direct, diffuse and global radiation measurements. Missing data was indicated by zeros in the files, and no data manipulation had been performed on any of the components presented as raw data. The monthly direct normal insolation levels for these two sites, shown in Figure 2.3, tracked each other closely throughout the period of measurements.

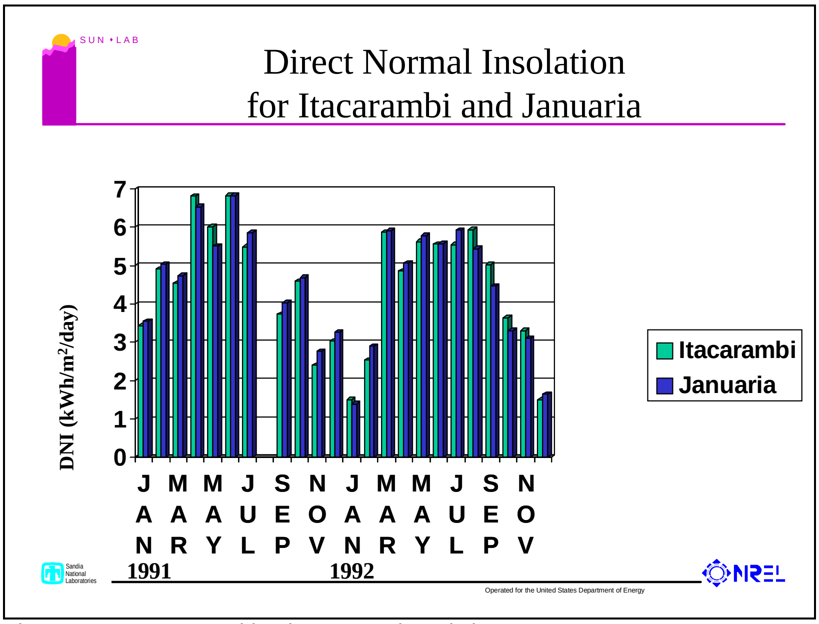
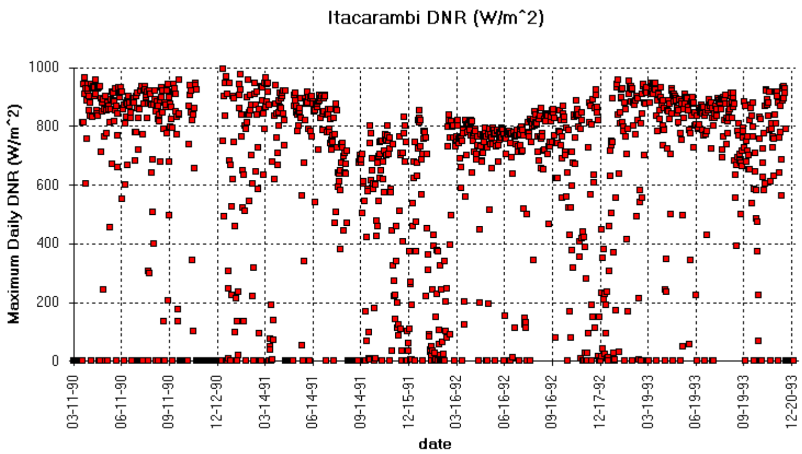


Figure 2.3 Average Monthly Direct Normal Insolation

Figures 2.4 and 2.5, more detailed plots of the direct normal insolation for both sites, show variations in the daily maxima which peak at approximately 800 to 1000 W/m2. In July, 1991, a noticeable drop, differentiable from the seasonal variations, is seen in the direct radiation levels and is likely a result of the eruption of Mt. Pinatubo. Yearly totals of direct normal insolation are shown in Table 2.1. Though partially corrupted by emissions from the Mt. Pinatubo eruption, the database appears to show that the insolation for these locations exceeds the 1900 kWh/m2a threshold level of viability for concentrating solar power electric technology.

Itacarambi Insolation



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National Renewable Energy Laboratory, Golden CO

Figure 2.4 Itacarambi Direct Normal Insolation

Januaria Insolation

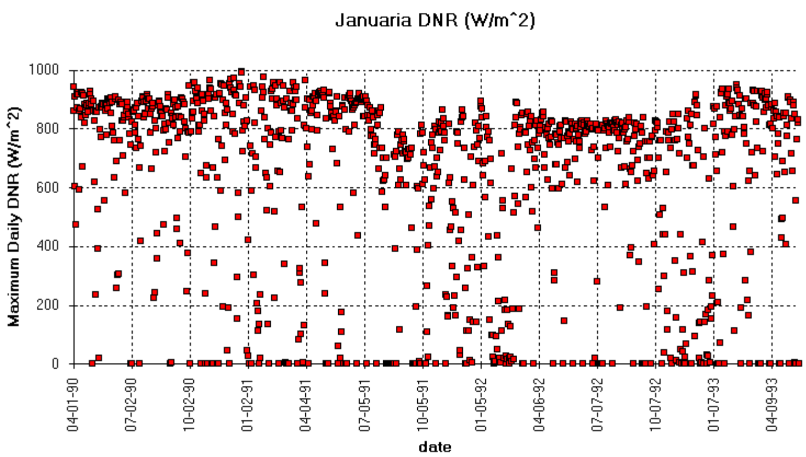

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Figure 2.5 Januária Direct Normal Insolation

The hourly records for the two sites were processed and assessed for the START Mission by the National Renewable Energy Laboratory (NREL) using SERI QC. SERI QC is a software package developed by NREL to assess direct, diffuse and global solar radiation. The code indicates departures from expected values, and provides input for the quality control of new data. The approach to quality assessment in this software utilizes theoretical limits, empirical limits, model estimates, and redundancy in determining boundaries for the data. Due to the difficulty of defining expected absolute values of solar radiation, the three components are normalized with respect to the known extraterrestrial radiation. The three radiation components are then tested individually, pair-wise and in total. Quality flags are assigned for each triplet of data, indicating which, if any, test failed, as well as the magnitude and direction of the departure. Experienced users of the package can identify particular sources of disturbance including instrumentation problems and weather variations.

NREL's assessment concluded that the data overall were of good to excellent quality, and that the discrepancies found were generally within the uncertainties of the test equipment used. Though a small percentage of data was flagged as having possible equipment alignment errors, a very high percentage of data was found to be within acceptable limits. The direct, diffuse and global radiation values, when analyzed simultaneously exhibited coherence, shown in Table 2.2 as a percentage of data falling within the given ranges of agreement between the three normalized components.

Table 2.1 Yearly Direct Normal Insolation (kWh/m^2)

	1991	1992	1993
Januária	2051	1781	2315
Itacarambi	1963	1743	-

Table 2.2 Percent of Data within Given Ranges of Agreement

Site	**<=5%**	**>10%**	**Missing**
Januária	83%	2%	11%
Itacarambi	73%	3%	15%

The SERI QC results that were flagged with slight alignment errors suggested that the direct normal measurements were low relative to estimates of the direct normal given by the global and diffuse data. Figure 2.6 shows the percent increase in direct normal insolation for this correction. This type of correction, resulting from readily available quality assessment measures, would have a direct impact on the performance evaluation and cost estimation of concentrating solar power systems.

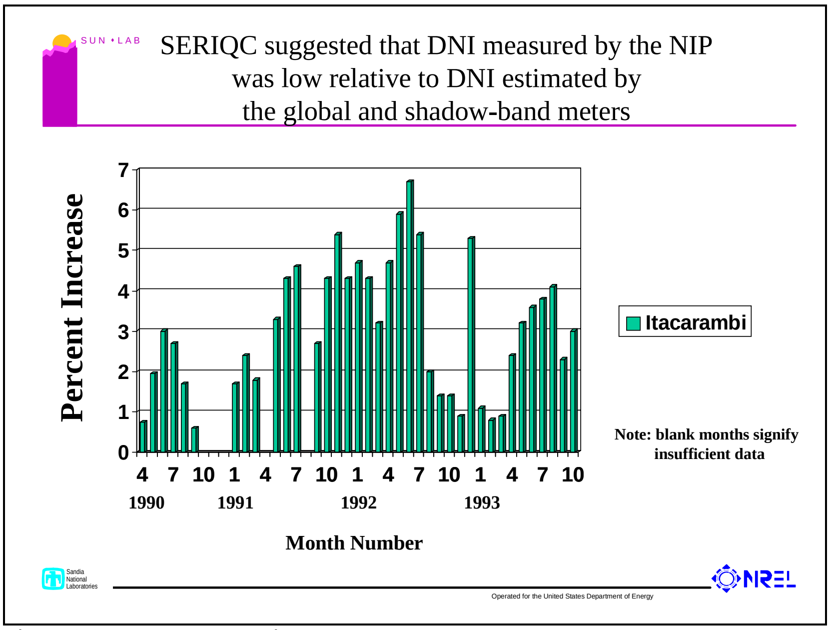

Figure 2.6 Percent Increase in DNI

The instrumentation for solar radiation data collection no longer exists at these two particluar sites. However, the START Team would recommend that more three-component data be collected, especially throughout the semi-arid and São Francisco River basin regions. Quality control measures should be implemented where possible to reduce uncertainty in the data, as a complete mapping of the solar resource is compiled.

3. Solar Thermal Electric Experience

3.1 Solar Electric Generating Stations

With 354MW of parabolic trough power plants currently operating in Southern California, USA, parabolic troughs represent the most mature solar thermal technology. To date there are over 80 plant-years of experience from the nine operating plants that range in size from 14-80 MW. A typical system schematic for a 30MW plant is depicted below.

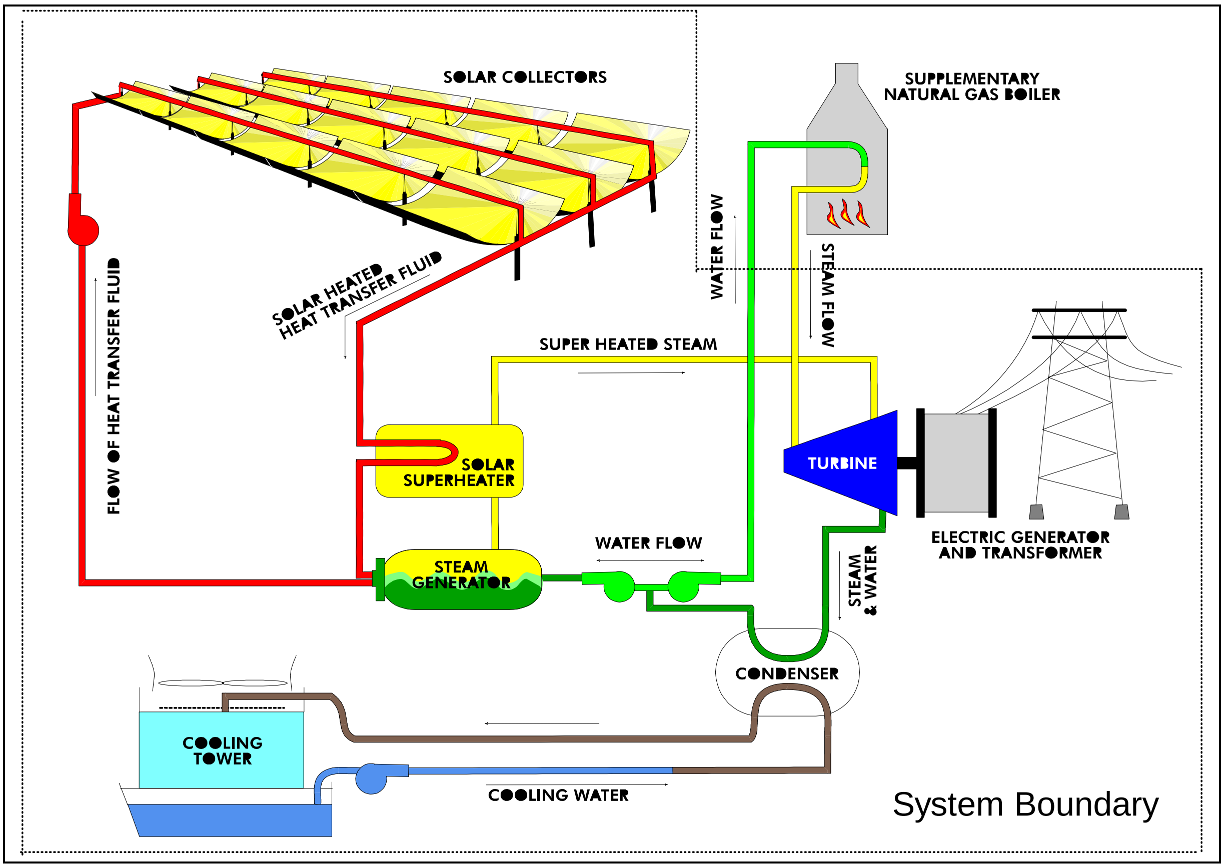

Figure 3.1 Schematic of a SEGS power plant built by LUZ International. Synthetic oil is heated to 390°C within a vacuum-jacketed pipe located at the focal line of a parabolic trough. The hot oil is delivered to a steam generator and returned to the solar field at a temperature of 290°C. The plant can run solar-only, but a fossil boiler is also installed to allow plant operation at night or during poor solar conditions.

The performance of these power plants continue to improve. For example, on July 1, 1997, the total solar-only output from the five 30MW plants at the Kramer Junction site was higher than any day during the previous 10 years. The Solar Electric Generating Station (SEGS) plant achieved a daily solar-to-electric efficiency of 18% gross. At the same time performance is improving and annual operations and maintenance costs are dropping (with a 30% reduction over the last five years).

3.2 Power Tower Plants

Although power towers are commercially less mature than parabolic trough systems, a number of component and system projects have been fielded around the world in the last 15 years, demonstrating the engineering feasibility and economic potential of the technology. Since the early 1980s, power towers have been fielded in Russia, Italy, Spain, Japan, France, Israel, and the United States. These projects are listed in Table 3.1 and the reader should note that only the last three are currently operating.

Table 3.1 Power Tower Projects

Project	Country	Power Output	Heat Transfer Fluid	Storage Medium	Operation Began
SSPS	Spain	0.5 MW_e	Liquid Sodium	Sodium	1981
EURELIOS	Italy	1 MW_e	Steam	Nitrate Salt/Water	1981
SUNSHINE	Japan	1 MW_e	Steam	Nitrate Salt/Water	1981
Rockwell	USA	2.5 MW_t	Liquid Sodium	None	1981
Solar One	USA	10 Mw_e	SH Steam	Oil/Rock	1982
Arco Solar	USA	1 MW_t	Sat. Steam	None	1982
CESA-1	Spain	1 MW_e	Steam	Nitrate Salt	1983
MSEE/Cat B	USA	1 MW_e	Molten Nitrate Salt	Nitrate Salt	1984
THEMIS	France	2.5 MW_e	Hi-Tec Salt	Hi-Tec Salt	1984
SPP-5	Russia	5 MW_e	Steam	Water/ Steam	1986
EPRI	Israel	200 kW_e	Hi Press Air	None	
TSA*	Spain	1 MW_e	Atmosp. Air	Ceramic	1993
DIAPR*	Israel	200 kW_t	Hi Press. Air	None	1994
Solar Two*	USA	10 MW_e	Molten Nitrate Salt	Nitrate Salt	1996
*Tower project is currently available for operation					

3.2.1 Solar Two and follow-on project

Solar power towers based on molten-salt technology are predicted to be cost competitive with coal-fired power plants after scaling plant size to the 100-200 MWe range. The essential elements of the technology are depicted in Figure 3.2.

As shown in Table 3.1, small experimental plants were successfully fielded in the USA and France in the mid-1980s that demonstrated the feasibility of the concept at a 1-2MWe scale. To help bridge the scale-up gap, a 10MWe demonstration project known as Solar Two is currently completing startup in California, USA. Initial data collected at the plant show that the molten salt receiver and thermal storage tanks should perform as predicted during design. For example, data collected on March 26, 1997, revealed that the receiver absorbed 39.8MWt, which is 93% of the design value. Considering the fact that the heliostat field had significant alignment problems at the time of the measurement, the receiver is expected to reach 100% of the design after realignment. The thermal storage system has also exhibited excellent thermal characteristics. For example, during a month-long cool-down of the hot storage tank, when it was filled with molten salt, the tank temperature dropped only 75ºC. This is within 10% of the design prediction.

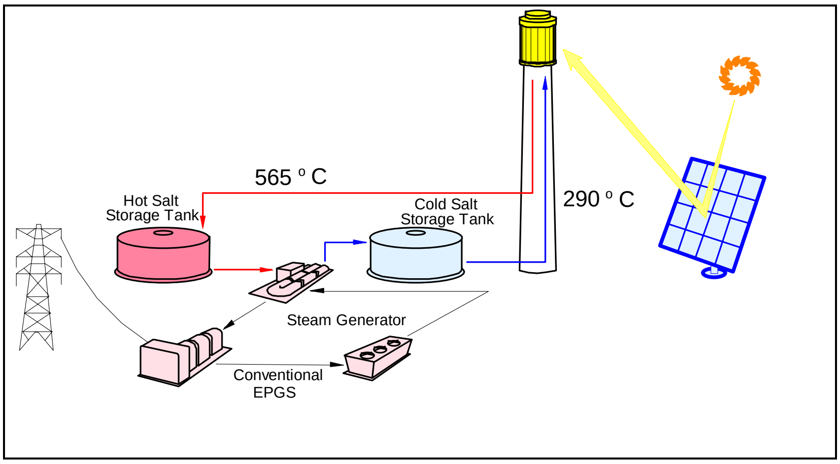

Figure 3.2 Schematic of a molten salt power plant. Molten salt is heated to 565°C within a tubular type receiver and pumped to the hot storage tank. When power is needed to meet the load demand on the grid, salt is extracted from the hot tank to a steam generator. The steam drives a conventional electric power generating system (EPGS). After making steam, molten salt at 290°C is returned to the cold tank and pumped back to the receiver.

3.2.2 PHOEBUS Concept

The following international companies and institutions contributed to the PHOEBUS development and system demonstration:

- FICHTNER DEVELOPMENT ENGINEERING (FDE) (managing partner, system engineering and the control system)
- DIDIER M + P Energietechnik (heat storage)
- the Swiss Consortium SOTEL
- Bechtel International
- L & C STEINMÜLLER (receiver, system delivery)
- CIEMAT and DLR (German Aerospace Research Center) at the Plataforma Solar de Almería

After successful component and system tests of the PHOEBUS concept at the Plataforma Solar de Almeria, L&C Steinmüller is ready to offer and supply a turnkey 30MW PHOEBUS plant on a commercial basis. The following economic and performance predictions have been made by the PHOEBUS Consortium for a reference site in Jordan.

Shown in Figure 3.3 is the simplified process schematic of the PHOEBUS cycle concept (Phase 1B).

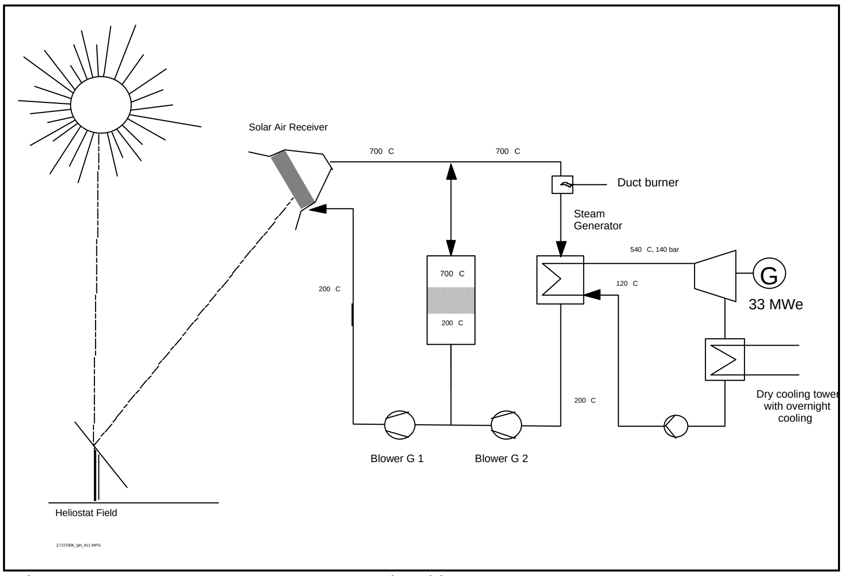

Figure 3.3 PHOEBUS 1B Cycle with Storage

Insolation is concentrated by means of the heliostat field onto a receiver. Air extracted by the receiver blower (G1) from the surroundings is then directed through this receiver causing it to heat up to 700 °C. The actual heat transfer process takes place in the absorber which is composed of wire mesh mats. Air is drawn in through the absorber, heated, and directed via air ducts to the steam generator and/or heat store by blowers. The purpose of the 3h store is to even out fluctuations in insolation due to cloud transients and to provide the thermal energy for the peak organization after sunset.

The steam generator blower (G2) regulates air flow through the steam generator, and the receiver blower (G1) regulates air flow through the receiver. By stepless variation of their speed, any desired power ratios between receiver, steam generator and heat store can be adjusted from full power to minimum part load, and from heat store charging to discharging mode.

Air exiting the steam generator is returned to the receiver inlet aperture in order to exploit the energy content of the exhaust air at 185°C, and hence improve overall system efficiency. Charging and discharging of the heat store can be managed easily by the blower speed control.

The hot air is used in the steam generator for producing live steam, which is then ducted to a turbine for electricity generation. The fossil-fueled burner upstream of the steam generator is used for plant start-up and to make good any shortfalls in heat store capacity. In the latest concept (Phase 1C, the thermal storage has been omitted for reasons of capital expenditure reduction.

Fluctuations in insolation due to cloud transients are evened out by means of the fossil-fueled burner only. In this case the steam generator blower (G2) is eliminated.

The plant is assumed to operate from sunrise to sunset. The turbine follows an ideal solar insolation curve as it varies throughout the day, but never dropping below 40% of its rated capacity. The plant is started up using fossil fuel.

On the basis of the economic assumptions taken in Table 3.2, the electricity generation costs of the PHOEBUS 1C plant were determined to be approximately 0.22DM/kWh for the first plant constructed without storage.

Table 3.2 Economic Parameters of PHOEBUS Project

Price Base	1994
Total capital cost	194.9 million DM
O&M Cost	2.375 million DM
Fuel costs, 1st year (15.13 DM/MWh)	1.923 million DM
Escalation of operating costs	3%/a
Escalation of fuel costs	1.5%
Interest rate	7%
Operating period	30 years
Net electric energy (with 100% availability)	89 GWh/year
Fossil energy (with 100% availability)	118 GWh/year

Substantial cost reductions are envisaged by cutting heliostat field costs, primarily by expanding volume production as well as by implementing prospective optimization measures. For the second plant a capital cost of around 161.8-million-DM is anticipated, the reduction being primarily attributable to a reduction in cost of the heliostat field.

Further cost reductions are expected when constructing subsequent power plants. For the solar farm technology concept, cost reductions of over 50% in comparison to the first plant were achieved. An estimate of the costs for the fifth plant in the 30MWe range results in capital costs of around 135-million-DM. If the capacity of the plant is upgraded to 100MWe, further cost savings are to be expected.

A comparison of the electricity generation costs for a plant with a heat store results in a figure of about 0.31-0.28DM/kWh. With favorable financial arrangements the generation costs of the first plant can be reduced. For an interest rate of 5%, a cost of 0.195DM/kWh is to be expected as electricity generation costs for the first plant, which represents a reduction of about 10%.

All the aforementioned, generation costs are based on a solar share of 1.0. That means that the full power is only at solar noon for the design day. If fossil operation is extended to 70%, the turbine investment is better utilized and the average generation reduced to 0.136DM/kWh for the first plant and to 0.124DM/kWh for the second plant. That means that 57.4MWh/a are produced by solar energy and 133.7 MWh/a are produced by fossil fuel.

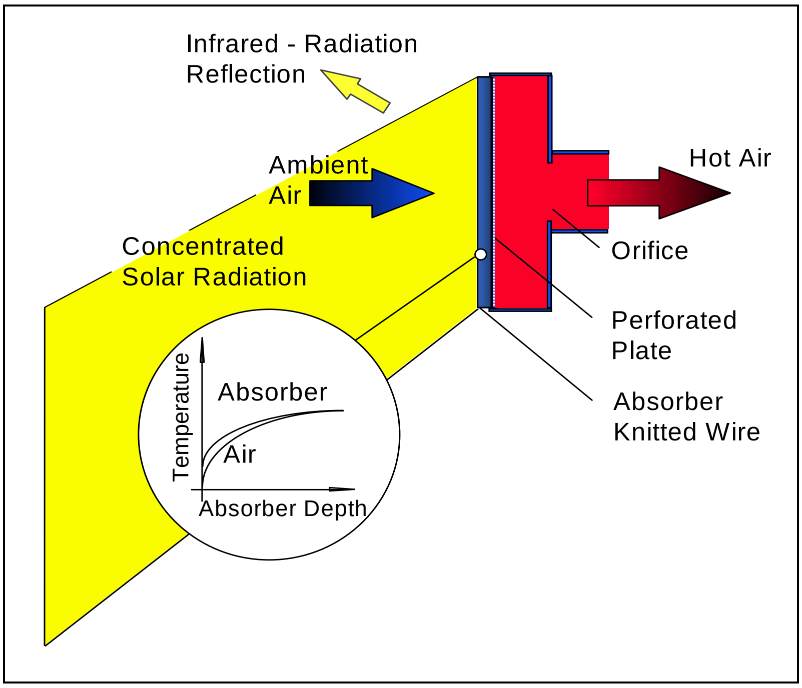

Figure 3.4 Functioning principle of the PHOEBUS Hot Air Receiver

Development concentrated first on the design of the receiver, which is modular for easy upscaling, and its operating characteristics with regard to availability, reliability, air flow distribution, recirculation and heat flow distribution, the design and operation of the thermal storage system, and an advanced heliostat concept. The functioning principle and fabrication of the 2.5MW$_t$ TSA Pilot Receiver at L&C.Steinmüller are shown in Figures 3.4 and 3.5. Schematics of the commercial-sized receiver, and a view of the operating 2.5MW$_t$ TSA Pilot Receiver at the Plataforma Solar de Almeria are shown in Figure 3.6. A view of the ASM-150 advanced stretched-membrane heliostat, developed by L&C.Steinmüller for the PHOEBUS project, is given in Figure 3.7.

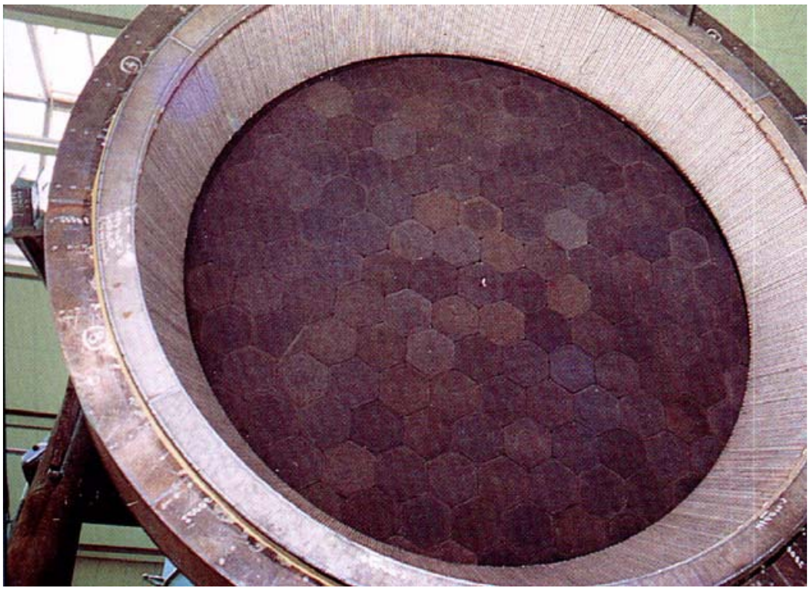

Figure 3.5 View of the 2.5MWt TSA Pilot Receiver during fabrication

Received with the same level of interest were subsequent system tests, with demonstrations of steaming rate, response to fluctuations in solar radiation, and start-up/shutdown behavior. The main test results obtained in the so-called TSA project at the Plataforma Solar de Almeria so far have been highly encouraging:

- A receiver outlet temperature of 700°C can be easily achieved within twenty minutes of plant start-up.
- Fixed flow devices in absorber elements keep outlet temperature constant over the absorber surface.
- Predicted receiver efficiency was confirmed.
- The nominal air receiver outlet temperature of 700°C has been achieved up to a 3MWt receiver load (design 2.5 MW_t).
- Fluctuations in solar irradiation have no effect on receiver outlet temperature, thanks to blower control and thermal inertia.
- Charging and discharging characteristics of the heat store are as predicted.
- Plant operation is very straightforward and is capable of rapidly tracking changing meteorological conditions while keeping steam parameters constant.
- No danger or damage occurs during various emergency and upset situations.

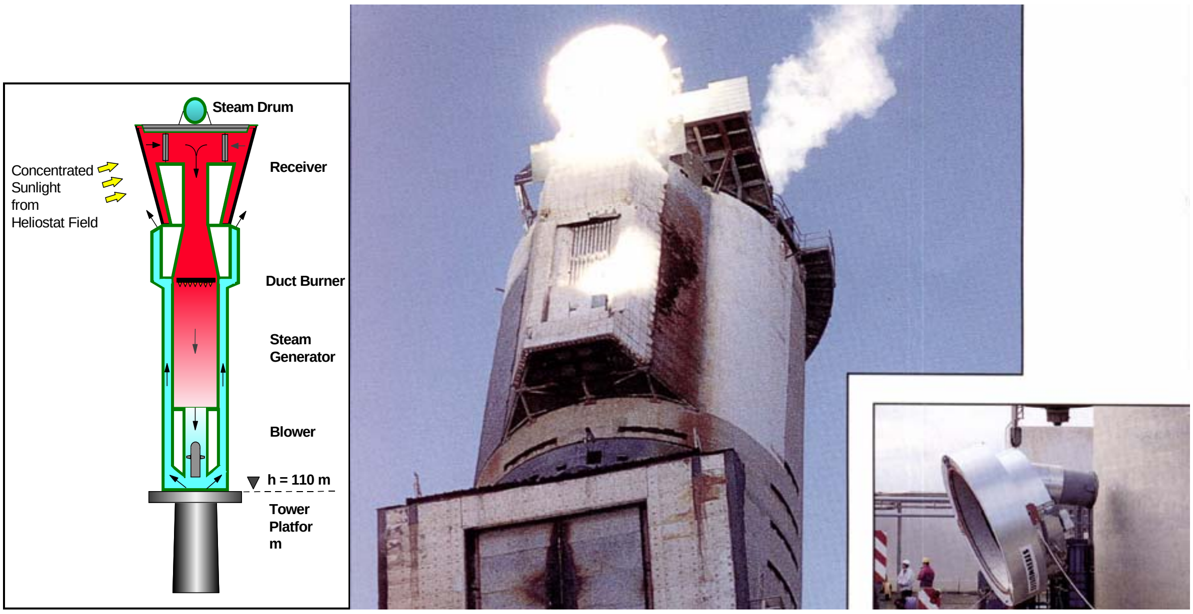

Figure 3.6 Schematics of Commercial Size PHOEBUS Receiver and View of 2.5MWt TSA Pilot Receiver operating at the Plataforma Solar de Almeria.

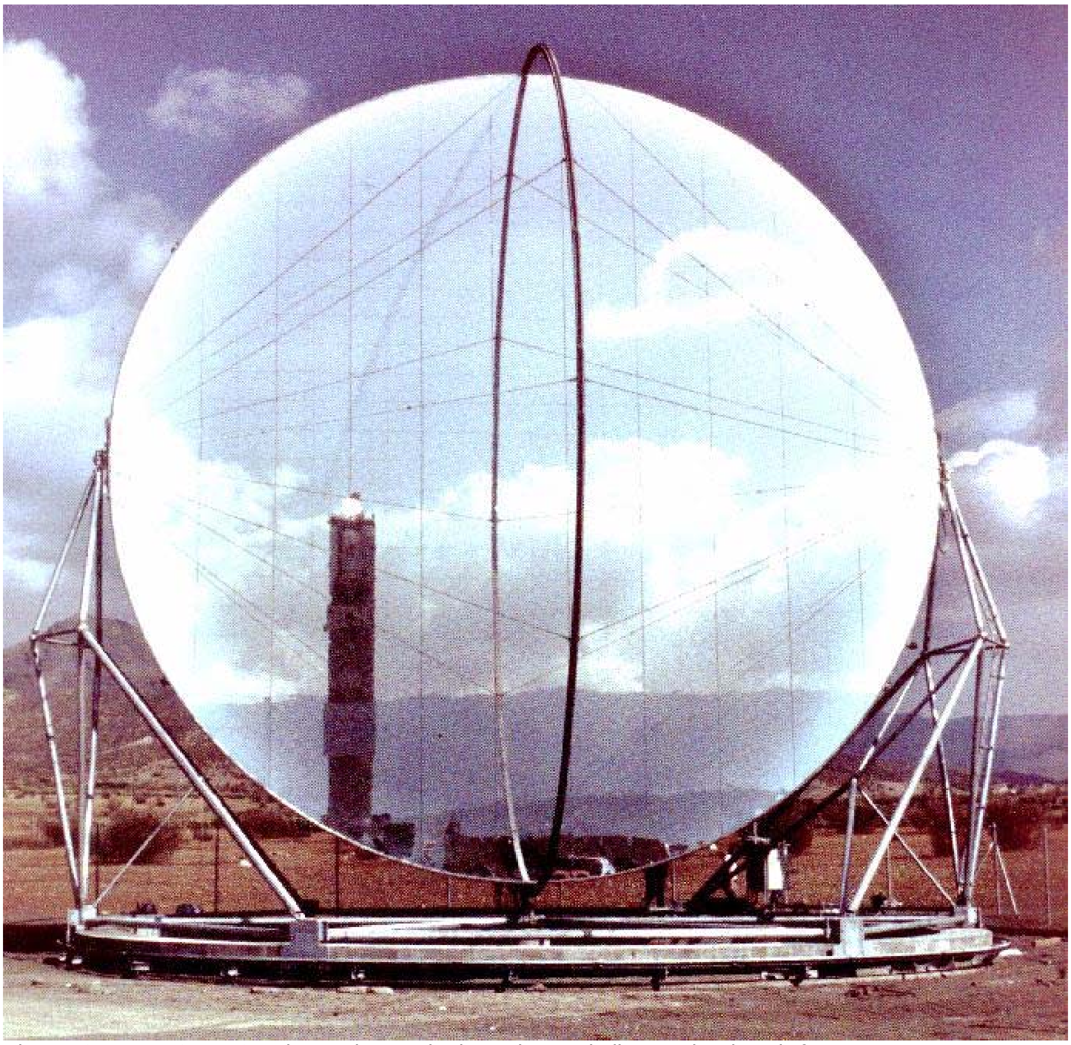

Figure 3.7 ASM-150 advanced stretched-membrane heliostat developed for PHOEBUS

3.3 Dish/Engine Experience

Several dish-Stirling prototypes have successfully operated over the last ten years, but large scale deployment has not yet occurred. To date, the most successful systems in the USA were the eight 25kW units developed by McDonnell Douglas Corporation (MDA) in the mid 1980s. In Spain, eight units with 8-10kW systems are now successfully operating. They were developed by the German company Schlaich, Bergermann and Partner (SBP). Next generation systems are currently undergoing research and development in the USA and Europe.

3.3.1 McDonnell Douglas Dish

The 25kW MDA system is currently being marketed by Solar Energy Systems of Phoenix, Arizona, USA, which is depicted in Figure 3.8. The systems tested in the mid-1980s routinely converted sunlight to electricity at a net efficiency of slightly under 30%. The cost of the MDA system is a strong function of annual production rate as depicted in Figure 3.9. Another US supplier of 25kW dish systems is Science Applications Incorporated of Golden, Colorado, USA, who has a single prototype that is currently operating and plan to build four more next-generation units in 1998.

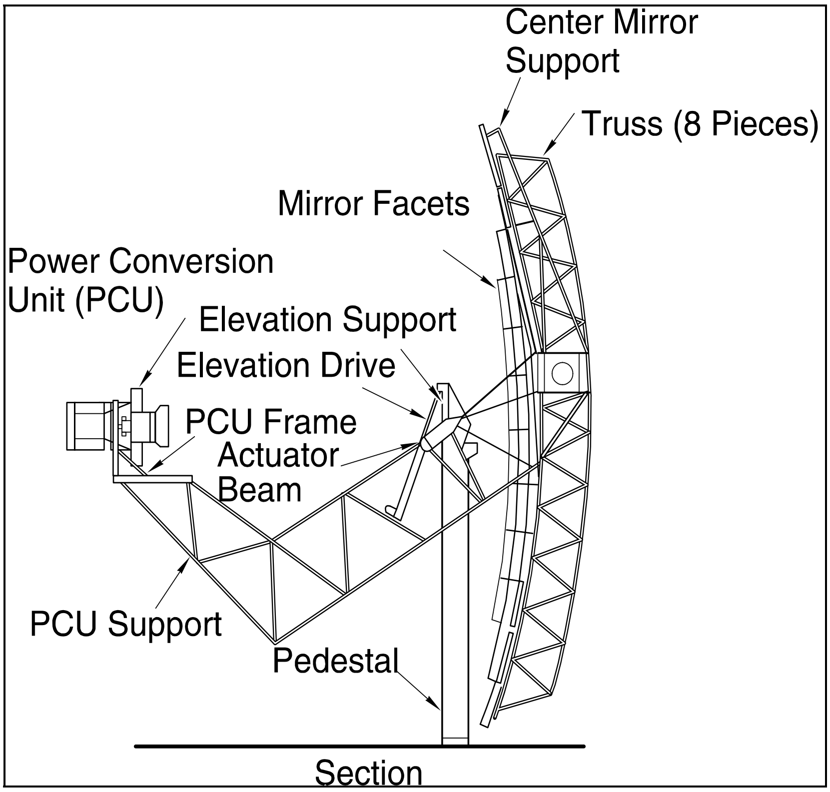

Figure 3.8 The 25 kW dish-Stirling system manufactured by MDA and marketed by Stirling Energy Systems (USA). Dish systems track the sun on two axes and focus direct normal solar insolation on a receiver. The receiver transfers the heat to the engine which converts the thermal power to mechanical power. A generator or alternator converts the mechanical power to electricity. Waste heat is rejected from the engine to the atmosphere.

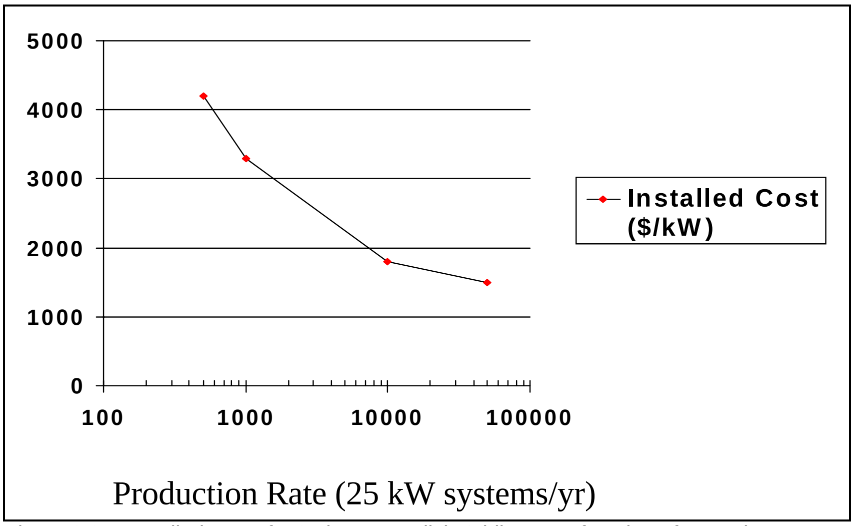

Figure 3.9. Installed cost of a 25 kW MDA dish-Stirling as a function of annual production volume [1].

3.3.2 Schlaich, Bergermann und Partner

Dish-Stirling Development

Schlaich, Bergermann und Partner have worked in the field of dish-Stirling systems for more than 17 years. From the first step in 1984 with two Æ17m/50kWel dish-Stirling systems in Riyadh, Saudi Arabia, to the small series of mature Æ8,5/10kWel dish-Stirling systems built at Almeria, Spain, in 1996 (see Figure 3.10), several steps were undertaken to improve the performance of components and the whole system while reducing system, operation, and maintenance costs.

- Two 50 kWel dish-Stirling units at a solar village in Riyadh / Saudi Arabia (1984)
- kWel dish-Stirling prototype at the campus of Stuttgart University (1989)
- Durability test of three 9kWel dish-Stirling units at the Plataforma Solar de Almeria in Spain in 1992, now with 27.000 hours operation experience
- Three 10kWel pre-commercial dish-Stirling units at the Plataforma Solar de Almeria in Spain in 1996

The present dish-Stirling system from Schlaich, Bergermann und Partner (the Æ8,5/10kWel dish-Stirling system) is approaching small series maturity. System costs have been significantly reduced. Figure 3.11 shows the actual and expected system costs evolution to a production figure of 10,000 units per year.

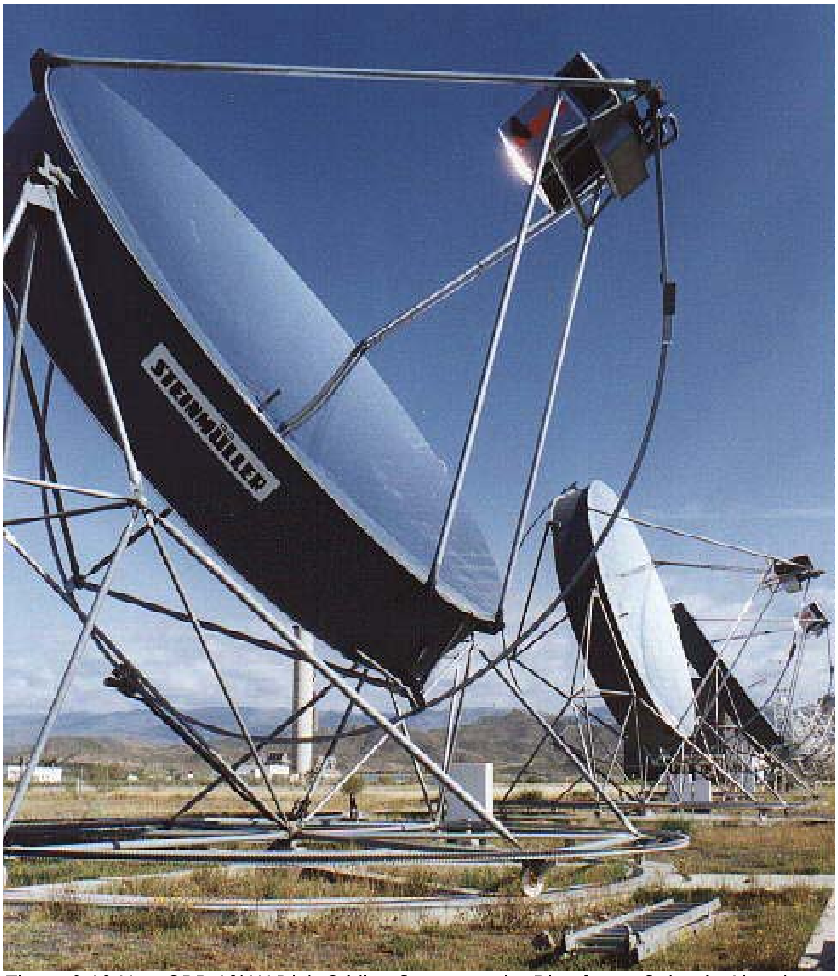

Figure 3.10 New SBP 10kW Dish-Stirling System at the Plataforma Solar de Almeria, Spain

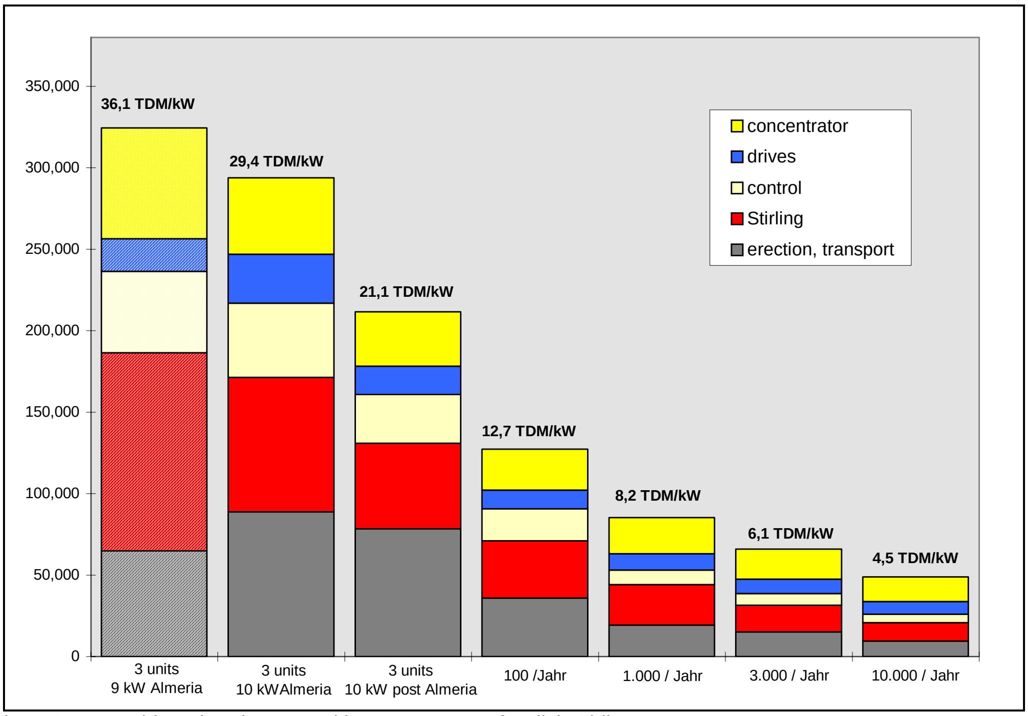

Figure3.11 Achieved and expected investment cost for dish-Sirling systems

On the basis of cost-and-performance data, the short-term, mid-term (2005), and long-term (2025) potential of CRS, DCS, SC and dish-Stirling systems was investigated in a study undertaken by the German Aerospace Research Center specially for the Mediterranean region.

Taking the general factors governing energy economy into account (basis demo-graphic/economic data, primary energy consumption, central and local power supply etc.), as well as insolation conditions (1,800-2,500kWh/m²/a) and the available land area and power consumption pattern in countries bordering the Mediterranean, the available technical and economic potential were calculated separately for the individual countries. To this end, the solar power generating costs were compared with the cost of power generated from fossil fuels.

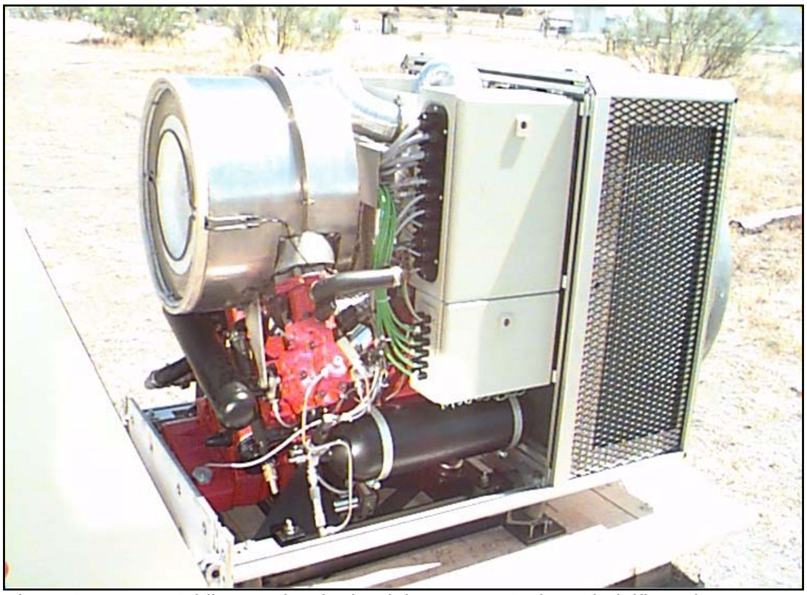

Figure 3.12 V161 Stirling Engine (Solo Kleinmotoren GmbH, Sindelfingen)

Hybrid System development

Hybrid dish-Stirling systems have been developed In close collaboration with DLR. Hybrid systems allow the Stirling engine to run in the case of low or completely absent insolation via fossil (diesel, natural gas) or renewable (biogas, hydrogen) fuels.

The hybrid dish/Stirling system is a reasonable supplement to the basic solar-only system if continuous power production has to be guaranteed. Although higher in investment cost, the hybrid dish-Stirling system opens a huge variety of further applications.

First operating experience was gathered on a prototype in Stuttgart, Germany. A continuous operation test is planned in 1998 in Almeria , Spain.

Future steps

As a next step towards getting into the market, it is proposed to build and operate 100 units as a 1MWel dish-Stirling power plant or as distributed clusters with several units each. This would lead to a reduction in system cost to approximately 12-13TDM/kWel and in following projects to below 10TDM/kWel. This would enable the dish-Stirling technology to compete with photovoltaic systems on the market. Other than the cost reduction, it is necessary to get more operating experience to evaluate performance and availability. With this broad data base it will be possible for the manufacturer to approve the expected operation and maintenance costs and to give the necessary warranties on lifetime and functionality.

Following the production and operation of the 100 units, it will be possible to penetrate niche markets. With increasing sale rates and accompanying further development of the system, it will be possible to establish the dish-Stirling system as a profitable product on the market.

Year	1996
Number built	3
Site	Almeria, Spain
Stage of development	3rd generation/pre-commercial system
Operating hours	500 h
Technical availability	n.a. %

Concentrator

Type Single-facet stretched-membrane concentrator

Design

Diameter	8.5 m
Total reflective area (projec	56.7 m²
Focal ratio, f/D	0.55
Concentration ratio (90%/av	2000
Tracking	Azimuth/Elevation on turntable
Drives	2 AC Servodrives
Reflective surface	Backsilvered 0.8mm glass bonded onto membrane

Performance

Net output (thermal /810 W/	37.2 kWth
Optical efficiency (Including intercept on receiver)	81 %
Technical availability	n.a. %

Stirling/Generator

Type SOLO 161 Stirling

Design

Net power (rated)	9.5 kWe
Number of cylinders	2
Stirling configuration	2 Piston 90° V single-acting
Displaced volume	160 cm³
Swept volume	n.a. cm³
Cooling system	Water /Air-forced radiator
Working gas	Helium
Mean pressure (max.)	15 MPa
Gas temperature (high)	630 °C

Performance

Net output (electrical)	9.5 kWe
Efficiency (thermal to electri	31 %
Technical availability	n.a. %

Receiver

Type Direct illuminated tube receiver

Design

Aperture diameter (Receive	260 mm
Peak flux on absorber surfa	70 W/cm²
Peak tube (front-side) tempe	850 °C

Performance

Output (thermal)	32 kWth
Efficiency	86 %
Technical availability	n.a. %

* Performance according to IEA-guidelines

Figure 3.13 Data Sheet of new 10 kW Dish/Stirling-System

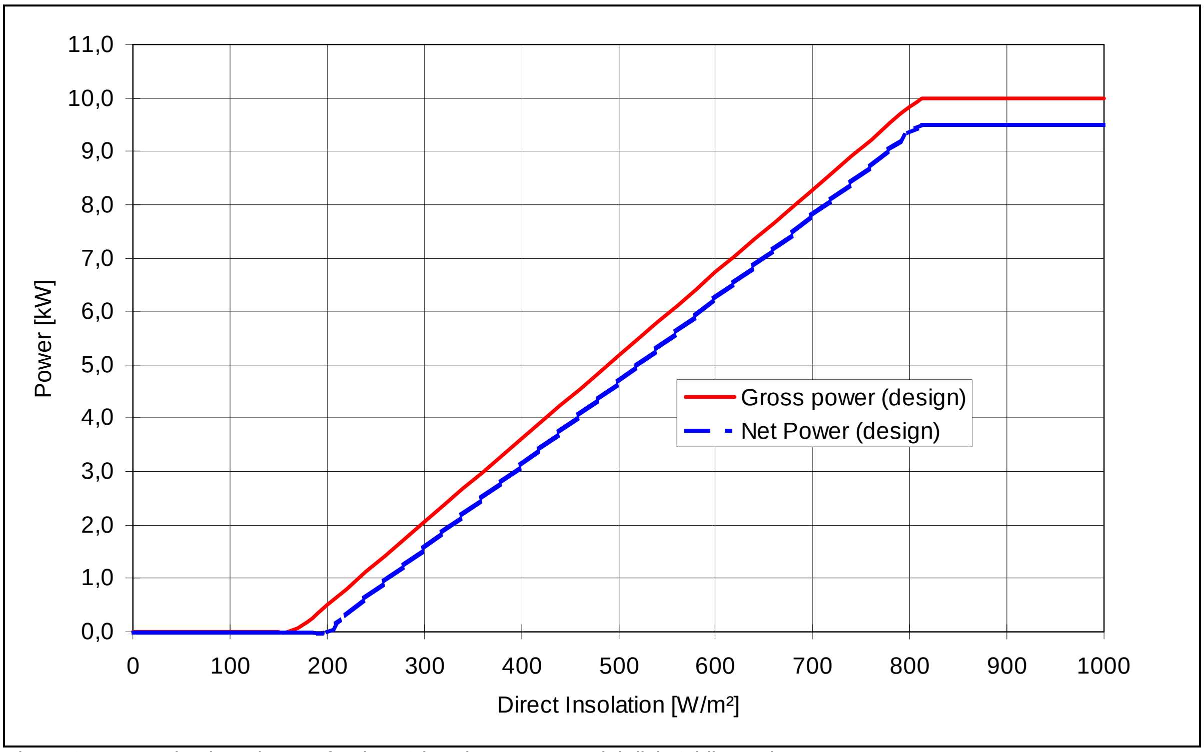

Figure 3.14 Design input/output for the 10 kWel pre-commercial dish-Stirling unit

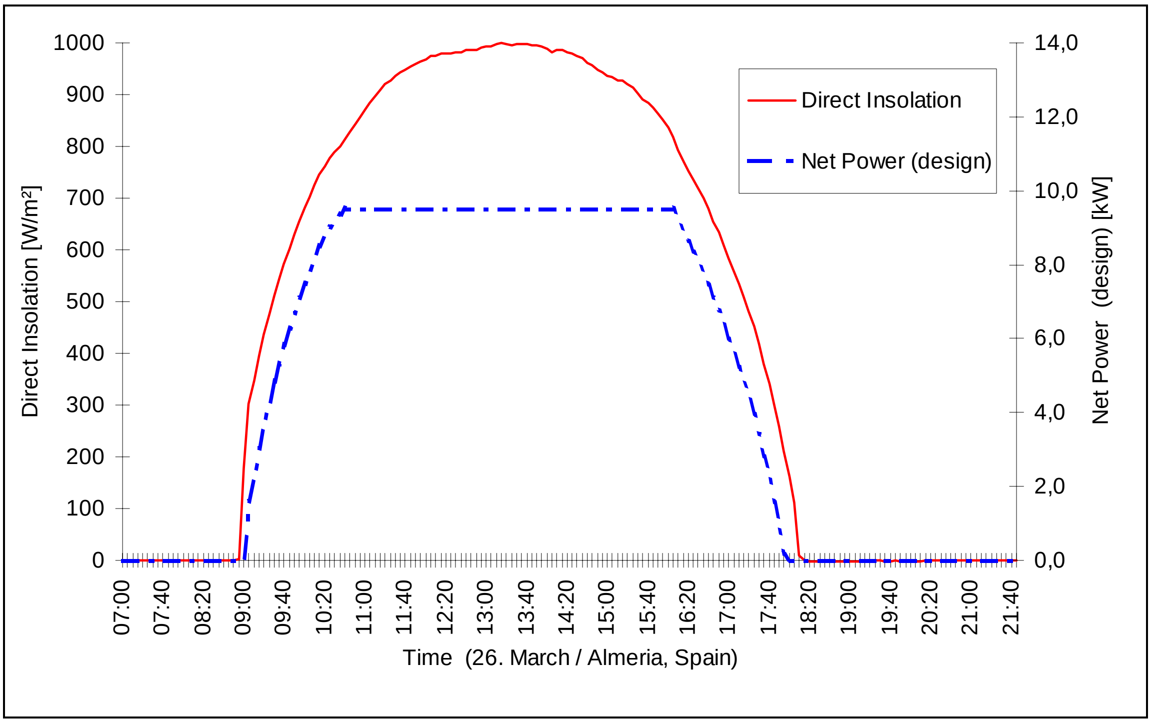

Figure 3.15 Design daily input/output curve for the 10 kWel pre-commercial dish-Stirling unit

4. Solar Thermal Advanced Research Lines

4.1 DIAPR and follow-on SCOT Project

The Solar Concentration Off-Tower/Combined Cycle (SCOT/CC) concept is aimed at heating air to 1300°C and 25 bars, compatible with the requirements of a modern and efficient gas turbine. It uses two recent developments by the Weizmann Institute of Science (WIS). The first development is the tower reflector optics. This concept is shown in Figure 4.1.

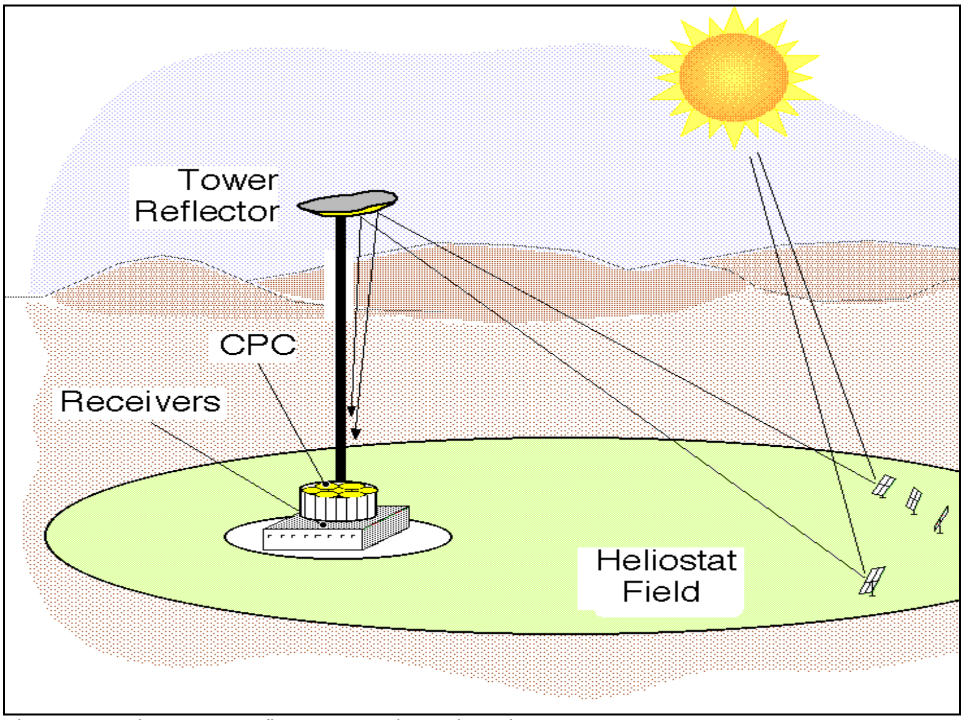

Figure 4.1 Solar 'Tower Reflector' Central Receiver plant concept

The Reflective Tower idea for solar central receiver system was proposed by Rabl (1976). A reflector is installed at the top of a tower, redirecting the concentrated solar radiation downward to a ground-level receiver. Several reflector shapes are possible; the preferred option is a hyperboloid with an upper focus coinciding with the heliostat field aim point. The reflector redirects the radiation toward the lower focus of the hyperboloid, near ground level. Final concentration devices (e.g., CPC) and conversion to thermal or other form of energy (receiver) are installed below the lower focal point. This optical configuration, called Cassegrain optics, is common in telescopes. It has several advantages for central receiver systems:

- <u>Better collection optics</u>: The Cassegrain arrangement produces a low concentration at its lower focus. However, it also produces a narrow view angle and a large effective focal length (due to magnification by the hyperboloidal mirror). This reduces optical aberrations, and allows a higher overall maximum concentration by a secondary concentrator installed at the lower focus.

- Stable flux distribution: The entire heliostat field has a single aim point, producing a single 'spot' at the lower focal region. This spot is divided among several CPC secondary concentrators. Each CPC accepts radiation from the entire field, and therefore the fraction of power allocated to each CPC varies little throughout the day. The overall power changes slowly during the day according to the cosine of the sun's declination angle. Thermal balancing and control issues are therefore absent.
- Ground-level plant: All major hardware (CPC, receiver, storage, power block, etc.) are conveniently located near ground level. This eliminates a massive and expensive tower, long piping, and the need for frequent personnel access to the tower top. The tower is light and inexpensive, supporting only a passive reflector component.

The second development is the Directly Irradiated Annular Pressurized Receiver (DIAPR), a volumetric, windowed cavity receiver that operates at aperture flux of up to $10 MW/m^2$. It is capable of supplying hot air at 1300°C and 20–30 bars. The two main innovative components of this receiver are:

- A Porcupine-like absorber made of an array of high- temperature ceramic (e.g., alumina) pins.
- A Frustum-like High-Pressure (FLHIP) window made of fused silica.

Based on the results of tests in the 30–50 kW range of this receiver, a 600kW prototype is under construction. It will be tested as the topping section of a two-stage partitioned receiver. The low-temperature section, exploiting the lower concentration edges of the ground image of the tower reflector optics, will be used for preheating the air before entering the central stage for final heating. The total capacity of the cluster of receivers will be about 1000kW. The testing of this demonstration project, including a 250kWe gas turbine, is scheduled for early 1999.

A detailed feasibility study was conducted to evaluate the performance and cost of this solar power generation system. Preliminary designs for two plant configurations were developed and optimized as part of this study, a 600kWe system and a $34MW_e$ system. These systems represent a typical range of plant scaling achieved using the new plant concept. The annual efficiency of the $34MW_e$ plant is significantly higher than the other designs of similar rating, mainly due to a higher efficiency power conversion unit (CC), and high receiver efficiency (made possible by the high-flux concentration). The annual efficiency of the 600kWe system is lower than the larger CC plant but still at the same level as the large 30MWe solar plants of conventional design.

The new reflective-tower/combined-cycle design has a clear installed-cost advantage when compared at a similar plant size. The small 600kWe system shows higher specific cost than the 34MWe plant, but still a very reasonable one; this degree of scaleability to small size at reasonable cost is not possible with the other central receiver plant designs.

4.2 Dual System Project

An original dual concept of energy storage and direct-electricity generation using central receiver (solar tower) technology was proposed by the Weizmann Institute and CEPEL as a prototype system for Brazil. The dual system consists of two independent receiver systems sharing the same tower where the cavities will be mounted. One of these cavities will be responsible for direct steam generation that will drive a steam turbo-generator. The other one will capture the energy necessary for carbon dioxide reforming of methane in the presence of a catalyst. The matching of the systems assures in this way that the storage of energy for electricity generation after sunset and avoids the operational problems associated with the passage of clouds.

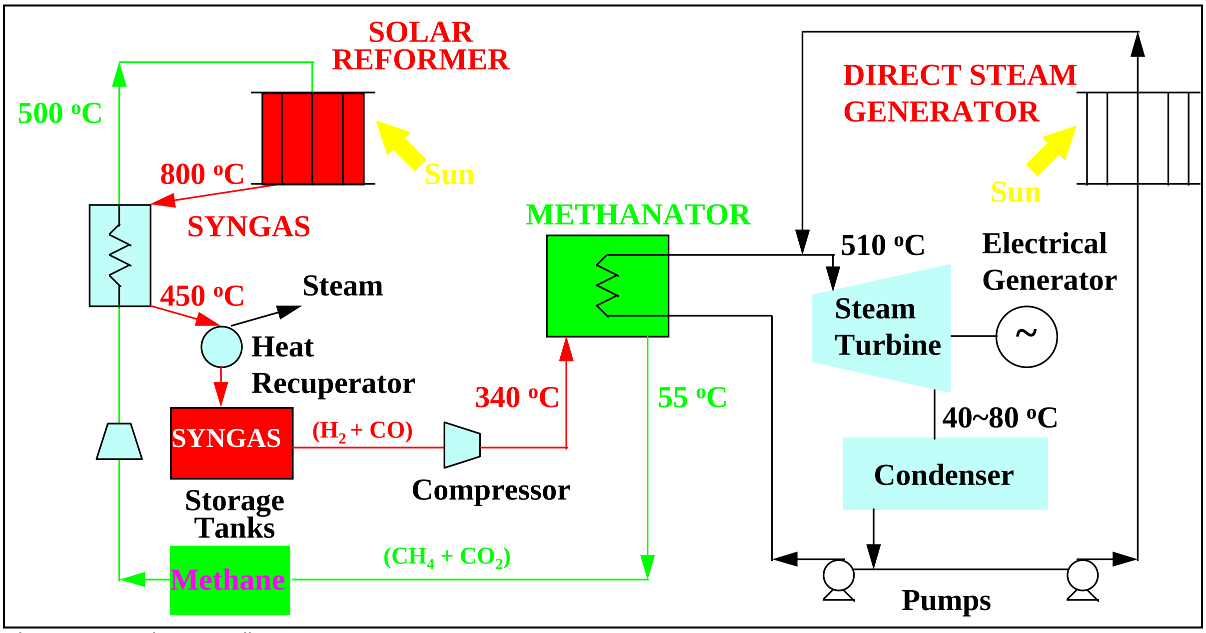

Figure 4.2 Dual system diagram

The energy will be stored as chemical energy in the products of the reforming process, being composed mainly by a mixture of hydrogen and carbon monoxide denominated as synthesis gas (SYNGAS). When needed, this thermal power can be recuperated through an inverse exothermic reaction to produce steam in a methanator, where the conversion of

SYNGAS to methane will take place in the presence of catalysts. The complete thermochemical process will occur in a closed loop. The system is referred to hereafter as "Dual System". Figure 4.2 is a diagram for the dual system proposed for the prototype. The prototype will be designed to generate daily up to 6MWh of electric energy at the best solar radiation conditions for irrigation purposes. The electric energy produced with the prototype will be used to irrigate 120 hectares. This system will use the Weizmann Institute of Science (WIS) technology for solar methane reforming based on the concept of thermochemical storage and transport of solar energy.

The main operational strategies of the dual system may be described as follows:

- The steam generation system shares the same power block as the thermochemical system. In this way, the system increment cost corresponds only to the investment on the solar boiler superheater.
- Direct steam generation upgrades the overall system efficiency being adequate to provide electricity for loads in phase with the incoming solar energy, for example, irrigation electric loads.
- Control systems will assure the compatibility of the joint operation of the thermochemical and direct-steam generation systems.
- Instability and storage problems are solved by the matching of systems.
- The possibility to generate saturated steam in the direct water/steam receiver and to superheat the steam; storing the solar energy using the 'chemical' part of the system will also be investigated.

In the following table the basic preliminary technical data are presented for a prototype system typical of an irrigation load. The potential sites are the northeastern region of Brazil and the northern state of Minas Gerais. The methane reforming technology can be integrated in the future with the Brazilian fuel-alcohol program.

Table 4.1Dual System Basic Characteristics

PROTOTYPE	DIRECT STEAM GENERATION AND THERMOCHEMICAL CLOSED LOOP
Thermal cycle Electrical power block Reformer (solar reactor) Solar boiler/superheater	Rankine cycle 2 x 250 kWe 2000 kW 2000 kW

Tower height	60 m
Heliostat field	9000 m^2
Thermochemical loop efficiency (storage/energy recuperation)	0.82
Dual system efficiency	0.13
Storage tanks for methane and SYNGAS	2 x 120 m^3 @ 50 bar
Power block	Steam turbo-generator

5. Brazilian Electric Sector and Business Climate

5.1 Energy Resources

Brazil's installed capacity of 55.5GW in 1995 included a 6.3GW share of the Itaipu Binacional hydroelectric power plant. Hydroelectric accounts for 93% of Brazil's total generation. One nuclear plant producing 657MW was brought on-line in Brazil and the second, slated for completion in 1999, will produce 1300MW. Self-producers hold approximately 3% of the installed capacity in large manufacturing and mining operations. Figure 5.1 shows the installed hydroelectric and thermoelectric capacities, with the thermoelectric resources separated into categories of diesel, fuel oil, coal, nuclear, and others (including firewood, bagasse, natural gas and wind).

BRASIL - CAPACIDADE NOMINAL INSTALADA - MW

Ano	Hidráulicas (1)	Térmicas					Total
		Diesel	Combustível	Carvão	Urânio	Outros (2)	
1986	35.877	1.016	1.975	896	657	12	40.433
1987 (3)	38.103	1.020	1.842	1.046	657	12	42.680
1988 (3)	39.663	1.200	1.842	1.046	657	31	44.439
1989 (3)	43.088	1.171	1.842	1.046	657	113	47.917
1990 (3)	44.198	1.107	1.842	1.046	657	113	48.963
1991 (3)	45.967	1.124	1.842	1.046	657	113	50.749
1992 (3)	47.064	1.130	1.842	1.046	657	-	51.739
1993 (3)	47.967	1.238	1.842	1.046	657	-	52.750
1994 (3)	49.297	1.262	1.842	1.046	657	1	54.105
1995 (3)	50.687	1.279	1.842	1.046	657	1	55.512

(1) Exclui as usinas de bombeamento da LIGHT;
(2) Inclui lenha, carvão vegetal, gás natural e eólica;
(3) Inclui 50% da capacidade instalada de ITAIPU pertencente ao país.

Figure. 5.1 Installed capacity by year and resource (Source ELETROBRÁS Relatório Anual 1995)

Brazil has an estimated 247GW of hydroelectric potential, 40% of which lies in the Amazon Basin. Figure 5.2 shows the distribution of Brazil’s hydro potential by geographic region. The country also has resources of coal, uranium, gas and oil. Brazil's supply of 4.2 billion tons of coal is of generally low quality due to a high sulfur and ash content. Most of the country's reserves of oil (2,800 million barrels) are located offshore and are therefore expensive to utilize. Natural gas reserves total 4.372 trillion cubic feet, and Brazil is moving toward the development of an 1180-mile pipeline from Bolivia to deliver 30 million cubic meters per day. Brazil's sugar cane industry generates waste products (or bagasse) equivalent to 270,000 barrels of oil per day. Figure 5.3 illustrates Brazil’s available energy resources, with purchases from Itaipu and self-producers accounting for 12% of the total.

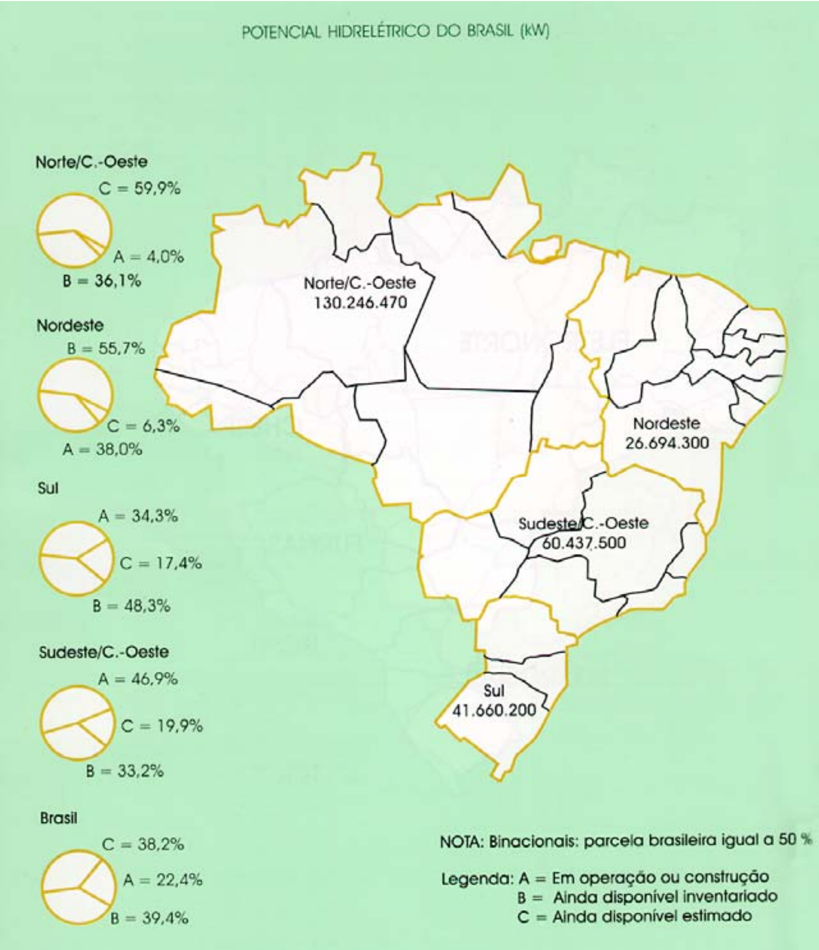

Figure. 5.2 Map of hydro potential by region (Source ELETROBRÁS Relatório Anual 1995)

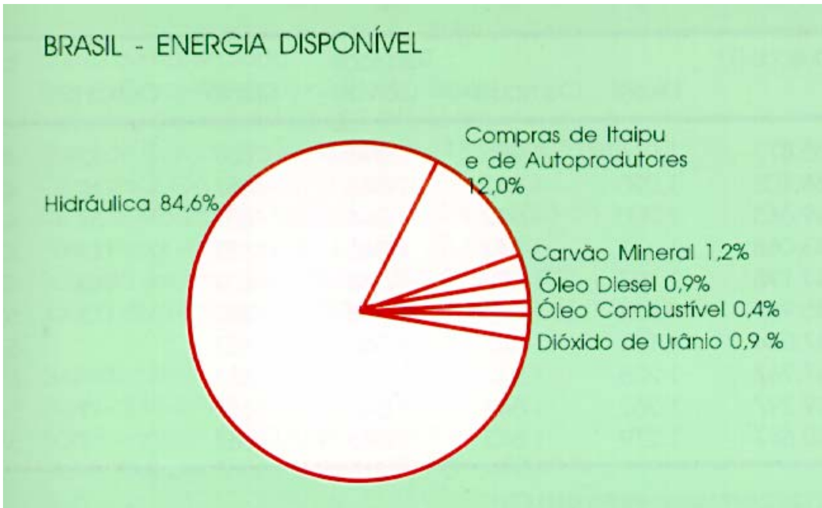

Figure. 5.3 Available energy resources (Source ELETROBRÁS Relatório Anual 1995)

5.2 Utilities

All concessions are granted according to provisions in the Brazilian constitution. In addition, it is the republic's prerogative to utilize the country's hydroelectric resources in cooperation with the states having those resources. The MME governs the country's energy policy and all development of energy resources. Until 1997 DNAEE) was the regulatory agency for electric power services. The new ANEEL will replace DNAEE under provisions enacted in 1996.

The Brazilian electric sector is comprised of two regional systems which operate independently of each other: the north/northeast region, and the south/southeast/west-central region. Together these two systems comprise 97% of the installed generating capacity of Brazil. The interconnection of these two systems will improve the overall level of guaranteed energy due to the differences in the hydrology of the two regions.

Four regional utilities (Figure 5.4) are responsible for the generation and transmission of electric energy: ELETRONORTE in the north and central-west regions, CHESF in the northeast, FURNAS in the southeast and central-west, and ELETROSUL in the southern regions. Figure 5.5 shows the breakdown of installed capacity by utility and resource.

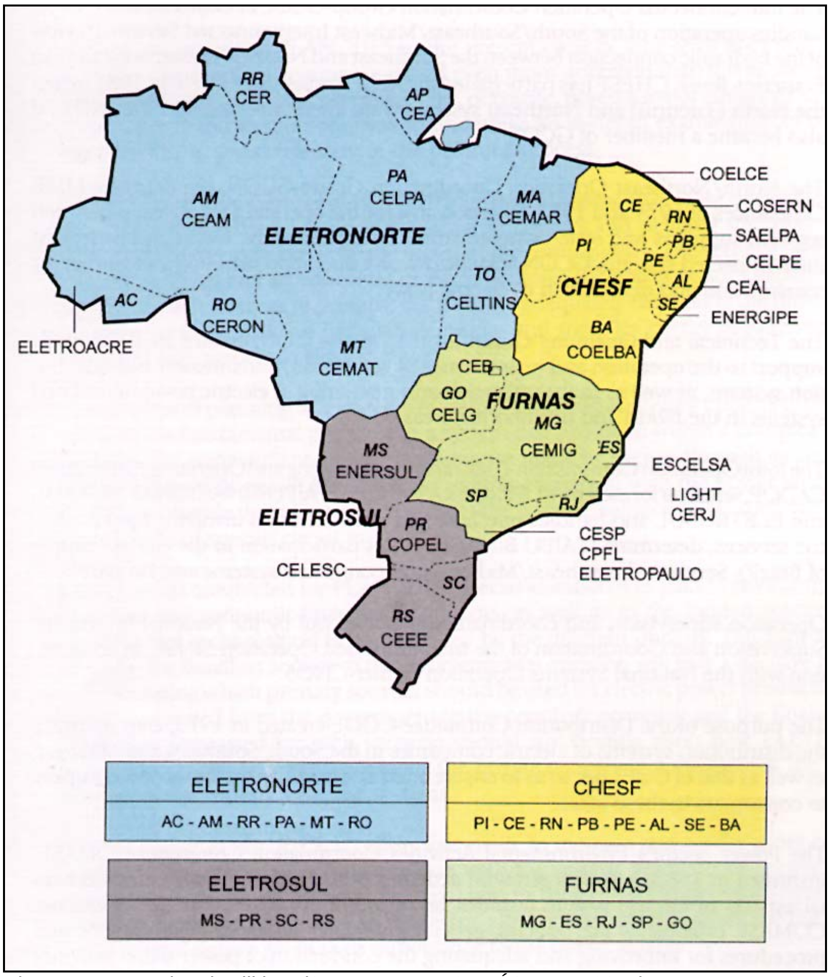

Figure 5.4 Regional Utilities (Source ELETROBRÁS PLAN 2015)

The federal and state governments own most of the 62 companies supplying electricity in Brazil. The central utility, Centrais Elétricas Brasileiras S.A. (ELETROBRÁS), is partly owned by the federal government and is charged with financing and overseeing programs for building and operating the systems for generation, transmission and distribution of electricity in all regions of Brazil.

BRASIL - CAPACIDADE GERADORA INSTALADA EM 31/12/95 MW

	Hidráulicas	Térmicas					Total
		Diesel	Combustível	Carvão	Urânio	Outros (1)	
SISTEMA ELETROBRÁS	23.660	761	1.191	554	657	-	26.823
FURNAS	6.800	-	666	-	657	-	8.123
CHESF	8.772	142	290	-	-	-	9.204
ELETROSUL	2.602	-	66	554	-	-	3.222
ELETRONORTE	4.710	619	169	-	-	-	5.498
LIGHT (2)	776	-	-	-	-	-	776
OUTRAS EMPRESAS	20.727	518	651	492	-	1	22.389
ITAIPU (3)	6.300	-	-	-	-	-	6.300
TOTAL	50.687	1.279	1.842	1.046	657	1	55.512

(1) Inclui 1 MW de eólica;
(2) Exclui as usinas de bombeamento;
(3) Inclui 50% da capacidade instalada de ITAIPU pertencente ao país.
Fonte: SIESE.

Figure 5.5 Installed capacity by utility and resource (Source ELETROBRÁS Relatório Anual 1995)

5.3 Energy Market

In 1995 Brazil's total grid-connected electric energy use was 296.3TWh, of which 35.2TWh was imported from Paraguay and 0.3TWh was purchased from self producers. The interconnected systems supplied 215.8TWh, Itaipu Binacional supplied 38.5TWh, and the remaining 6.4TWh was provided by the independent or isolated systems. In the northeastern region of Brazil are some 316 isolated electrical grid systems of various sizes and complexities whose operations are critical. In these areas, only 53% of the sites have 24 hours of service per day.

Besides the large number of consumers in the industrial, commercial and rural sectors, the system brought new service to 1.023 million new residential consumers in 1995. The residential electric service rate stayed at approximately 90%, the highest of any of the public services.

Power losses due to pirate consumers are a frequent occurrence in large cities in Brazil. For example, in Rio de Janeiro, Companhia Elétrica do Rio de Janeiro (CERJ) loses about 27% of the electricity it supplies and Light Services de Electricidade (Light), before privatization, was losing about 16%. In April of 1997, the Ministry increased electric rates for federal utilities and state distribution companies by 10%. The most recent increase before this was in November 1995.

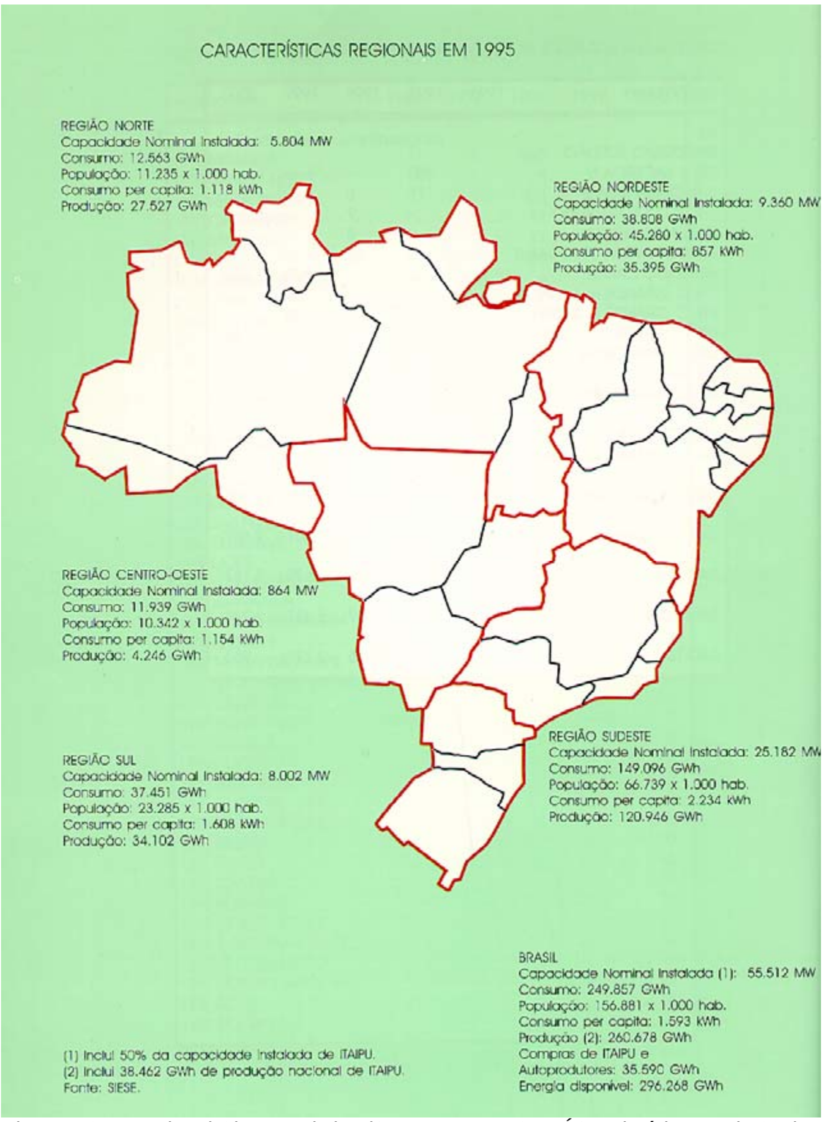

Figure 5.6 Regional Characteristics (Source ELETROBRÁS Relatório Anual 1995)

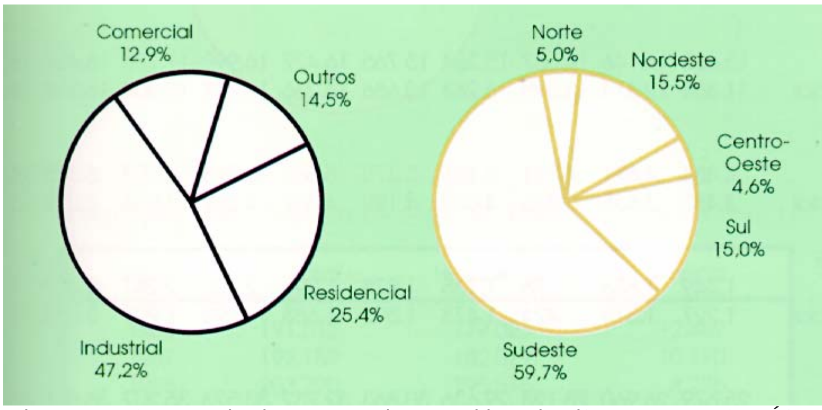

Figure 5.7 Consumption by sector and geographic region (Source ELETROBRÁS Relatório Anual 1995)

BRASIL: CONSUMO DE ENERGIA ELÉTRICA - GWh*

Ano	Industrial	Residencial	Comercial	Outros	Total
1986	97.155	35.792	19.611	24.678	177.236
1987	97.376	38.407	20.472	25.695	181.950
1988	103.636	40.564	21.354	27.182	192.736
1989	107.194	43.718	22.377	28.182	201.471
1990	104.422	48.053	23.814	29.020	205.309
1991	107.619	51.110	24.960	30.735	214.424
1992	108.882	51.864	25.938	31.722	218.406
1993	113.422	53.629	27.403	32.667	227.121
1994	116.756	55.952	28.881	34.038	235.627
1995	117.964	63.522	32.142	36.229	249.857

* Inclui tarifas especiais.
Fonte: SIESE.

Figure 5.8 Electric energy consumption by sector and year (Source ELETROBRÁS Relatório Anual 1995)

BRASIL: NÚMERO DE CONSUMIDORES DE ENERGIA ELÉTRICA - mil unidades

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
NORTE										
Total	824	890	968	1.128	1.223	1.309	1.390	1.487	1.573	1.659
Residencial	710	769	845	988	1.072	1.147	1.224	1.313	1.389	1.452
NORDESTE										
Total	5.330	5.700	5.986	6.323	6.622	6.909	7.195	7.618	8.005	8.361
Residencial	4.655	4.975	5.248	5.548	5.802	6.025	6.278	6.666	7.018	7.307
SUDESTE										
Total	13.622	14.146	14.587	15.284	15.765	16.427	16.990	17.738	18.451	18.956
Residencial	11.884	12.314	12.695	13.283	13.686	14.236	14.741	15.404	16.019	16.406
SUL										
Total	4.454	4.671	4.911	5.166	5.375	5.588	5.828	6.107	6.375	6.601
Residencial	3.480	3.635	3.825	4.035	4.199	4.367	4.569	4.808	5.022	5.201
C.-OESTE										
Total	1.449	1.553	1.676	1.735	1.878	1.999	2.120	2.257	2.407	2.546
Residencial	1.227	1.313	1.424	1.473	1.592	1.688	1.795	1.909	2.034	2.139
BRASIL										
Total	25.679	26.960	28.128	29.636	30.863	32.232	33.523	35.207	36.811	38.123
Residencial	21.956	23.006	24.037	25.327	26.351	27.463	28.607	30.100	31.482	32.505

Fonte: SIESE.

Figure 5.9 Consumption by geographic region and year (Source ELETROBRÁS Relatório Anual 1995)

5.4 Privatization

The Concessions Law passed in February of 1995 has allowed Brazil to begin selling government-owned electric generation assets. The National Privatization Council determines which of the federally-owned electric assets are next in line for privatization. ELETROSUL was to be privatized in the fourth quarter 1997, followed by FURNAS in the first-quarter 1998. Federal and state assets of 50,608MW have been identified for privatization on a partial-ownership basis. The National Development Bank (BNDES) manages the auction process. US$32B made from such sales in 1997.

CEMIG, the generation and distribution utility in the State of Minas Gerais, for example, plans to sell a 33% stake in its 5,000MW utility. CEMIG is seen as an excellent acquisition.

ELETROPAULO, CPFL and CESP in the state of São Paulo are Brazil's three largest distribution companies, owning over 11,000MW of generating capacity. The population of São Paulo State is about 33 million and represents about 22% of the entire country. The state assembly has passed legislation to allow the utilities to restructure into as many as 21 generation, distribution and transmission units to facilitate privatization. Concessions will be awarded for periods of 35 years for generation companies and 25 years for distribution. The state will retain some shares and a certain degree of management control.

CERJ has about 1.2 million customers in the city of Niteroi and distributes about 20% of the power in the state. Light distributes electricity to the city of Rio de Janeiro and to the remainder of the state. A controlling share of Light, formerly held by the federal government, was sold in May 1996.

A nation-wide completion program for hydro and thermal plants, whose development was suspended due to lack of funding, comprised 22 projects totaling 10,132MW. The utility concession holders for Canoas 1 and 2, Ita, Igarapava, Serra da Mesa, Dona Francisca, and Jacqui have already found private partners to finance completions. The remaining 15 projects, representing 6,550MW, are still seeking partners.

A utility/industrial consumers consortium was formed in 1994 for the US$270-million, 210MW, Igarapava hydroelectric project. The utility partner is CEMIG and the industrials are mining and steel companies (Companhia Vale do Rio Doce, Companhia Mineira de Metais, Mineracao Morro Velho, Companhia Siderurgica Nacional, and Eletrosilex).

5.5 Expansion

Although the growth rate is the highest in the north, northeast, south and central-west regions, the southeast still has the highest intensity of electric consumption and the highest volume of consumption. The total electric energy consumption of Brazil, excluding imports, will rise from 258TWh in 1995 to between 416TWh and 449TWh by the year 2005 according to ELETROBRÁS.

BRASIL: PREVISÃO DO CONSUMO DE ENERGIA ELÉTRICA POR CLASSE - GWh *

ANO	INDUSTRIAL	RESIDENCIAL	COMERCIAL	OUTROS	TOTAL
1996	116.900	65.200	33.400	37.100	252.600
2000	136.300	80.900	42.000	45.100	304.300
2005	170.200	104.500	54.700	55.800	385.200

* Não inclui tarifas especiais e autoprodutores.

Figure 5.10 Consumption forecast by sector and year (Source ELETROBRÁS Relatório Anual 1995)

BRASIL: PREVISÃO DO CONSUMO DE ENERGIA ELÉTRICA POR REGIÃO - GWh *

REGIÃO	1996	2000	2005
Norte	13.900	20.200	31.600
Nordeste	40.200	49.700	65.400
Sudeste	147.000	170.300	205.200
Sul	38.900	47.600	60.800
Centro-Oeste	12.600	16.500	22.200
BRASIL	252.600	304.300	385.200

* Não inclui tarifas especiais e autoprodutores.

Figure 5.11 Consumption forecast by region and year (Source ELETROBRÁS Relatório Anual 1995)

Figure 5.12 Map of main plants (Source ELETROBRÁS Relatório Anual 1995)

The Public Service Law enacted in July 1995 specifically addresses the right of independent power producers to produce and sell electricity. The MME is awarding concessions for new power plant development through the year 2004 through a program of solicitations. The program includes 94 hydro and 17 thermal projects representing a total capacity of 37,106.4MW and a total investment of US$37,652-billion. The concessions were previously held by various utilities but were revoked because development had stalled.

Figure 5.13 Map of transmission lines (Source ELETROBRÁS Relatório Anual 1995)

5.6 Deregulation of the Economy

In 1990 a strong movement began to shift the Brazilian economy away from centralization toward liberalization. The trend of privatizing mining, telecommunications, and the electric sector continues as Brazil trudges along a new path of economic planning which includes the Real Plan for the new currency and controlled inflation and the National Privatization Program for selling off state-owned companies.

Privatization efforts from 1991 through 1997 realized over US$18-billion of income for Brazil, with 20% of that from foreign companies. Brazil anticipates revenues of US$120-130-billion per year over the next few years of continuing privatization.

Structural reform depends in great part on changes to the constitution with respect to public service, taxes and retirement, and the pension system. The progress of these reforms, indispensable and essential to long-term stabilization, has been extremely slow. Improvement in the budget situation for 1997 is due to three factors: (1) reduction in the cost of servicing internal debt proportional to the drop in interest rates; (2) the start of adjustments in state and municipal administrations after the grading of internal debts; and (3) the increase in income from privatization with the sale of important companies of mineral extraction, distribution of electricity, and telecommunications.

The Organization for Economic Cooperation and Development (OECD), an international institution of high level economists comprised of the 29 most developed nations of the world and highly respected for its impartiality, warns that sustained improvement in the fiscal situation in Brazil will require new budget measures and an acceleration of structural reforms.

5.7 Economic Indicators

With a Gross National Product (GNP) over US$750-billion, Brazil is one of world's ten largest economies. The country has a population of 160 million, a diversified industrial base, and a growing agricultural base. Per capita gross national product in 1991 was US$2900 and by 1996 had increased to US$4700. According to OECD, per capita gross national product in 1997 had increased 4.5% from the year before and is projected to increase another 4.0% in 1998.

Inflation in Brazil in the year 1993 was 2700%. By 1996 that figure was less than 10%. Along the same lines, the rate of growth of the Consumer Price Index continues to slow, as 1997 increased 8.0% over 1996 and is expected to increase only 6.0% in 1998. Brazil maintained the pace of growth started last year, with the increasing inflow of capital and lower nominal interest rates creating conditions for a general comeback. Actual personal consumption and growth in fixed investments were sustained over the past year.

According to the OECD the economy of South American countries should continue to grow 3-6% per year due to the inflow of external capital and the increase in consumer demand. The principle risk continues to be that concerns in relation to the sustainability of the debt load in a country as big as Brazil could provoke a flight of capital and a strong increase in interest rates in the entire region.

5.8 International Investments Trading and Opportunities

In 1993 Brazil's foreign investments totaled US$1-billion. By 1997 that number had exceeded US$10-billion, with Brazil becoming a worldwide production center. In the mid-80s Brazil had international trade of around US$45-billion, in 1996 close to US$100-billion, and in 1997 reached US$110-billion.

The Mercosul Trading Block started a free-trade zone between Argentina, Brazil, Paraguay, and Uruguay and included Chile and Bolivia as associate members. Mercosul is now a market of 200 million people with a gross product over US$1-trillion. Trade within Mercosul was US$2.3-billion in 1987, US$4.5-billion in 1991, and by the close of 1997 around US$20-billion. The OECD notes that an increase in the external debt of Brazil could bring about protectionist pressures and that any measures intended to limit importation would severely affect the rest of Mercosul, whose principle import market is Brazil.

Large investments are currently required in Brazil's manufacturing and distribution infrastructure. Foreign investment is encouraged by the current administration and foreign ownership is generally allowed. Business opportunities exist in manufacturing of consumer goods, utilities such as electric generation, telecommunications, public transportation, mining, and the pharma-chemical industry.

6. START Mission Findings

6.1 Solar Thermal Project Options

Power to supply off-grid village and irrigation loads, as well as grid-connected power for cities, have been identified by CEPEL and others as the market for the deployment of solar thermal power plants in Brazil. These plants would be located in the high-solar regions along the São Francisco River and in the Northeast (see cloud cover map presented previously). The total potential for solar-powered irrigation loads has been estimated by CEPEL to be between 4500-7500MW [2] and CHESF estimates a total solar potential of ~15000 MW [3]. The size of the proposed plants are from 10's of kW to ~100MW. All three solar thermal technologies (trough, tower, and dish) could be deployed to fill the market need.

6.1.1 Solar Trough

Parallel to the development and implementation of the commercial solar-thermal parabolic trough SEGS plants in California, the former Luz International Ltd.(LUZ) and its industrial German partner Flachglas Solartechnik Gmbh[1] (FLAGSOL) initiated in 1989 SEGS project development activities in Brazil and formed for this purpose a consortium together with ABB do Brazil and the Tenenge/Odebrecht group. With partial funding support from the German Ministry for Research and Technology (BMFT), the following project development activities where carried out:

- Site Surveys in the concession areas of CEMIG, CHESF and ELETRONORTE [4-6], which concluded in the recommendation of Januária in CEMIG's area as the preferred site for the implementation of a first 80MW SEGS type solar plant.
- Prefeasibility study on the implementation of 420MW of SEGS plants in the State of Minas Gerais between the years 1991 and 1999 [7]
- Prefeasibility study on the implementation of Integrated Solar Combined Cycle Systems (ISCCS) in the State of Minas Gerais [8]

While the detailed information is available in the final reports of the aforementioned. studies, a brief summary of their main findings and results is given in the following:

[1] Flachglas Solartechnik GmbH has changed in 1996 its name into Pilkington Solar International Gmbh (PilkSol)

6.1.1.1 Site Survey in the CEMIG Area

From 1989 to 1990, under leadership of Flachglas Solartechnik, the aforementioned. German-Brazilian consortium conducted together with CEMIG a survey in the concession area of CEMIG to find one or two optimal sites for the implementation of large-scale solar thermal power plants of the SEGS technology.

Two separate teams of experts from FLAGSOL, with the active support and participation of CEMIG's experts from the department of operations, planning and R+D, screened the entire state of Minas Gerais searching for the high potential areas. After comprehensive preliminary research in CEMIG's offices, the northern part of Minas Gerais had been identified to have high solar radiation potential as well as a strategic need for power generation facilities. Within the regions of Noroeste, Alto São Francisco and Jequitinhonha, 20 possible sites were identified (see Figure 6.1) and then visited by specialized field analysis teams. After a first field trip to these sites, 4 high potential sites (#1 Janaub, #6 Cacarema, # 18 Itacarambi and # 19 Januária) were recommended to a second field analysis team for further review.

It was found that the Januária site showed the highest potential in terms of insolation, infrastructure, electricity grid connection, accessibility and water availability. The site is situated approximately 20 km south-east of the city of Januária on the eastern bank of the Rio São Francisco. The Januária site offers abundant flat land and is very near to a double circuit 138 kV transmission line. Optimal road access directly to the site is the BR 135, a paved highway from Montes Claros to Januária. Water is available from the Rio São Francisco (approx. 5 km).

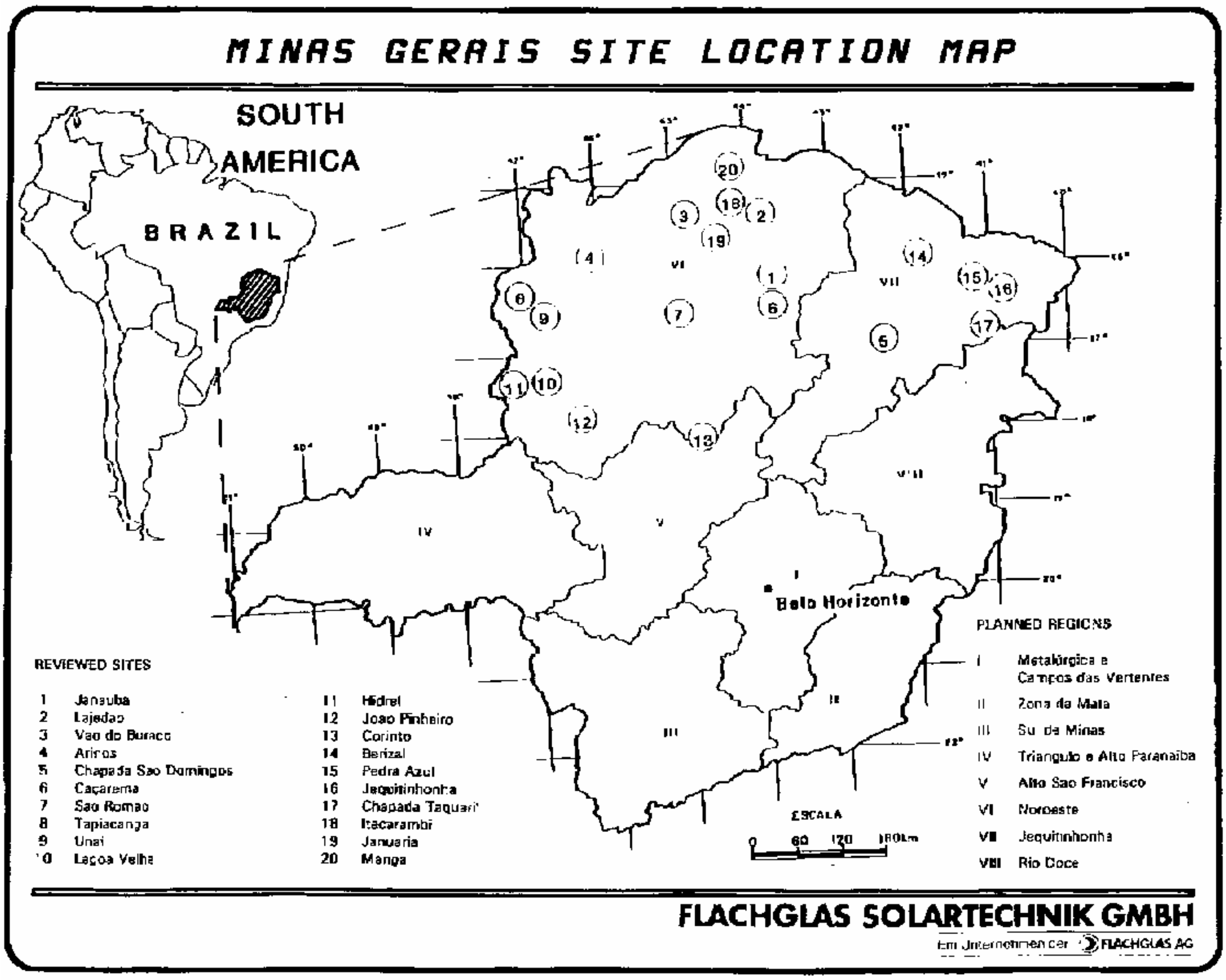

Figure 6.1 Prospective sites in the state of Minas Gerais for solar thermal plants as surveyed by the CEMIG-Flachglas Solartechnik teams in 1989-1990 [Courtesy of Pilkington Solar International, Cologne]

6.1.1.2 Site Survey in the ELETRONORTE Area

The Joint ELETRONORTE - FLACHGLAS SOLARTECHNIK Site Evaluation Team commenced its site survey activities in August 1988 with the purpose to identify one or two suitable sites for the implementation of SEGS type solar thermal plants.

Measured direct normal solar radiation data were not available in ELETRONORTE's supply area. For the proposed sites in ELETRONORTE's area, global data were converted to direct normal insolation through a theoretical model.

Figure 6.2 Prospective sites in the concession area of ELETRONORTE for solar thermal plants as surveyed by the ELETRONORTE-Flachglas Solartechnik teams in 1989-1990 [Courtesy of Pilkington Solar International, Cologne]

The general climatic conditions of the Amazon Basin are difficult for SEGS, although the theoretical solar potential is among the highest in the world. The massive body of the Amazon river creates a climate of its own, with characteristics similar or even worse than coastal environments. Precipitation is high throughout the territory and there is considerable cloudiness, due to evaporation, These two factors still allow the implementation of SEGS, from the technical standpoint. The greater problem for SEGS in this region is that during the dry (sunny) period of the year, pioneers who are clearing the forests burn the felled trees for some three months. During that time, the sky is effectively covered with smoke, sometimes reducing the direct insolation to unacceptably low levels. The degree to which the smoke affects the insolation level is thus a critical criteria in the site survey.

The survey examined each site's qualities within certain categories. These were solar insolation, proximity to a work force, climatic conditions, current installed capacity, electricity demand and its future evolution, grid interconnection possibilities, soil quality, topography and access by road, rail and boat.

Based on these criteria, the sites at Chapada dos Guimaráes near Boa Vista presented themselves as the best sites for further SEGS investigation and evaluation. While Vilhena and Porto Velho also showed good infrastructural conditions, the smoke problem severely affected the radiation level in the dry season. The disparity between these two and the prime candidates is hence so great that attention should be directed at Cuiabá and Boa Vista. The Site Team did not recommend further investigation of any of the other sites at this stage.

Boa Vista

Boa Vista insolation is the most intense, but has relatively low duration; (6-7 months) yearly sunshine are 2500 hours. Solar-electric generation will probably not be possible during the rainy season, despite low precipitation but will reach full potential in the summer. In conclusion, Boa Vista is promising, and although real insolation most probably is lower than at Chapada dos Guimaráes, further investigation of solar radiation should be carried out there. The proposed site, suitable for the implementation of 80MW SEGS, was some 10 km from the city.

Chapada dos Guimaráes (Cuiabá)

Over the year Cuiabá insolation shows higher levels than all other sites, averaging 2565 hours of sunshine per year, singling it out on this first basis. Of greater importance is that useful direct normal radiation at this site will be relatively high. Chapada dos Guimaráes is located on a high plateau 70 km north of Cuiabá and most of the smoke from the burning trees dissipates below the site, thus interference is quite low. Precipitation is lower than at other locations, enhancing these insolation statistics. Concerning infrastructure, a 138 kV line which connects to Cuiabá is located only some 3 km from the proposed site, facilitating interconnection. The site has excellent access; trucks can transport equipment from the nearest port at Caceres in one day.

The ELETRONORTE - Flachglas Solartechnik site survey team recommended two sites for consideration by ELETRONORTE: Boa Vista and Chapada dos Guimaráes

(Cuiabá). Boa Vista was recommended to be chosen for a first feasibility study, if a preceding solar measurement program would show a sufficient level of solar radiation.

6.1.1.3 Site Survey in the CHESF Area

A Flachglas Solartechnik team with CHESF assistance has screened in 1988 to 1989 the CHESF territory looking for high potential areas. After a preselection procedure the designated sites were subjected to a detailed examination. Three high potential sites were recommended by the first site survey team. The second team has ruled out one of these sites The following two locations were recommended for a further feasibility study:

Petrolina Area
This area offered several feasible sites. As best among them the Juazeiro Site about 8 km south of Juazeiro City was considered. The topographical conditions (surface, slope, soil, water availability) is excellent. Access is easy as the paved road and the railway track to Salvador touch the site. The cities of Petrolina, Juazeiro and the CHESF Sobradinho residential community provide a good infrastructure. A 230 kV substation is adjacent.

Bom Jesus da Lapa:
The area around the city is flat land, disturbed however by small mounds and many dips, increasing the amount of necessary earthwork. Access is very difficult on unmaintained dirt roads and might be improved by using river barges. Due to its relatively isolated location the city can only provide a basic civilian infrastructure. Technical support is weak. Bom Jesus de Lapa is at the edge of the CHESF grid. A 230 kV substation is nearby.

Both locations offer a good solar potential, however, the German team gave its preference to the Petrolina Area.

6.1.1.4 Prefeasibility Study on the Implementation of a First 100MWe SEGS Plant in Minas Gerais

This study was carried out jointly by CEMIG and FLAGSOL with financial contribution of the BMFT (Federal Ministry for Research and Technology, Federal Republic of Germany). Solar data were retrieved from CEMIG's records of their own existing solar surveys from INPE, as well as from other, mostly Brazilian, sources. A new solar measurement program in the vicinity of the selected site was initiated by CEMIG with the first phase in Janauba in June 1989 and the second phase in Januária and Itacarambi in March 1990.

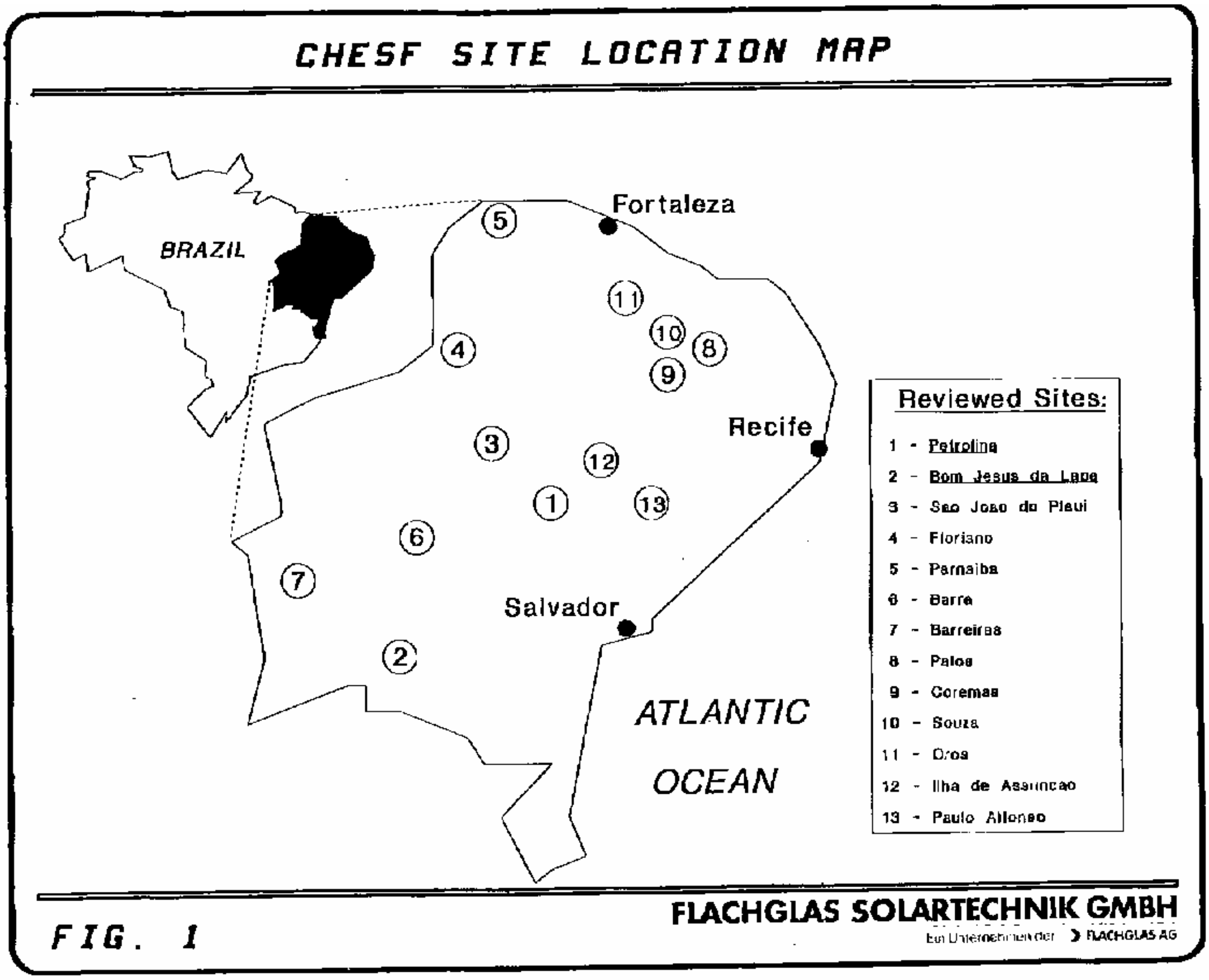

Figure 6.3 Prospective sites in the concession area of CHESF for solar thermal plants as surveyed by the CHESF-Flachglas Solartechnik teams in 1989-1990 [Courtesy of Pilkington Solar International, Cologne]

It was proposed to locate a first 100MW$_e$ SEGS project at Pedras de Maria da Cruz, on the east bank of the São Francisco River, some 12 km south of Januária. This site was chosen from among twenty locations based on the following criteria:

- ample solar radiation
- water availability
- fuel availability
- suitable topography (flat land)
- proximity to the transmission grid
- availability of land (adequate to implement 420 MW$_e$ of SEGS projects)
- availability of infrastructure
- local electricity demand profile

The only significant shortcoming of this site was the distance from the sources of consumables such as fuel and nitrogen. Fuel was available in Montes Claros, some 165 km away and would have to be transported by truck for the first 100 MW_e SEGS unit.

The first 100 MW_e plant (net 92MW_e) would include a solar field of LS-3 type, parabolic trough collectors of about 431,640 m^2 of collecting surface. In parallel, a conventional fuel fired Heat-Transfer-Fluid (HTF) heater would be installed to maintain the HTF at temperatures sufficient for the generation of steam, as needed by the utility at times of insufficient solar radiation (or at night) or when the water reservoirs are low. In CEMIG's predominantly hydro power systems, the solar thermal plant would grant firm capacity in the years of low precipitation. Although this would only require few hours of fossil operation, the plant would receive full capacity credit.

The first 100 MW_e plant in Januária was expected to generate 117.2 GWh of electricity from solar only for the CEMIG grid on a yearly average, based on available data of solar radiation. Under CEMIG operating conditions, that require operation of the fossil backup only for periods when the hydro reservoirs are low, in average only 41 days per year were expected to be run on fossil fuel. This means a yearly generation of 61.4GWh/a by fossil fuel, using 18'400 tons of fuel oil. Under these operating conditions, the solar share was expected to be 65%. According to the Brazilian regulations, the solar part would receive a capacity credit of 13.8MW_e and the fuel part a capacity credit of 36.9 MW_e.

The initial 100 MW_e plant was expected to require a relatively high investment, mainly because of the relatively smaller size of the plant and because of the need to establish at an early stage the human and physical infrastructure necessary for the efficient implementation of the program.

Without the high Brazilian taxes, such investment cost was anticipated to reach about US$ 271.7 million (in official US$ of July 1990), taking into consideration estimates of unit costs for labor, and materials and quoted estimates of equipment costs in Brazil. Taxes would add another US$ 70 million to this cost. Capital costs fur subsequent projects of 160 MW_e were expected to reach approximately US$ 350-380 million for each project. The detailed cost breakdown is given in Table 6.1.

Based on CEMIG's experience in operating existing conventional plants, the O&M group of such 100MW_e SEGS project would consist of 114 people. Annual operating and maintenance costs (excluding fuel) were expected to be about US$ 4.15 million/yr. for the first 100 MW_e project in a mature operating year.

Flachglas Solartechnik estimated in this study that average electricity cost of such first SEGS plant would be 89.30 US$/MWh in July 1990 US$ dollars without Brazilian taxes. Including the high taxes, such costs would be 25-30% higher. CEMIG concluded that these generation costs of a SEGS project would not be competitive within the Brazilian power generation sector.

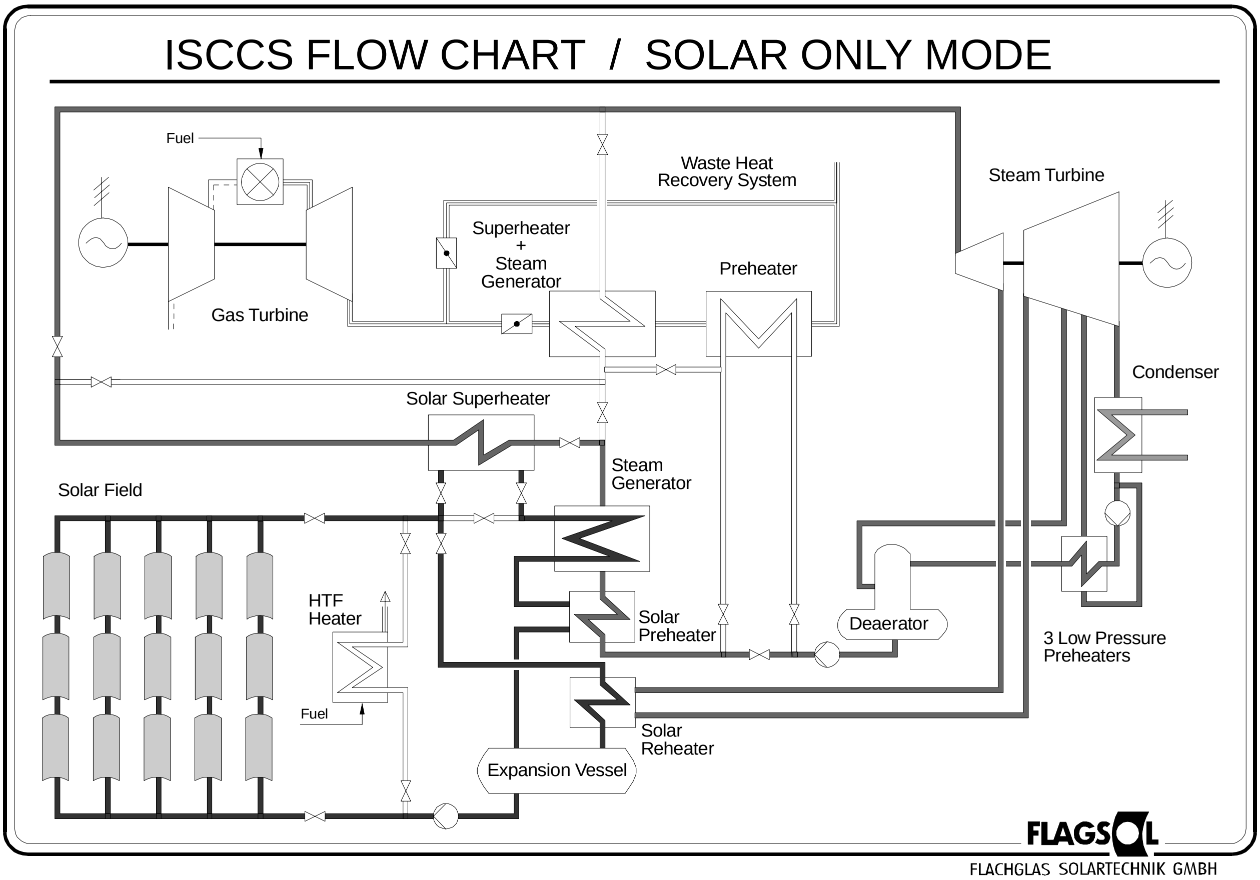

Figure 6.4 Schematic of the Integrated Solar Combined Cycle System (ISCCS) as proposed by Luz International Ltd., Flachglas Solartechnik GmbH, ABB and Tenenge in 1991 to CEMIG for implementation at the Januária site [Courtesy of Pilkington Solar International, Cologne]

6.1.1.4 Prefeasibility Study on an Integrated Solar Combined Cycle System (ISCCS) in Minas Gerais

To improve the economics of solar thermal power generation in Brazil, Flachglas Solartechnik and LUZ proposed a new power plant cycle which integrates a Solar and a state of art Combined Cycle System power plant (ISCCS) (see Figure 6.4). Following this proposal the consortium members (ABB/FLAGSOL/LUZ/TENENGE) conducted a technical and economical feasibility assessment in order to evaluate if the ISCCS concept would justify further project development activities. The proposed ISCCS concept combined

- a 274’680m² LS-3 parabolic trough field, feeding live steam of 100 bar pressure and 370°C temperature into the 83MW$_e$ steam cycle of a combined cycle.
- a 148MW$_e$ combined cycle power plant consisting of a 65MW$_e$ gas turbine and a 83MW$_e$ steam turbine.

The ISCCS plant was envisaged to be operated in six different modes:

a) Solar Only Mode (40.4MW$_e$ net)

b) Solar & Combined Cycle Integrated Mode (140.8 MW_e net)

c) Heater & Combined Cycle Integrated Mode (140.8 MW_e net)

d) Steam Only HTF heater Mode (83MW_e)

e) Steam Only Hybrid Mode (83MW_e)

f) Gas Turbine Only Mode (65MW_e)

Out of these, option a) and a hybrid mode out of option b) and c) were considered as the most probable operation modes in CEMIG's hydro-based power generation system. It was assumed, that the plant runs 39 days per year in baseload operation and the rest in solar only mode. Thus the solar only production was expected to be 79.1 GWh_e/a and the fossil production 103 GWh/a. Annual fuel consumption would be 21'204 tons/a. The solar share was expected to be 43.4% under these conditions. According to the Brazilian regulations, the solar part would receive a capacity credit of 9.4MW_e and the fuel part a capacity credit of 72 MW_e.

The cost estimation was based on the same model used for the previous SEGS Prefeasibility study. Each item was derived from the figures of the Feasibility Study taking into account its capacity, size, amount etc. and, if applicable, the economy of scale. If the figures could not be derived from the Feasibility Study (Gas Turbine, Waste heat Recovery System, etc.) figures from budgetary quotes were adjusted.

A performance estimation has been carried using a computer aided performance simulation model. For the purpose of performance calculation an overall system availability factor of 90% was applied.

Based on those results and on estimations of the marginal costs of electricity generated by fuel, CEMIG supported the performance calculation by defining the operating conditions for the ISCCS and SEGS option within the predominantly hydro based interconnected system. After the average annual hybrid operating time was calculated, based on information available from CEMIG, the actual net electricity production, its solar and fuel share and the resulting total annual fuel consumption were calculated.

With the results of the performance estimation, the investment and O&M cost and CEMIG's applied tariffs for electricity generation the economics of the two solar power concepts SEGS and ISCCS were evaluated on a basis under the Brazilian operating conditions.

The levelized electricity cost and the Internal Rate of Return (IRR) for the two alternatives were then calculated assuming a 25 years project lifetime. The performance and generation cost results obtained by Flachglas Solartechnik GmbH are summarized in Table 6.1. By integration of the solar field into a combined cycle sytem, average solar fossil generation costs drop from 89.30 USD/MWh_e for SEGS to 55.10USD/MWh_e for

ISCCS. Both figures do not include the high Brazilian taxes, which would increase the generation cost by 25 to 30%.

Under the financing structure envisaged by the consortium, the ISCCS would provide an Internal Rate of Return of 16.17% while the SEGS would only offer 2.59% IRR.

Figure 6.5 Aerial view of a 30MW SEGS Plant at Kramer Junction, California [Courtesy of Kramer Junction Operating Company, USA]

	ISCCS	SEGS
Technical Data		
Solar field area (sqm)	274,680	431,640
Installed gross capacity (MW_e)	148	100
Gas turbine capacity (MW_e)	65	0
Steam turbine capacity (MW_e)	83	100
Performance Data		
Overall system availability	90%	90%
Solar only mode:		
Net capacity (MWe)	40.43	79.72
Avail. Annual net energy prod. (MWh_e)	79,101	117,225
Base load mode:		
Net capacity (MW_e)	140.84	91.92
Possible annual net energy prod. (MWh_e)	1,048,713	727,619
Annual fuel consumption (tons)	199,665	164,425
Under Brazilian operating conditions:		
Avg. expected annual base load operating days	39	41
Avg. expected annual net energy prod. (MWh_e)	182,150	178,620
by solar	43.43%	65.05%
by fuel	56.57%	34.95%
Solar Capacity Credit (MW_e)	9.41	13.80
Fuel Capacity Credit (MW_e)	71.98	36.87
Total Capacity Credit (MW_e)	81.39	50.66
Average fuel utilization efficiency	44.11%	30.88%
Avg. expected annual fuel consumption (tons)	21,204	18,432
Project Cost (US$ mio.)		
Infrastructure	4.80	4.80
General Site Works	7.66	10.10
Solar Field	90.68	124.84
HTF-System	11.58	20.00
Power Block	54.63	37.32
B.O.P.	46.32	25.01
Services	27.21	27.30
Insurance	2.91	2.99
Contingencies	7.29	7.48
TURN-KEY SUPPLY TOTAL	253.08	259.84
CEMIG	18.62	26.32
TOTAL	271.69	286.16
Specific investment cost (US$/kWe)	1,835.77	2,861.56
O&M Cost (US$mio.)		
Total O&M training	5.71	5.71
annual basic O&M cost (million US$)	4.80	4.15
Fuel Cost		
specific fuel cost (US$/ton)	172	172
Avg. expected annual fuel cost	3.65	3.17
Avg. expected annual fuel related O&M cost	0.28	0.16
Marginal cost of fuel generated MWh_e (US$)	38.14	53.36
Levelized Energy Cost ($/$MWh_e$)	55.10	89.30
Internal Rate of Return IRR (Base Case)	16.17%	2.59%

Table 6.1 Solar Thermal Electricity Generation with SEGS and ISCCS in Brazil as analyzed by Flachglas Solartechnik GmbH.

A few million dollars were spent to identify and characterize solar sites. Instrumentation was installed to collect direct-normal insolation data and systems analysis was performed to determine the economic feasibility of a SEGS project. In the end, the project was put on hold by the Brazilian utility CEMIG because the electricity cost from the project was significantly higher than the hydro and fossil alternatives. A major reason for the high electricity cost was due to the excessive import duty levied on the solar equipment (~$120 M) which was largely coming from Germany and Israel. Unless tax legislation is changed in Brazil, this problem will encumber other solar thermal technologies that heavily rely on imported components.

Discussions at the START Mission Workshop indicated that technologists in Brazil generally believe that tower and dish technology hold a stronger promise for future application within Brazil than trough technology. Reasons for the current negative view of troughs include the following:

1. Troughs lack a cost effective energy storage system
2. Heavy reliance on imported components
3. Lower efficiency relative to dish and tower

Responses to these criticisms could be:

1. Energy storage may not be important for irrigation applications
2. Foreign companies could set up offices within Brazil to manufacture components locally
3. Efficiency is not a good measure of the economic viability of a technology, levelized energy value and cost are a much better measure

6.1.2 Solar Tower

PHOEBUS Concept

After successful component and system tests of the PHOEBUS concept at the Plataforma Solar de Almeria, L&C Steinmüller is ready to offer and supply a turnkey 30MW PHOEBUS plant on a commercial basis. Economic and performance predictions have been made by the PHOEBUS Consortium for a reference site in Jordan, which has about 10-15% higher annual direct normal insolation than the Brazilian sites. No efforts have been taken yet to determine the technical and financial feasibility of the PHOEBUS concept at a Brazilian site like Itacarambi or Januária.

Solar Two Concept

Assuming success at Solar Two, the next logical step would be to scale-up further and develop a 30-100MWe project within the USA or another country within the sunbelt such as Brazil. The plant could be built by an IPP industrial consortium consisting of USA's Boeing and Bechtel Corporations combined with local industrial and financial partners. To explore this possibility, a Memorandum of Understanding has been signed between CEPEL and USA's Boeing-Rocketdyne to jointly explore the development of Solar-Two-type power tower projects within Brazil.

Comparison of Power Tower in Brazil vs. USA

Most historical techno-economic studies of solar thermal power plants have assumed the plant is to be located within desert regions in the northern latitudes. In this section we explore how the conclusions of a study might change if the plant was located in non-desert regions in Brazil rather than the USA's Mojave Desert. Since there are many solar thermal technologies, an exhaustive comparison is beyond the scope of the START Mission's budget. Rather, an example case based on Solar-Two-type tower technology will be given. A brief reference to solar troughs will also be made.

The objective of the study is to compare the design, performance, and cost of 100MWe solar-only molten-salt power towers with annual capacity factors of 40%. One plant in the USA (assumed to be located at Barstow, California) is located at 35°N Latitude and has an direct normal resource of 7.4 kWh/m^2/day. A plant in Brazil (assumed to be located at Itacarambi, Minas Gerais) is located at 15°S Latitude and has a direct normal resource of 5.7 kWh/m^2/day. The average annual insolation resource for Barstow is based on many years of data and is known with certainty; however, the resource data for Itacarambi is based on only a few years of data and has a high degree of uncertainty.

The DELSOL and SOLERGY software, developed by Sandia National Laboratories, USA, was used to develop the optical design of the plants and to simulate their annual performance. The simulation time step was 15 minutes. The 100MW power block was a Rankine cycle with wet-condenser cooling, and the plant was assumed to be down for maintenance for 10% of the year. The solar technology was assumed to be similar to that which is currently being demonstrated at Solar Two and Sandia National Laboratories (e.g. tubular receiver, large-area glass heliostats at 150m^2 each, etc.). The economic model was based on assumptions that are typical for an electric utility within the USA [9].

The designs of the two plants are compared in Table 6.2 and Figure 6.6 below.

Since the annual insolation is less in Brazil, it will take a larger solar field and thermal storage system to achieve the same annual capacity factor. This is accomplished by adding heliostats to the southern portion of the field so that it is nearly circular (see Figure 6-6). Adding heliostats to the south adds more power to only the southern receiver panels and thus the size of the receiver is approximately the same in Brazil as in the USA. The annual efficiencies for the subsystems and the plant as a whole are virtually identical (see Table 6.3) .

Table 6.2 Comparison of 100 MW Power Tower Designs with 40% capacity factors

	Barstow, USA	Itacarambi, Brazil

Number of Heliostats	5936	7822
Field Land Area	5.5 km^2	6.9 km^2
Tower Height	155 m	180 m
Receiver Size	17 m (diam.) 18.7 m (ht.)	18 m (diam.) 19.8 m (ht)
Receiver Power	468 MW_t	578 MW_t
Peak System Eff.	23%	23%
Thermal Storage	1560 MWh_t (6 hours)	2080 MWh_t (8 hours)

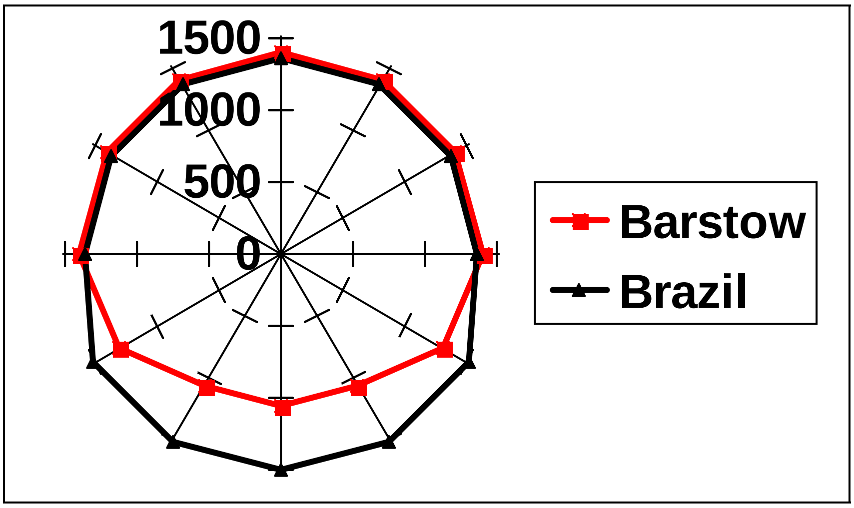

Figure 6-6 Comparison of field geometries

Table 6.3 Comparison of Annual Performance (100 MW Power Towers with 40% capacity factors)

	Barstow, USA	Itacarambi, Brazil
Field η	0.56	0.57
Field outage	0.97	0.97
Receiver η	0.79	0.79
Storage η	0.99	0.99
Gross Power Block η	0.42	0.42
Parasitic η	0.92	0.91
Plant outage	0.90	0.90
Total annual η	0.148	0.149

A first-order cost comparison of the two power towers is presented in Table 6.4. Cost estimates are based on extrapolations of costs that were originally made by potential US equipment vendors. The heliostat cost ($106/m^2) is based on an annual production rate of ~3000/yr. This equates to an installation rate of one 100MW plant every two years. The cost for heliostats could be higher or lower if other installation rates are chosen (see Figure 6.7).

Table 6.4 First-order cost comparison

	Barstow, USA	Itacarambi, Brazil
Heliostats	$93 M	$121 M
Receiver/Tower	$26 M	$29 M
Thermal Storage	$24 M	$31 M
Power Block	$68 M	$68 M
Total Direct Costs	$211 M	$249 M

Installed Costs	$327 M	$386 M
1st year O&M Cost	$4.6 M	$4.8 M
Normalized Levelized Energy Cost	1.0	1.12

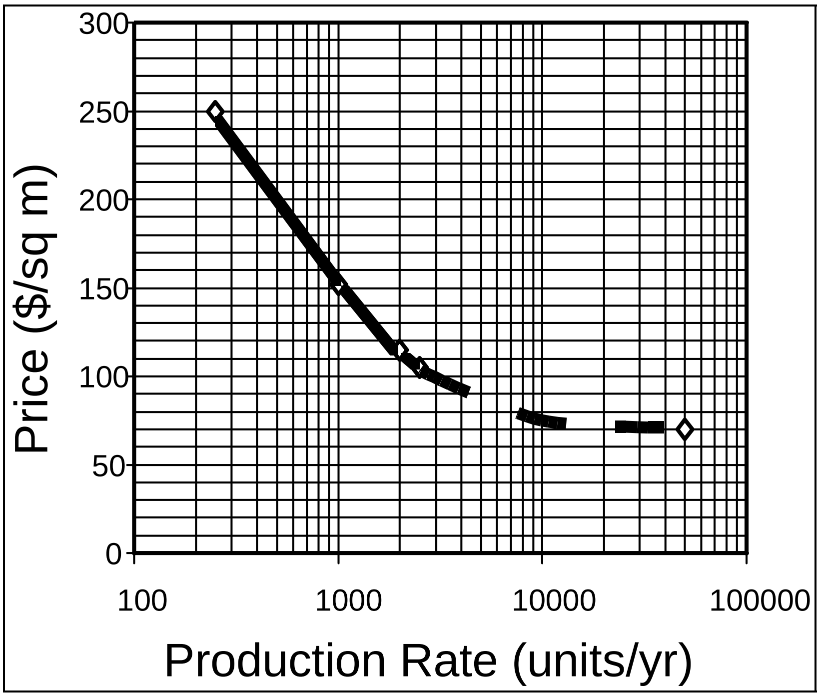

Figure 6.7 Heliostat price as a function of annual production volume. These prices apply to a heliostat with a surface area of 150 m^2 and is similar in design to those tested at Sandia National Laboratories. Solid portion of curve is based on estimates by USA manufacturers. Dashed portion is a reasonable extrapolation.

Levelized energy costs are presented in terms of normalized values. Absolute values are not presented because they are highly dependent on financial parameters such as interest and inflation rates, taxation policy, etc. However, we have presented the basic technology input parameters (i.e., capital costs, annual O&M cost, annual electricity production) to allow readers to perform financial calculations on their own for the power tower option. Additional input parameters for trough, tower, and dish-engine case studies can be downloaded via the SunLAB World-Wide-Web site at http://www.eren.doe.gov/sunlab/. Finally, the START Team has attempted to perform financial calculations for hypothetical solar thermal projects operating in the country of Jordan. Our methods were used to estimate levelized energy costs, debt-equity ratios, and the grant amount that was needed to close financing on a particular first-project opportunity. For more information concerning the methodologies used, please see reference [10].

As can be seen in Table 6.4, the electricity cost for the plant in Brazil is ~12% higher than a similar plant in the USA, even though the insolation resource in Brazil is ~25% less. This non-linear relationship is due to the fact that to achieve a given capacity factor (i.e. 40%), only the size of the heliostat field and storage system need to be increased for a plant in Brazil.

The cost of the power block and receiver are virtually the same for both plants.

The energy costs presented in this section are based on 100MW solar-only plants. Further cost reductions for the solar plant are possible if it is hybridized with a conventional fossil plant and/or if a larger plant is built (e.g. 200MW).

6.1.3 Dish/Engine for Remote Areas

Modular dish/engine systems are suitable for off-grid applications of smaller size or as fields of dishes tied together for larger scale grid-connected applications.

During the START Mission workshop, Givanildo Jose de Almeida of CHESF proposed the installation of a 1MW dish-Stirling power plant in CHESF's territory and requested a cost estimate for such a facility. Greg Kolb reported that a US-based 25kW system would cost approximately US$8000/kW for an order of 40 dishes. This is consistent with an extrapolation of the information presented in Figure 6.7. To obtain an accurate cost estimate, dish manufacturers should be contacted directly.

6.2 National and International Programs

PRODEEM of the MME may be an opportunity for solar thermal projects in that it focuses on the supply of decentralized renewable energy for isolated communities.

CEPEL has performed a pre-feasibility study for a GEF grant on the development of a central receiver pilot plant with a dual steam and methane reforming receiver system able to produce 6MWh of electricity per day to be located in the São Francisco river basin, with a total estimated cost of US$10.4-million.

Based on the CEPEL pre-feasibility study, UNDP recommended that Brazil apply for funding of a study extension (PDF-B) to include a comparison with other solar thermal power technologies. The final report will be submitted to GEF for decision on further approval of the implementation of the pilot plant. During the study extension, the following steps must be taken: (1) discuss and select the final solar thermal technology; (2) conduct pre-engineering design of the pilot plant (sizing, location and cost estimation); (3) identify industrial manufacturers, partners, investors and funding structure; and (4) analyze system scale-up to determine commercial scale economics. Brazil has requested a US$200K PDF Study for such purpose.

The Inter-American Development Bank (IADB) Sustainable Markets for Sustainable Energy (SMSE) Program targets regions requiring immediate off-grid electric sources. Though dish-Stirling systems are not seen as a mature enough technology today for use in the SMSE Program, IADB has an interest in possible future utilization of dish systems.

6.3 Conclusions

An aggressive capacity expansion program is underway throughout Brazil in an effort to improve the availability and reliability of the grid, to increase the national household service rate on and off the grid, and to accommodate the projected growth in consumer demand. Projections show annual consumption rising from 280 TWh in 1996 to at least 560 TWh and possibly as much as 826 TWh in the year 2015. In the Northeast, the CHESF supply area after the year 2000 will need new capacity installed at a rate of 1000 MW per year. In particular, CEPISA, one of the state utilities within the CHESF area, expects new plants to be producing an additional 3800 MW by the year 2004. In the FURNAS supply area, CEMIG has plans to install over 7000 MW of new hydro and thermal capacity over the next 15 years. Consequently, there is currently huge potential for new resources to enter into the market. Brazil's ongoing restructuring of the electric industry, i.e. the privatization of utilities and the decoupling of generation, transmission and distribution, offers a window of opportunity to pursue the science and technology that will provide the country with sustainable growth.

Both the expansion program and privatization raise the potential for solar thermal electricity in that new options are needed for the future power supply. Electricity costs in Brazil are likely to increase during expansion and restructuring for several reasons. First, though Brazil has great hydro potential, expansion has hit various roadblocks including environmental restrictions and high costs for village relocations in obtaining the best hydro sites. Secondly, the areas needing fossil-based expansion rarely have local supplies of fossil fuels, resulting in high annual fuel expenditures for new plants. At the same time, increased global awareness and concern over greenhouse gas emissions may drive up the real cost of operating fossil fuel plants. Privatization will increase the cost of electric service because the government has historically provided subsidies which now face an uncertain future. Also, electric service has been generally inadequate in many parts of Brazil due to lack of capacity, with consumers facing frequent power interruptions and some having service available only 12 hours of the day. Raising the level of service will most likely raise the cost of the service.

The semi-arid region of Brazil's Northeast and the São Francisco River basin have the best solar radiation levels, low precipitation, low humidity, and long days. The hydroelectric resource in some of these regions will be dried out by the end of century, and then expansion costs will rise dramatically. The vast solar resources can be tapped to complement the existing hydro generating capacity and protect against dry hydrological periods. The combined hydro-solar energy capacity and daytime peak demand for irrigation systems will call for solar electric systems with minimal fossil hybridization or storage needs. Small, modular solar thermal electric systems can be used to replace expensive, isolated, off-grid service typically handled by diesel generators, while medium-range generating stations based on towers, troughs or dishes can be implemented for utility scale applications.

Is the potential for solar thermal electricity high enough to attract utility interest? Given the energy situation that exists in Brazil today, solar thermal plants represent a clear match between needs and resources. Utilization of the many plant years of trough experience could provide immediate electric generating capacity. Research, development, and demonstrations of dish and tower systems in Brazil will prepare the electric power industry for acceptance of the newer technologies and build a technology base by which system performance and reliability can be assured. Many institutions in Brazil are committed to developing solar thermal as a significant future power supply option. The Brazilian Ministry of Mines and Energy's sponsorship of CEPEL in the IEA/SolarPACES Program in 1996 demonstrated the institutional commitment to solar thermal as a viable option for future electric power generation. Within the expansion and rural electrification programs Brazil now has the opportunity to increase its firm capacity and protect itself against climatic fluctuations by expanding its predominantly hydro system with solar thermal electric generation.

Recommendations

The START Team recommends that Brazil continue pursuing the application of solar thermal electric technology, specifically focusing on furthering the following: technology development and evaluation; resource and market studies; and policy making in the financial, regulatory, and energy planning areas. It should be noted here that policy making activities are not only eligible for GEF funding, but are normally a prerequisite for such.

Trough systems produce significant net electricity; the dish and tower technologies still require systematic improvements for cost reduction and reliable operation in locations that may be far from high-tech support. Solar thermal electric technology development should therefore follow a dual approach, utilizing proven solar thermal systems to produce electricity in immediate, visible applications, while research proposals move forward with the advances required for other robust solar thermal electricity supply solutions.

Various levels of technology evaluations have been conducted for dishes, troughs and towers in the Brazilian market, and these should now be unified, comparing the three on a consistent basis. Specifically, the calculation of cost of energy, including a careful study of parasitics and capacity factors in the determination of guaranteed energy credits, should now be standardized for the three technologies. The cost of energy for troughs has already been calculated using the Brazilian electric sector's standard methods, which should now similarly be applied to dishes and towers. Alternatively, the three technologies' costs of energy could now be calculated by any standard method adopted by IEA/SolarPACES.

The solar thermal electric community should take advantage of unique opportunities that present themselves in Brazil. For instance, biomass technology has developed into a large industry in Brazil, and as such presents opportunities both for biomass to replace fossil fuel backup for solar plants, and for developing the solar processing of biogas and alcohol fuels. A major opportunity for short-term application of solar thermal energy is small size off-grid systems, for example, 1-10 MWe, for irrigation purposes in the northeastern regions. These could replace expensive fossil fuel systems and compete economically with the electricity currently produced by diesel generators. Combined hydro-solar energy and the peak demand for irrigation call for only minor hybridization and storage needs. CHESF, responsible for the supply of electricity to the eight northeastern states, has exhausted most of the hydro-potential in the region, and therefore should be of high priority for solar thermal deployment.

The START team also recommends, with respect to resource analysis, that Brazil continue with the collection of radiation data, installing insolation stations throughout the country. In order to further explore solar thermal electric options in Brazil, additional sites from the surveys for CHESF and FURNAS should be re-visited, with the changes in solar thermal technology and the restructuring of the electric sector in mind. All options must be explored and compared on a consistent basis.

A thorough market study for solar thermal electric technology is recommended. The intent of such a study would be to identify: the extent of current off-grid power generators; the long-term potential and marginal costs of off-grid and grid connected solar thermal electric systems; and the major barriers to introduction of solar thermal electricity generation into the Brazilian power market. A detailed study about the current off-grid power generators and the potential growth for the next ten years is of primary importance for the solar thermal community. This study should list: the number of units, their location and size, the type and cost of fuel used, the average cost of electricity for each category, and the purpose of consumption (e.g., irrigation, domestic, agriculture, etc.)

Rural development programs are frequently using renewables for off-grid applications, and should now consider solar thermal electricity as one of their options. Though PRODEEM has thus far been using wind power and photovoltaics, the program's intention is to utilize appropriate solutions and so should now investigate the application of solar thermal technologies in these areas. Programs such as IADB Sustainable Markets for Sustainable Energy can be used to leverage the future deployment of solar thermal systems by opening up a comparison of the value of current off-grid solutions with that of solar thermal parabolic dish systems.

Regulatory, financial and energy planning policies have historically favored conventional power plants. The START team sees the current transition period in Brazil as a good time window to introduce regulations on renewable electricity generation and its compensation schemes. Of particular concern is tax equalization between renewable and conventional power technologies. CEMIG stopped pursuing a solar thermal expansion option after a feasibility study showed an energy cost of USD 114/MWh for a solar trough system, which included USD 286M for the solar equipment and USD 70M for the various taxes imposed. Emissions regulations should also be sought, either penalizing fossil fuel emissions or giving credits to emission free power production to remove distortions in pricing between fossil and renewable electricity generation.

Equally relevant in removing distortions would be access to low-cost finance packages. Policies are needed to define financing schemes and power purchase conditions for renewable electricity, and to encourage private sector investment in renewable energy projects (i.e. independent power producers).

Energy planning policies must encourage sustainable growth. Brazil now has the opportunity to evaluate the economic and environmental costs and benefits of integrating solar thermal plants into the national expansion plans. MME should begin to identify how solar thermal projects could be included in the national expansion plans and to guide the prioritization and development of the science and technology needed to maximize the sustainable growth of electricity generation.

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