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A DECADE OF CHANGES TO AN ALTERNATIVE POWER SOURCE FOR A RURAL UTILITY

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Since 1993, the Navajo Tribal Utility Authority (NTUA) has installed stand-alone photovoltaic (PV) systems on the Navajo Reservation to provide some of its most remote customers with electricity. This report summarizes the rural utility's experience over the last decade with solar electric power. In particular, it examines the technical and economic drivers that led to four generational changes of their PV systems.

SOLAR POWER:

THE ALTERNATIVE ENERGY OF CHOICE FOR NTUA

The Navajo Tribal Council established NTUA in 1959 to meet the utility needs of the Navajo reservation.[2] The reservation spans 26,000 square-miles across remote sections of eastern Arizona, southern Utah, the northwestern edge of New Mexico and a small portion of southwestern Colorado (the Four Corners region). NTUA purchases power generated off the reservation and transmits that power via transmission lines throughout its territory. The rural utility began utilizing PV technology in 1993 as an economically viable means of electrifying some of its most remote households that were

[1] Sandia is a muliprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC-04-94AL85000.
[2] For a comprehensive history of NTUA, see http://www.smecc.org/iii-_chapter_8.htm

not accessible by the grid. Over the last decade, stand-alone PV has remained NTUA's choice for solving many remote application problems.

NTUA deals with a customer base that chooses to live in extremely rural places. The choice to live in such a remote location is related in many ways to the Navajo culture. Traditionally, Navajo people were herders and lived in small family units. The Four Corners region is characterized ecologically as a high desert zone requiring vast grazing territories to support livestock. Therefore, families spread far apart, each having a low elevation winter grazing territory and a cooler summer grazing territory in the mountains. One family might have the grazing rights to thousands of acres, passed down to the next generation in a matrilineal (ancestral decent through the mother's side of the family) fashion. In this way, the Navajo people inhabited every inch of their reservation. Contemporary Navajos who choose to live on their ancestral lands in remote locations do so because they have deep ties to the land itself. For example, a family farm, cemetery or child's umbilical cord might exist on the land. Children may have heard stories relating to the land by elders. A Navajo may know the site where a particular ceremonial herb grows. Tribal land is trust land, not private land. An individual is granted *grazing rights* (not ownership) to the land, which may be taken away by the tribe if it is not lived upon and used.

Figure 2. Monument Valley on the Navajo reservation.

Most rural Navajos have lived without utility services. It is likely these people never used a modern household appliance such as a microwave, refrigerator or washer

and dryer. They used batteries to power radios and oil to light lanterns. This type of customer, one who is not acculturated into grid-tied electricity usage patterns, is a prime candidate for PV due to the technology's inherent load limitations. Stand-alone PV supplies a limited amount of electricity each day that must be rationed among different loads to be effective. NTUA's PV customers are provided enough electricity to power a few compact fluorescent light bulbs, a TV, a very small energy-efficient refrigerator made specifically for PV and other minor appliances for a few hours each day.

As a rural, non-profit utility, NTUA's mission is unique when compared to an investor-owned utility. Investor-owned utilities have corporate status with a board of directors and shareholders and are driven by their bottom line. For-profit entities rarely invest in humanitarian projects that do not promise a future financial return to their shareholders. The Navajo Nation Council created NTUA as a service entity for the reservation. As a sovereign nation, Navajo has a government-to-government relationship with the United States and can submit grant proposals through the bid and selection process for funding of different projects on the reservation. Appropriations obtained from government agencies including the US Department of Energy (DOE) and the US Department of Agriculture (USDA) have been awarded to the Navajo Nation for electrical utilities projects. The Navajo Nation then employs NTUA to implement the projects as outlined in its proposals. While NTUA operates its business solely on revenues generated from ratepayers, the rural utility also fulfills humanitarian efforts by servicing the needs of the Navajo people as outlined by the tribe.

The unique condition under which NTUA operates offers an understanding of why the rural utility has chosen to consistently invest in PV. Stating that PV is an

economically viable alternative power source for NTUA deserves explanation. Grid power is usually affordable. PV power can be 5-10 times more expensive than grid power generated from hydropower, natural gas and coal/lignite generating plants (see Table 1).[3]

Table 1. Costs of New Electricity Generation in Cents per Kilowatt Hour

Electricity Source	Generating Costs
Hydropower	2.4-7.7
Natural Gas	3.4-5.0
Coal/lignite	4.3-4.8
Photovoltaics	25-50

With many Navajo families living in dispersed remote locations, grid supplied electricity is not always an economically feasible option on the reservation. NTUA estimates that 18,000 out of 48,000 homes within the Navajo Nation are without electricity.[4] Non-electrified homes exist on the Navajo Nation at a distance of approximately 1 to 45 miles from the electrical grid and to extend the electrical lines would cost homeowners approximately $27,000 per mile.[5] Add to those figures the fact that the Navajo reservation has the highest density of non-electrified homes in the United States and NTUA's rural electrification dilemma soon becomes apparent.

[3] http://www.worldwatch.org/
[4] Navajo Tribal Utility Authority, *Navajo Electrification Demonstration Program Navajo Electrification Solar Project*, Navajo Nation, Technical Progress Report April 21, 2004.
[5] Tsebetsaye, S., "Navajo Tribal Utility Authority: Electrification Demonstration Program Developing a Sustainable Tribal and Rural Cooperative Solar Program", Sandia National Laboratories, SAND 2003-3202P.

Figure 2. Traditional eight-sided Navajo home, 'hogan'.

"Indian households on reservations are disproportionately without electricity. A total of 14.2% of Indian households have no access to electricity, as compared to only 1.4% of all US households." Navajo accounts for 75% of the households without electricity.[6]

NTUA's capital cost per PV unit over the last 10 years has been on average $15,000. Given the remoteness of the residential locations and the high cost of line extension, PV becomes a viable option for remote residential off-grid electrical generation.

To reiterate, NTUA, as a non-profit rural utility whose mission is to bring electricity to the Navajo people, has used PV technology over the last decade to bring electricity to its remote customers. The decision to use PV was not necessarily based on economic variables such as net present value and internal rate of return (IRR), but rather on humanitarian values that aim to bring basic electrical service to one of the nation's most underserved populations. In addition, electrifying Navajo's remote households with PV strengthens one of the more traditional Native American cultures in the US by providing service to the communities that choose to live in very isolated and remote locations.

[6] 2000 Report: *Energy Consumption and Renewable energy Development Potential on Indian Lands*, Energy Information Administration, SR/DNEAF/2000-01 April 2000.

FOUR GENERATIONS OF PV

Since 1993, NTUA has purchased and installed PV systems on four separate occasions. The details of each purchase are outlined in the Table 2.

Table 2.

	Financing	Customer Price / month	Array Output	Total Kilowatt-hour / day	# of Units	Manufac-turer (Integrator)	NTUA Champion
1993	DOE - WAPA	$40	240 Watt 260 Watt	1.3 kWhr/day	40	Solar Mart	Jimmie Daniels
1999-2001	USDA - RUS	$95	640 Watt	1.6 Kwhr/day	200	Photo Com. / Kyocera	Paul Denetclaw Jr., Pam Myron
2002-2003	DOE - NEDP	$75	880 Watt hybrid small wind (Phase I)	2.0 Kwhr/day	40	SunWize (NADAC)	Larry Ahasteen
2002-2003	DOE - NEDP	$145	880 Watt hybrid LP gas generator (Phase I)	2.0 Kwhr/day	4	SunWize (NADAC)	Larry Ahasteen
2003-2004	DOE- NEDP	$75	880 Watt hybrid small wind (Phase II)	2.0 Kwhr/day	63	SunWize (Ducommon Tech.)	Larry Ahasteen

In 1993, NTUA and the DOE signed a contract for Solar Energy Based Electrical Systems, Agreement Number 92-SLC-0209. NTUA received $300,000 from the DOE and $50,000 from Western Area Power Administration (WAPA) for a total of 40, 240 or 260 Watt PV units. The systems consist of a 240 or 260 Watt PV array, a 460 amp hour (Ah) battery bank and a 12 volt (V) DC to 120 volt AC inverter. Although today most of these systems are obsolete, many of the households are still using PV electricity because they requested to have their systems replaced with later procurements of NTUA PV equipment.

The next generation of PV came about in 1999. With a loan for $2 million from the USDA's Rural Utility Service (RUS), NTUA was able to purchase 200 standardized

units from Kyocera Solar, Inc. Each system consists of a 640 Watt PV array, 876 Ah battery, 2.4 kVA inverter, battery charge controller and associated electronics mounted on a self-contained steel skid.[7]

Formal recognition of the electricity needs on the Navajo Nation paved the way for NTUA's third and fourth PV procurements. In the year 2000, the Navajo Nation developed an active relationship with Sandia National Laboratories (SANDIA) and the DOE through a signed a Memorandum of Understanding (MOU).

> This MOU documents the parties' mutual interests in the region's economic development, diversity, and technology deployment. This is demonstrated by working together on activities and initiatives that will benefit the parties, New Mexico and the region.[8]

In 2001, President Bush signed a law introduced to the senate by New Mexico Senator Jeff Bingaman, called the Navajo Nation Electrification Demonstration Program (NNEDP) Section 602, Public Law 106-511. The basis of the law is for the Secretary of Energy to establish a 5-year program to assist the Navajo Nation in meeting its electricity needs for the estimated 18,000 occupied structures on the Navajo Nation that lack electric power.[9]

Through the authorized NNEDP, Navajo was appropriated $800,000 for PV from the DOE in 2002. The PV system designed under this procurement had significant changes. The PV array was larger, generating 880-Watts, and added an additional power source to create a hybrid system. Forty of the hybrid units incorporated small wind turbines and four had propane generators. The rest of the system was standardized to ease maintenance and operations for NTUA staff. The system consists of an 880 Watt/24

[7] http://www.nrel.gov/ncpv_prm/pdfs/33586073.pdf
[8] *Memorandum of Understanding Among the Navajo Nation, the US Department of Energy, and Sandia Corporation,* Sandia National Laboratories, Sandia MOU number 00-S-284.
[9] See footnote 7 above.

V DC array, a 24 V dc battery bank at 770 Ah and 2500W/120V ac power inverter and either a 400 Watt/24 V dc AIRX Wind Turbine or 5.5 kW LPG Generator.

One year later, the DOE funded $1.15 million to procure 63 PV hybrid units. All of the units utilized wind technology in the hybrid design. Most of the design specs from the third generation were identical in the fourth generation PV. The system consists of eight solar panels in an 880-W array, a 400-W Air-X turbine, and four 6-volt, 770-Ah batteries in series to create a 24-VDC configuration. Minor modifications were made to the system design to improve operations and maintenance (O&M) stemming from recommendations by NTUA electricians.

DRIVERS:

THE MODIFICATION OF PV SYSTEM DESIGN

With respect to the specifications mentioned above, the design changes to NTUA's PV system over one decade represent a wealth of knowledge concerning the technical issues, deployment and business application of photovoltaics for a rural utility cooperative. The result is that NTUA's PV has evolved each generation to more accurately fit the specific needs of NTUA as a technical solution for rural electrification and a business operation.

FINANCING AND PRICING CHANGES

There is a strong tie between the type of financing obtained for a project and the shape that project eventually takes. Financing weighs heavily on pricing, ownership and

O&M decisions. Over the last decade, NTUA has been forced to learn the optimal financing and pricing of PV as specifically applicable to a rural utility.

The first acquisition of PV by NTUA was a pilot project. Forty units were acquired through grants from the DOE and WAPA for $300,000 and $50,000, respectively. Sandia helped NTUA develop a request for proposal (RFP). NTUA used the grant money to purchase 40 units and maintained ownership throughout the life of the equipment. With an original customer agreement for 5 years, the rural utility charged each household $40 per month for the PV electricity produced, which was based on expected O&M fees. Although at first glance PV appears to be a self-sustaining system, regular maintenance is required to ensure the operational life of the unit is optimized. The most significant result of this project was that NTUA demonstrated the business potential of utilizing PV electricity for remote residential applications.

It took six years of planning and preparation for NTUA to bring its business application of PV to fruition. In 1999, the rural utility received $2 million dollars from the RUS "hardship program", this time in the form of a loan, to finance its business plan.

> The Electric Program of USDA's Rural Utilities Service (RUS) provides leadership and capital to upgrade, expand, maintain, and replace America's vast rural electric infrastructure. Under the authority of the Rural Electrification Act of 1936 … [t]he Electric Program makes loans and loan guarantees to finance the construction of electric distribution, transmission and generation facilities, including system improvements and replacement required to furnish and improve electric service in rural areas, and for demand side management, energy conservation programs, and on-grid and off-grid renewable energy systems. [10]

Financing the project with a loan called for significant changes from the way NTUA handled its first generation of PV. The 640 Watt units were sold to the customers

[10] http://www.usda.gov/rus/electric/index.htm

through a contracted lease purchase agreement. The price was $95 per month for 15 years after which time the customer would own the PV equipment. The price was determined by amortizing the interest, principal, installation and projected O&M costs based on past NTUA financial information of each unit over 15 years. The financial arrangement of this particular procurement has been one of NTUA's most significant business lessons during the last decade.

NTUA designated roughly $12 out of the $95 monthly customer bill for O&M costs. The amount has not been enough to cover the utility's costs incurred performing O&M services. NTUA's contract with RUS included a requirement that the 640 Watt systems receive proper maintenance. To fulfill this obligation, NTUA has had to regularly perform O&M services regardless of their cost. The situation is on-going because NTUA also signed a contract with each customer agreeing to provide PV electricity over the expected life of the units, 15 years. Over time, the rural utility has realized their O&M budget needs adjustment. NTUA has not recovered their initial capital investment on the 640 Watt units and is currently working to develop a plan to remedy the situation.

This experience led NTUA to reevaluate the relationship between financing, pricing and O&M in future PV procurements. Although O&M seems to be a technical issue, it has direct financial implications. NTUA performed a one-year analysis of the O&M costs incurred for the 640 Watt units in preparation for the third generation PV procurement of the 880 Watt systems in 2001. The results of this analysis showed the appropriate charge for semi-annual maintenance of a unit comparable to the 640 Watt system to be about $75 per month per unit.

The 880 Watt hybrid systems were installed in two phases from 2002-2004. Both procurements were the result of the Navajo Nation's effort to obtain a Congressional appropriation (earmarked funds), which was authorized by Public Law106-511, better known as the NNEDP. Funding for both 880 Watt systems was in the form of a cooperative agreement. By financing the capital costs of the equipment with this type of funding, NTUA was able to retain ownership of each unit on behalf of the Navajo Nation. The rural utility charged each PV customer $75 per month for an 880 Watt PV small wind hybrid unit and $145 per month for an 880 W PV propane generator hybrid unit. The customer price is based exclusively upon expected O&M charges.

TECHNICAL DESIGN CHANGES

Over the last decade, the amount of power output by the PV systems has increased to meet growing electricity demand. The first generation 240/260 Watt systems, at 1.3 kW hours per day, provided DC lighting and one AC electrical outlet per house. The 640 Watt units increased production to 1.6 kW hours per day. Finally, the PV array of the 880 Watt hybrid units produces 2.0 kW hours per day and the hybrid (either small wind or propane generator) produces additional power that flows directly to the batteries to help maintain their charge.

Design changes reflect a combination of external technical advice from Sandia and the Southwest Technology Development Institute (SWTDI), internal decisions, recommendations by NTUA electricians and technological advancements. In 1993, Terry Schuyler, from Sandia's Photovoltaic Design Assistance Center, studied existing residential PV installments on the Navajo reservation procured earlier by the Navajo

Housing Service (NHS).[11] The results of his work helped the team at Sandia design the technical specifications of the 240/260 Watt units for NTUA. Schuyler and his teammates, Roger Hill and Mike G. Thomas, trained NTUA employees in the assembly and installation of the PV systems, established an O&M schedule, tested a prototype unit at the lab and provided general technical assistance. The contract between NTUA, DOE and WAPA mandated that Sandia develop two different systems for the solar electrification project. Therefore, the first generation had both 240 Watt units and 260 Watt units. These were the only units NTUA designed to deliver both AC and DC power over the last decade. They were also the only units to be designed as a pole-mounted array.

Figure 3. 240 Watt unit.

A major evolution of the 640 Watt units was the standardization of the design known as the portable 'Sun-Pack' solar electric power system. All 200 units were identical, which eased the sale, distribution, knowledge, training and O&M for NTUA. According to the 'Sun-Pack' manufacturer, Kyocera Solar, Inc., (then known as Golden Genesis Co.), "The system is fully integrated and tested at the factory. Installation of the system basically consists of deploying and securing the system, electrically connecting the system to the dwelling, installing remote monitoring and control equipment inside the dwelling and commissioning the system".[12] Adjusting the design for ease of mobility

[11] Schuyler, Terry, 1993. Residential PV Systems in the Navajo Nation, Sandia National Laboratories, Albuquerque, NM.
[12] Golden Genesis Company, 1999. Installation, Operation and Maintenance Manual, prepared exclusively for Navajo Tribal Utility Authority.

meant changing from a pole-mounted array to a skid-mounted array; hence the notion of "drag and drop".

As a utility company, NTUA owned the heavy equipment necessary to lift and transport the fully integrated system. This proved to be a better option than sending a crew of workers to a remote site to mount eight large solar panels on a pole and facilitated removing a system from a home site. The skid is a steel-framed structure with the PV panels mounted on top. The angle of the array is adjusted every six months as prescribed by the bi-annual maintenance schedule to optimize its seasonal exposure to direct sunlight. Below the array, two locked boxes housed on the skid contain the batteries, charge controller and inverter.

Figure 4. Integrated 660 Watt unit ready to be deployed on NTUA trailer.

Sandia was instrumental in the technical details of the 'Sun Pack' design. Roger Hill of Sandia's Renewable Energy Department said the 640 Watt system produces "enough electricity to power a single household for a day – if the family members are conservative in their use of electricity".[13] As with the first generation PV, Sandia tested one of the units at the lab for potential problems and along with SWTDI, provided training to NTUA.

> Training was needed because the NTUA experience with PV and dc systems in general was minimal. The electricians, engineers, and technicians were provided with an introduction to PV systems, their components, and principles of operation. They were provided extensive training on installation issues and on system test and troubleshooting techniques. Maintenance procedures were covered at length, as was overall safety… Customer support issues were also addressed.[14]

[13] http://www.sandia.gov/media/NewsRel/NR2000/navajos.htm
[14] http://www.sandia/pv/docs/PDF/ASES%20Brown.pdf

Sandia technical staff members Marlene Brown and Sandra Begay-Campbell traveled to the reservation to provide technical support and show customers the proper use and maintenance of the equipment. Brown provided additional help to the NTUA staff by troubleshooting units on-site.

The third generation PV was the 880 Watt hybrid (wind or propane generator) Phase I units. NTUA kept the 8-panel skid mounted design but increased the power of each panel from 80 watts in the 640 Watt system to 110 watts in the 880 Watt system. NTUA electricians recommended the array be moved higher above the battery box to allow better access to the equipment they service which is located in the locked boxes.

Figure 5.

Figure 6.

Figure 5 shows NTUA electrician, Vircinythia Charley, working in the cramped quarters of the 640 Watt battery box. In Figure 6, NTUA's Larry Ahasteen, shows Sandia student interns the improved working conditions under the Phase I 880 Watt array.

The hybrid power source was integrated into the system to counteract some of the problems associated with the limitations inherent in PV power and energy storage. Obviously, the effectiveness of PV is compromised when there is a lack of sunlight but the major technical issues have to do with the batteries. In 2001, SWTDI prepared a report for NTUA containing their results from data acquisition systems (DASs) installed on nine PV hybrid power systems in the Kayenta area of the reservation. An excerpt from an SWTDI report states:

> The excessive load on two of the systems is reflected in their continuous condition of very low battery state of charge. The batteries of these systems are probably never adequately charged to the gassing voltage. They are likely experiencing electrolyte stratification at this time and will eventually (if not already) experience the deposition of hard sulfation deposits. These conditions will have reduced and will continue to reduce the capacity of these batteries to store energy. The only way to address these problems is to reduce the loads at each of these homes. In addition, some remedial benefit may be obtained for these batteries if they are charged regularly (e.g. monthly) using a generator.[15]

NTUA originally planned to add a propane generator to each unit, which would be used on an intermittent basis to fully charge or over charge the batteries when necessary. People in the PV industry advised NTUA that generators would prove to be cost prohibitive. Based on the DOE's Solar Reliability Database, Sandia technical staff member, Larry Moore, conducted a financial analysis of the O&M costs of a PV hybrid propane generator and recommended to NTUA a customer price of $145. In the end, only 4 of the 44 hybrids added to NTUA's 880 Watt PV were propane generators.

NTUA found the small wind turbine a financially sound alternative to the propane generator. The wind turbine, the AIRX 400-24 by Southwest Wind Power, is mounted independently from the PV array. At NTUA's first wind turbine installation in Ganado, Arizona, the utility invited their electricians, Southwest Wind and other contractors to witness the event for educational purposes. The turbine was mounted on a metal pole held secure by guy wires. Many of those in attendance felt the installation posed potential safety problems

Figure 7. Phase I Small wind turbine mounted on a utility pole.

[15] Southwest Technology Development Institute, *PV Hybrid System Second Performance and Data Report Three Kyocera 'Sun-Pak' Solar Electric Power Systems owned by: Navajo Tribal Utility Authority Ft. Defiance, Arizona*, January 2001.

due to the guy wires and they suggested NTUA incorporate utility poles into the design. Considering that the utility owns the equipment necessary to place utility poles in the ground and the electricians' expertise working on utility poles, NTUA accepted the idea. The change aligns with conditions specific to NTUA's working environment: Sending one electrician to a remote home site to repair or remove one wind turbine on a utility pole versus sending more than one worker out to disassemble the pole held by the guy-wires and perform the same maintenance.

Figure 8. The Phase II 880 Watt small wind hybrid unit.

The fourth generation PV is the 880 Watt wind hybrid, Phase II units. The distinction has been made between the Phase I and Phase II units because they are similar and yet contain noteworthy differences. Phase II, procured under the same funding source as Phase I only one year later, allowed NTUA time to make technical adjustments to its successful 880 Watt hybrid design. NTUA purchased only wind hybrid units for Phase II. The generators proved too expensive for their customers because they required extensive maintenance to comply with the manufacturer's warranty. (Recall the customer price was based exclusively on O&M fees.) Wind, on the other hand, required very little maintenance and performed equally well.

NTUA's electricians, who work most often with the company's PV system, had many suggestions for improvements. Phase II added an external generator hook-up to the inverter box. (NTUA's customers are not allowed access to the equipment contained in

locked boxes under the array.) When systems fail, households may be without electricity for days due to their remote location. The generator plug, located outside of the locked box, allows the customer the ability to generate electricity with a separate source, run it through the inverter and into the house while the PV is not working. The electricians asked for a meter to read the current energy output from the wind turbine. They also recommended relocating the holes venting the equipment boxes to cut down on dust and dirt blowing inside.

With the major technical design issues of NTUA's PV system understood, the company was able to direct its attention to peripheral goals associated with PV's potential for economic development on the Navajo Nation. NTUA's Larry Ahasteen realized the 640 Watt systems had been integrated in Scottsdale, Arizona and he knew that resources were available that would allow the job to be performed on the reservation. Thereafter, NTUA's nationwide bid to vendors for the Phase II 880 Watt hybrid systems included a requirement that the PV units be integrated on the Navajo Nation. The Navajo Nation Economic Development Division was a resource for contractors to find companies on Navajoland that could perform the job. SunWize, a contractor out of Kingston, New York, approached Ducommon Technologies in Fort Defiance, Arizona, to perform the integration services using their Navajo workforce. NTUA's PV Selection Committee recommended SunWize to be awarded the contract because, among other attributes, their bid detailed the PV integration to be performed on the Navajo Nation. The units were locally tested and inspected and records of each inspection were maintained.

One goal of NTUA is to deploy its PV in a highly efficient manner providing the customer with immediate satisfaction of his electricity needs. The 240/260 Watt units

were pole mounted which meant NTUA integrated and installed the units at each home site. NTUA instructed each customer to refrain from using the electricity provided by the PV system until the array had sufficient time to charge the batteries. The 640 Watt units were deployed with the batteries fully charged so the customer was able to turn on lights immediately after the electricians wired and installed the system ('drag and drop'). Moving one step closer to this 'plug and play' idea, the equipment of the 880 Watt Phase II units was completely integrated so that electricians only wired the systems directly to the homes.

LESSONS LEARNED

Over the last decade, the biggest hurdles NTUA technicians have faced have been with batteries. PV systems will not last if the batteries are not regularly maintained. Maintenance includes refilling the water level of each battery cell, providing equalization of cells, and keeping the batteries clean of dirt and crystallized battery acid. NTUA has learned that even the simplest system will fail if the batteries are not maintained properly -- and customers are not relied upon to perform the maintenance.

Customers are instructed to manage their electrical loads and not discharge the batteries below a depth of 40%. NTUA installs an LED DOD-meter inside the house to keep the customer aware of the battery charge level. The inverter automatically shuts off electricity to the house if the batteries drop below 10% which helps ensure they last as long as designed. Another aspect of battery life has to do with equalization, which is the overcharging of a fully-charged battery. Overcharging the battery evens the charge among the different battery cells and reduces permanent sulfation of the battery plates. It is recommended by the manufacturer to be performed every 90 days. NTUA has made

design changes specifically aimed at solving battery issues. The Phase II hybrid design incorporates the Morningstar TS45 charge controller that automatically equalizes the batteries according to a prescribed schedule. Power created by the small wind or propane generator hybrid unit flows exclusively into the batteries to help maintain their charge. New PV systems deployed with the batteries fully charged insures a healthy state of electrical charge from the beginning of its use.

Vandalism has been an issue NTUA has had to face. Early in the program, NTUA saw vandalism when customers tried to pry open the locked boxes containing the inverter, meters, batteries and charge controller. The boxes were damaged when people tried to remove the batteries for other uses. The utility noticed that sometimes vandalism of the locked boxes was the result of a person trying to "fix" a unit when electricity stopped flowing to the house. NTUA found that educating the customer about their PV system helps the situation because the user has fewer problems. When a repair is necessary, NTUA has learned to expedite the problem efficiently by maintaining an up-to-date O&M manual and training its staff to follow O&M flowcharts specific for PV. More recently, NTUA has seen a slight increase in vandalism to the PV modules. By creating a unit that is highly mobile, the utility can easily repossess its property if it has been vandalized which helps reduce further damage to the equipment.

Customer education not only helps fight vandalism, it is an essential component of a sustainable PV system. Customer awareness is needed due to the unique, and sometimes foreign, electrical system installed at the customer's house. Scripted by Sandia's Connie Brooks, NTUA produced a video in 2002 called "Power from the Sun" that is specifically designed to teach Navajo people about living with PV electricity. The

video, available in Navajo or English, explains how PV works, describes issues concerning PV limitations and load management, suggests appropriate load management, and illustrates the promise of the positive difference that PV can make in the lives of remote customers. The video is designed to be shown to prospective PV customers to help them make the choice of whether or not PV would work for them.

NTUA has learned the importance of "champions" when it comes to success and sustainability with PV. With the adoption of new technology, the importance of a champion positively influencing a company to consider and adopt the technology cannot be stressed enough. Jimmie Daniels, who retired from NTUA, was the principal force behind the utility integrating PV into its business portfolio. In July 2002, Larry Ahasteen picked up where Daniels left off. Ahasteen retired from a career with the Navajo Nation where he was instrumental in incorporating PV into reservation homes. Familiar with the intricacies of government funding and project management, Ahasteen oversaw the successful deployment of the Phase I and Phase II hybrid units at NTUA. He has been tireless in his efforts to improve the system's design and efficiency and is always thinking of new ways to provide electricity on the reservation. At NTUA, the electricians, more than any other staff, are the people working with and using the PV units on a regular basis. Two female solar champions have risen from among the electricians. Vircynthia Charley (Journeyman Electrician) and Melissa Parrish (Apprentice Electrician), of NTUA's Kayenta District, have worked to make NTUA's solar program as successful as possible. They have

Figure 9. NTUA's Larry Ahasteen.

promoted the technology among their customers, although the remote location of the PV homes adds a substantial load to their full time duties, especially during the bi-annual PV maintenance process.

Over the decade, NTUA found long-term support for its PV program from the staff at Sandia, SWTDI and the DOE. Champions for NTUA's PV program have emerged from these organizations throughout the years. The benefits of the program have been mutual for all organizations involved, as a greater understanding of the technical and financial issues surrounding the application of PV in a rural setting are shared. DOE Program Manager, Dan Sanchez, has worked with NTUA on the procurement of funds for each of the four PV generations. As Senior Project manager of SWTDI, Andy Rosenthal has had many opportunities to contribute his engineering expertise to NTUA's PV program along with Program Manager, John Wiles support with PV training. Sandia staff members Michael Thomas, Roger Hill, Terry Schuyler, Sandra Begay-Campbell, Marlene Brown and Connie Brooks have individually help the program at different points in time. As a Principal Member of the Technical Staff at Sandia and a member of the Navajo Nation, Begay-Campbell has emerged as a unique champion for the NTUA PV program. On one hand, Begay-Campbell draws from her cultural heritage to explain options to her people and other Native Americans, and on the other hand she is able to serve as a cultural interpreter to Sandia. From an interview in 2001, Begay-Campbell was quoted as saying:

Figure 10. Sandia's Sandra Begay-Campbell.

> "It can be difficult for a technical person to understand that despite the presence of all the physical conditions that allow a particular technology to succeed, it still may not be acceptable because the community doesn't want it….Photovoltaics is a good option because it is a clean, quite source of renewable energy that is in harmony with the Native American Philosophy of Seven Generations."[16]

One lesson learned is that there are benefits for the participating organizations stemming from a long-term relationship with NTUA and its PV program. Sandia and SWTDI have the opportunity to study a large-scale rural PV application in their own back yard. Such large installations are usually found in developing countries. "The NTUA Solar program serves as a model for other tribes, and their experiences can directly apply to rural utilities across the nation. If successful, the Program can lead to the opening of a large sustainable market for solar with the rural electrical cooperatives."[17] The organizations also share in the NTUA's success. A report by Brown and Rosenthal in 2001 stated "The Navajo Tribal Utility Authority now operates and maintains the nation's largest off-grid, residential PV program in a way that is technically and economically sustainable."[18]

As the Renewable Energy Specialist, Larry Ahasteen is helping to guide the future direction of distributed energy resources at NTUA. Vircynthia Charley designed a PV data-acquisition form that she uses at each site visit. Ahasteen has said he would like to see all NTUA electricians use the form to gather data on the PV units and Sandia's Sandra Begay-Campbell considers the data highly useful for better understanding stand-alone PV. Ahasteen and Begay-Campbell are currently discussing the logistics of integrating data into NTUA's business operations database SAP system. One 880 Watt

[16] Sandia National Laboratories, "*Making Decisions for Seven Generations"*, Sandia Technology A Quarterly Research & Development Journal, Volume 3, No. 4, 2001.
[17] See footnote 7 above.
[18] See footnote 14 above.

wind hybrid unit is being tested at Sandia's PV laboratory to gather data and optimize the system. The research findings will be presented to NTUA.

In looking to the future, Ahasteen is open to considering many renewable energy applications on the reservation. He is currently using anemometers from the DOE's Wind Powering Native America Program. Anemometers measure wind speeds and ultimately locate areas with the best wind resources for commercial application. He is researching the potential for creating energy with a biomass facility at an old Forest Service products plant in Sawmill, Arizona. Ahasteen is developing a strategic plan for the application of micro-turbines and fuel cells to generate energy for small clusters of remote Navajo homes.

NTUA's commitment over the last decade to PV technology and its plans to incorporate other renewable sources in the future captures the attention of those interested in distributed energy technology. The creation of a highly sustainable renewable energy program at NTUA could not have happened without taking from the many lessons learned over the course of the program. Starting small and working toward ever-larger energy producing systems has been a key factor, as has the passion, dedication, and partnering of the NTUA staff and all those with whom they have interacted. Through its dedication of service to the Navajo Nation and its people, NTUA has become a model of success for businesses that follow into the renewable energy industry.