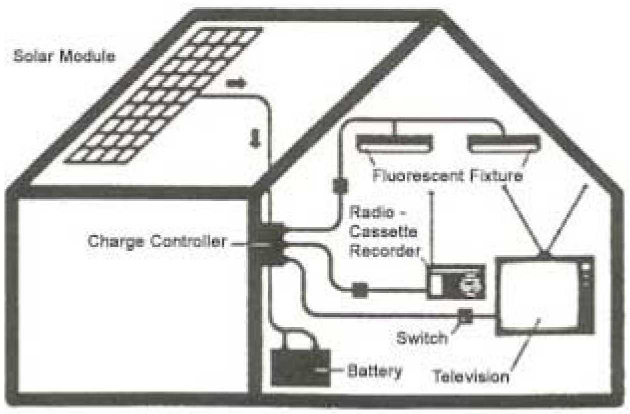
Solar TECHNOLOGY

Photovoltaics (PV) convert sunlight directly into electricity. Photons in sunlight interact with the outermost electrons of an atom. Photons striking the atoms of a semiconducting solar cell free it's electrons, creating an electric current. The Photovoltaic effect was first discovered in the 19th century, and was used by Bell Labs in 1954 to develop the first PV solar cell. PV found its first applications in space, providing electricity to satellites. These early PV cells were produced in small quantities from exotic materials. While early cells were inefficient, converting less than 1% of the incident sunlight into electricity, they quickly increased to 6% when researchers experimented with crystalline silicon, the principal component of sand. Current conversion efficiencies have surpassed 30% in the laboratory, and 15% in large-scale production.

Two main types of silicon cells vie for market share: crystalline and thin-film. Crystalline silicon cells are produced by slowly extracting large crystals from a liquid silicon bath. These crystals are sliced into 1/100th-of-an-inch thick slices, or "wafers", which are processed into solar cells that are then connected and laminated into solar "modules." While this production process yields highly efficient (10-15%) cells, the production process is expensive. Thin-film silicon cells are produced by depositing vaporized silicon directly onto a glass or stainless steel substrate. While the efficiencies achieved are lower than with crystalline silicon, the production process is less expensive. Modules from crystalline cells have a lifetime of over twenty years. Thin-film modules will last at least ten years. Other PV technologies, such as Gallium-Arsenide or Cadmium Telluride, are also being used. These types are highly efficient, but more expensive at the present time.

PV is measured in units of "peak watts"(Wp). A peak watt figure refers to the power output of the module under "peak sun" conditions, considered to be 1000 Watts per square meter. "Sun hours," or "insolation," refers to how many hours of peak sun, on average, exist in different countries. North America averages 3 to 4 peak sun hours per day in summer while eqatorial regions can reach above 6 peak sunlight hours.



Solar Home System:

A standard small SHS can operate several lights, a black-and-white television, a radio or cassette player, and a small fan. A 35 Wp SHS provides enough power for four hours of lighting from four 7W lamps each evening, as well as several hours of television. "System Size" (20, 35, or 50Wp) determines the number of "light-hours" or "TV-hours" available.

Solar Home Systems are 12-volt direct-current (DC) stand-alone systems which use PV to electrify small rural homes. Each SHS includes a PV module, a battery, a charge controller, wiring, fluorescent lights, and outlets for other appliances. Descriptions of the components follow:

Module:

Solar modules for an SHS range between 20-60 Wp. They are mounted on a rooftop or atop a pole. Both crystalline and thin-film technologies are appropriate for an SHS, with price, weight, long-term guarantees and degradation being the determining factors.

Battery:

An electrochemical storage battery is used to store the electricity converted by the solar module. During the day, electricity from the module charges the storage battery. During the evening, the battery is discharged to power lights and other applications. Batteries are typically 12-volt lead-acid batteries, ranging in capacity from 20-100 Amp-Hours (Ah). Batteries are typically sized to provide several days of electricity or "autonomy", in the event that overcast weather prevents recharging.

Deep-cycle batteries are best for an SHS, as they are designed to operate over larger ranges of charge levels. While car batteries are only designed to be discharged 15% of their maximum charge, deep-cycle batteries can be discharged to 70-80% without incurring damage. Both deep-cycle and automotive batteries are typically used, as they are readily available throughout the developing world. Car batteries have a 3-5 year lifetime; deep-cycle, both sealed and unsealed, can last 7-10 years.

Charge Controller:

A charge controller is utilized to control the flow of electricity between the module, battery, and the loads. It prevents battery damage by ensuring that the battery is operating within its normal charge levels. If the charge level in the battery falls below a certain level, a "low voltage disconnect (LVD) will cut the current to the loads, to prevent further discharge. Likewise, it will also cut the current from the module in cases of overcharging. Indicator lights on the controller display the relative state of charge of the battery.

Lights:

Compact fluorescent lightbulbs as well as fluorescent tube lights are used for lighting. An SHS normally includes two to six lights. By utilizing efficient fluorescent lighting, an SHS can provide substantially higher lighting levels than would be possible with incandescent lighting. A 9 watt CFL provides equivalent illumination to a 60 watt incandescent bulb. Compact fluorescent lights have a 5 year lifetime; tubes have much shorter lives, but are cheaper and are more readily available in most developing countries.

Wiring & Mounting:

An SHS also contains additional materials for mounting and connections. Metal frames are included to attach the PV Modules to a pole or roof. SHS components are connected by wires and contain switches for the lights. In some cases, wiring is housed inside conduit attached to interior walls.

Solar Home Systems: PRICING

Solar Home Systems are the least cost method of houshold lighting and electricity. Rural households that currently use kerosene lamps for lighting and disposable or automotive batteries for operating televisions, radios, and other small appliances comprise the principal market for Solar Home Systems. Families are spending up to thirty dollars per month on home energy services, depending primarily on income levels and fuel prices. A 1993 World Bank study from a dozen countries found that the average monthly expenditure for lighting and entertainment communications alone ranges between $2.30 for low income families, to $17.60 for upper income families.

These expenditures are similar to the monthly cost of a SHS, which SELF approximates on a general world-wide level at $10 per month. A family in the middle, or upper-income brackets could have an SHS for less than they are already currently spending for energy services.

Comparisons between the different sources should also be made in terms of lighting-services provided per dollar. Because a SHS includes highly efficient compact fluorescent lights (CFL), it can provide lighting services for a lower cost per unit of light delivered.

A family using 6 kWh per month to power 9 watt CFLs would need over 30 kWh to receive the same amount of light from 60 watt incandescent bulbs. The average 50 Wp SHS provides approximately 200 watt hours a day, or six kilowatt-hours (6 kWh) per month. Based on the price of SHS components, and cost of relative fuels in its country markets, SELF estimates that using 8 watt fluorescent lights generating 400 lumens, a $500 SHS can provide high quality lighting at an average cost of $7.15 per million lumen-hours. For a diesel generator lighting 60W incandescent bulbs, this figure is $28.77 per million lumen-hours. A kerosene lamp can provide lighting at $400 per million lumen-hours.

To judge accurately the affordability of Solar Home Systems in rural areas, one must look not only at comparative lighting costs and how much families are already paying for energy services, but how much more they would be willing to pay for electricity from a Solar Home System. While a simple price comparison is useful in showing that PV is comparable to existing household expenditures for lighting, and the least-cost means of delivering household lighting, it does not convey the higher value placed on electricity over kerosene lighting, or the environmental benefits of solar-based electrification.

Reduces local air pollution

Use of solar electric systems decreases the amount of local air pollution. With a decrease in the amount of kerosene used for lighting, there is a corresponding reduction in the amount of local pollution produced. Solar rural electrification also decreases the amount of electricity needed from small diesel generators.

Offsets greenhouse gases

Photovoltaic systems produce electric power with no carbon dioxide (CO2) emissions. Carbon emission offset is calculated at approximately 6 tons of CO2 over the twenty-year life of one PV system.

Conserves energy

Solar electricity for the Third World is an effective energy conservation program because it conserves costly conventional power for urban areas, town market centers, and industrial and commercial uses, leaving decentralized PV-generated power to provide the lighting and basic electrical needs of the majority of the developing world's rural populations.

Reduces need for dry-cell battery disposal

Small dry-cell batteries for flashlights and radios are used throughout the unelectrified world. Most of these batteries are disposable lead-acid cells which are not recycled. Lead from disposed dry-cells leaches into the ground, contaminating the soil and water. Solar rural electrification dramatically decreases the need for disposable dry-cell batteries. Over 12 billion dry-cell batteries were sold in 1993.

Reduces kerosene-induced fires

Kerosene lamps are a serious fire hazard in the developing world, killing and maiming tens of thousands of people each year. Kerosene, diesel fuel and gasoline stored for lamps and small generators are also a safety threat, whereas solar electric light is entirely safe.

Improves indoor air quality

Fumes from kerosene lamps in poorly ventilated houses are a serious health problem in much of the world where electric light is unavailable. The World Bank estimates that 780 million women and children breathing kerosene fumes inhale the equivalent of smoke from 2 packs of cigarettes a day.

Increases effectiveness of health programs

Use of a solar electric lighting systems by rural health centers increases the quality of health care provided. Solar electric systems improve patient diagnoses through brighter task lighting and use of electrically-lit microscopes. Photovoltaics can also power televisions and VCRs to educate health workers and patients about preventative care, medical procedures, and other health care provisions. Finally, solar electric refrigerators have a higher degree of temperature control than kerosene units, leading to lower vaccine spoilage rates, and increased immunization effectiveness.

Allows telemedicine

Telemedicine is the use of telecommunications technology to provide, enhance, or expedite health care services, by accessing off-site databases, linking clinics or physicians' offices to central hospitals, or transmitting x-rays or other diagnostic images for examination at another site. Deep in the Brazilian Amazon, SELF demonstrated the feasibility of telemedicine in remote areas by using a combination of solar power and satellite communications. Within moments of plugging in the new telemedicine device, local Caboclo Indians can have meaurements of blood pressure, body temperature, pulse, and blood-oxygen uploaded via satellite to the University of Southern Alabama for remote diagnosis.

Improves literacy

Solar rural electrification improves literacy by providing high quality electric reading lights. Electric lighting is far brighter than kerosene lighting or candles. Use of solar electric light aids students in studying during evening hours.

Increases access to news and information

Photovoltaics give rural areas access to news and educational programming through television and radio broadcasts. With the advent of television and radio, people previously cut off from electronic information, education, and entertainment can become part of the modern world without leaving home.

Enables evening education classes

Ongoing education classes and adult literacy classes can be held during the evening in solar-lit community centers. SELF has electrified community centers and schools in many countries, and has witnessed the development of adult literacy and professional classes possible with the introduction of solar electric lighting systems in community centers.

Facilitates wireless rural telephony

Solar electricity, when coupled with wireless communications, makes it possible to introduce rural telephony and data communication services to remote villages.

Solar Home Systems ROLE

Rural households currently using kerosene lamps for lighting and disposable or automotive batteries for operating televisions, radios, and other small appliances are the principal market for the SHS. Solar PV is affordable to an increasing segment of the Third World's off-grid rural populations. For home lighting, the cost of an SHS is comparable to a family's average monthly expenditure for candles, kerosene or dry-cell batteries. Besides providing lighting, an SHS can also power a small TV. In addition, a family with an SHS need no longer purchase expensive dry-cell batteries to operate its radio-cassette player, which nearly every family has. Solar PV is competitive with its alternatives: kerosene, dry-cell batteries, candles, battery re-charging from the grid, Gensets, and grid extension.

Approximately 400,000 families in the developing world are already using small, household solar PV systems to power fluorescent lights, radio-cassette players, 12 volt black-and-white TVs, and other small appliances. These families, living mostly in remote rural areas, already constitute the largest group of domestic users of solar electricity in the world. For them, there is no other affordable or immediately available source of electric power. These systems have been sold mostly by small entrepreneurs applying their working knowledge of this proven technology to serve rural families who need small amounts of power for electric lights, radios and TVs.

The success of SHS implementation has been greatly determined by quality of the components and the availability of ongoing service and maintenance. When well-designed systems have received regular ongoing maintenance they have performed successfully over many years. However, when poorly designed components have been used, or when no after-sales service was available, systems often fail. Past failures of these systems has undermined local confidence. Fly-by-night salespeople have sold thousands of substandard SHS in South Africa, for example, which failed shortly after installation. Well-designed components and after-sales service and maintenance have become recognized as essential parts of a successful PV program.

Many of these SHS were provided by non-governmental organizations (like SELF) or through government-sponsored programs with international donor support, such as in Zimbabwe where 10,000 SHS are being installed on a financed, full-cost-recovery basis (in a program designed by SELF for the United Nations in 1991.) In Bolivia, 2,500 SHS are being leased to users by a cooperative "utility." In Kenya, over 20,000 SHS have been installed since the mid-'80's by independent businessmen on a strictly cash basis. The World Bank estimates that 50,000 SHS have been installed in China, 40,000 in Mexico, and 20,000 in Indonesia.

According to the United Nations Development Programme, 400 million families (nearly two billion people) have no access to electricity. The European Union's renewable energy organization EuroSolar estimates the global market for solar photovoltaic home lighting systems is 200 million families. Based on market studies in India, China, Sri Lanka, Zimbabwe, South Africa and Kenya conducted by various international development agencies over the past 5 years, the consensus is that approximately 5% of most rural populations can pay cash for an SHS, 20 to 30% can afford a SHS with short or medium term credit, and another 25% could afford an SHS with long term credit or leasing.

EXTENDING OPPORTUNITY TO THE EDGE OF THE DESERT

In the desert grasslands of Northern Nigeria, village life has changed little over the centuries. Many people still live in houses constructed of mud and thatch, use donkeys or cattle-drawn carts for transportation and scratch out a subsistence living by growing their crops in the harsh conditions found just south of the Sahara Desert. Cooking is done over wood fires and kerosene lamps provide meager lighting that produce toxic fumes and the danger of fire. Public education is not free and is therefore limited, as are the opportunities for employment. In most villages, water of questionable quality is either pulled from an open well by rope or brought to the surface with hand pumps.

Rural areas in Northern Nigeria lack the modern energy sources needed for improvements in health, education, transportation and commercial development. Outside of major cities and towns, there has been very little electrification in this region and what supply there is, is often unreliable. In contrast, Nigeria has an abundance of petroleum-based energy resources and in fact is the sixth largest supplier of oil to the U.S. Unfortunately, very little revenue from the sale of this resource filters down to help the rural population.

With the intention of addressing the unavailability of energy in villages, SELF Executive Director Robert Freling and Jigawa State Governor Ibrahim Siminu Turaki began a dialog in 2001 concerning the possibility of using solar–electricity (photovoltaic or PV) to power essential services in the far-flung villages of Jigawa State. Governor Turaki is a firm believer in using modern technology to jump-start development in his remote and economically challenged state. Under his leadership, Jigawa State has started a computer technology trade school and is the first state in Northern Nigeria to create a satellite-based broadband internet and communications system to link all local government districts. Given his interests, vision and knowledge, it was very easy for him to see the benefits that PV can bring to his people.

As project plans developed, funding commitments were obtained from the United States Agency for International Development and the United States Department of Energy. The U.S. Government entities committed about 60% of the necessary funding with the balance coming from Jigawa State. SELF was the lead implementing organization and partnered with the Jigawa Alternative Energy Fund (JAEF), a non-government organization formed specifically to promote the use of renewable energy.

As a result of numerous meetings with enthusiastic villagers, a very ambitious project goal developed: to demonstrate the comprehensive use of solar-generated electricity in a village setting to improve education, water supply, health, agriculture, commerce, security and women's opportunities. There are thousands of villages scattered around globe that benefit from some type of PV application; usually lighting for homes or water pumping or vaccine refrigerators. In very few places has PV been used to address virtually all of the things that a community needs energy for.

But that's what we decided to do and we were going to do it in three villages where over 7,500 people would benefit from the results.

Project Description and Impacts

Having a reliable water supply is the first priority of any village and this is especially true in the semi-desert of Jigawa State where there are few rivers or other sources of water on the surface of the land. Typical methods of getting water range from open wells with rope and bucket, to hand pumps, to government supplied diesel-powered pumps that work only until they break down or until villagers run out of money to buy the expensive diesel fuel. The powerful solar-powered pumps supplied with this project are designed to run maintenance free for eight to ten years or more and are currently supplying the villages with clean, fresh water from deep wells. Because the wells are tied into a village distribution system with numerous taps, the time that families used to spend getting water has been reduced as well.

The village health clinics now benefit from solar energy. Lights enable health officers to see patients at night for the first time, vaccine refrigerators allow more people to be vaccinated at greater frequency and fans increase the comfort level of staff and patients alike.

Village primary schools now have at least two illuminated classrooms and teachers report that they are being heavily used in the evenings for adult education and as places for children to come and do their lessons. Each school has also been provided with a computer and computer instruction for the teachers. These are the first computers in the project villages and there are plans to eventually hook them to the internet via the State's broadband system- a process that can literally open the village to the rest of the world for healthcare, education and commerce.

Streetlights are among the most valued PV systems used by the villagers. In such a hot climate where people enjoy the cool of the evening, a great deal of business and socializing take place after sunset. Streetlights now give people bright places to congregate. Several new food-selling businesses are now open for business beneath the lights at these new market locations. Many streetlights are located conveniently by water taps and all supply much valued security for people at night.

Villagers also appreciate having electricity in their mosques. Lighting makes nighttime activities possible and public address systems facilitate the call to prayer five times each day.

The solar-powered micro-enterprise buildings are the project centerpieces in each village. Each center provides electricity to 6 very small businesses that would otherwise not have access to electricity. The shared PV system, much less expensive than individual systems for each shop, allow tailors to move up from manual sewing machines to electric, barbers, from manual clippers to electric, and similar improvements in productivity for other types of businesses.

This project has introduced home lighting systems to each village. Compared to the kerosene lights that they replace, solar lighting offers a better light without the inherent fumes and fire danger of the old lamps. System users report that it is now easier for children to do their studies and home businesses are thriving under the better lighting conditions. And of course, families appreciate going about their normal activities with good lighting. With about 20 systems in each village, we have created demand and a great deal of interest in home systems. JAEF will be able to continue electrifying houses using a micro-credit scheme where the payments for each system will accumulate to purchase additional systems for more homes.

One of the project villages, Wawan-rafi, has a lake nearby that is used to irrigate cash crops during the rainy season. However, many of the poorest farmers are limited in their growing ability by only being able to water their fields using a hollowed-out gourd – a slow and labor intensive process. For these farmers, we developed a cattle or person pulled cart with fold-out unbreakable solar modules powering an efficient pump that can be moved from field to field. More efficient irrigation will enable farmers to produce and sell more to provide greater income for their families.

The only source of income for most village women is the production and sale of peanut oil. Traditionally, small amounts of oil are made in a process taking great amounts of time and strenuous labor. In Wawan-rafi, we have incorporated a solar-powered oil expeller that will save time and labor while earning more income for women.

Sustainability

As in all SELF projects, sustainability is the prime concern. A great deal of care has been taken to ensure that this project will be technically, financially and organizationally sustainable. In its role as the maintainer of all project systems, JAEF provides both local and professional staff technicians to frequently check each system. Extensive training will ensure that there is always someone in each village to address any problems that might arise. Small, affordable fees collected from users will be used to pay technicians and to maintain an inventory of spare parts.

The comprehensive application of solar electricity in these villages will bring profound changes in education, health and commerce while easing the burdens of living in a harsh environment. Beyond the benefits to these three villages, we have also created a viable model that can be replicated in Northern Nigeria and elsewhere. This project has already garnered a great deal of media attention both within Nigeria and internationally with coverage from CNN. It has been visited by the Governors of surrounding states, by acting U.S. Ambassador Rick Roberts and by Nigerian President Obasanjo. Other governments have contacted SELF with interest in implementing aid projects that replicate what we’ve done in Jigawa State.

Governor Turaki is well-pleased with this project and has begun to plan the next phase that will bring the multiple benefits of PV to his people in 30 more villages. SELF will be offering its experience and expertise to JAEF to help manage this project. Watch a CNN profile of this project.

Mekong Delta, VIETNAM

SELF launched a first-of-its-kind household solar PV project in Vietnam in association with the Vietnam Women's Union (VWU) in February 1994. The VWU is a nationwide social service organization with eleven million members. The program has directly benefited over 1,500 people through the installation of solar home systems (SHS), and indirectly benefited hundreds more through solar systems in village community centers and village markets. Preparations are being made for a larger-scale program of solar rural electrification.

During the first stage of the project, 115 SHS were installed in rural communities in the provinces of Tien Giang and Tra Vinh in the Mekong Delta. Another 15 were installed in Hoa Binh Province near Hanoi with the assistance of the Institute of

Energy, the government agency responsible for renewable energy research and development. In the second stage completed in February 1997, SELF and the VWU installed another 110 SHS in the Tra Vinh communes of Long Hoa and Hoa Minh. Solarlab, a PV technology group based in Ho Chi Minh City, was contracted by SELF to provide technical assistance directly to the Women's Union, and to oversee the after-sales maintenance program.

SELF's Technical Manager, Marlene Brown, along with Solarlab, trained a total of 25 local technicians on behalf of the Women's Union. In addition, the VWU trained 20 "motivators" to sign up families and collect their down payments. Customers pay 10% down and make four years of monthly payments to the VWU revolving credit fund. As the solar fund grows, additional SHS are purchased through SELF.

Two hundred forty rural families can now enjoy solar light in their houses. Many of the families have purchased black-and-white TV's allowing access to educational and entertainment programming. Before SELF and the VWU joined forces to disseminate SHS, only solar battery charging stations and remote telecommunications facilities had made use of PV technology.

SELF continues to actively work with the VWU to launch an economically sustainable, national household solar electrification program. The program would serve the 70 percent of Vietnam's population without electricity. The VWU's solar project has been approved by Electricity of Vietnam to serve rural people. In April 1997, SELF and the VWU sponsored a national seminar on solar electrification in Hanoi, attended by government policy makers and planners, practitioners and PV users, and representatives of the World Bank, UNDP and other donors.

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