SAND2018-8805J

Navajo Residential Solar Energy Access as a Global Model

Sandra K. Begay, Principal Member of the Technical Staff
Sandia National Laboratories[26]

Abstract

This case study focuses the Navajo Nation's efforts to provided residential power access through solar photovoltaic systems to some of its approximately 34,000 remote off-grid tribal members. A deep dive into their solution and the collaboration with Sandia National Laboratories offers insights into how the Navajo Tribal Utility Authority's work could serve as a residential model to meet the needs of the 1.2 billion people globally that are without electrical residential power.

Keywords

Navajo, Indian tribes, solar energy, solar residential system, photovoltaic, off-grid systems

[26] Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525

Table of Contents

Acknowledgements

Contributing information by Jessica Lin.

Navajo Nation February 16, 2018 site visit by Jessica Lin and Sandra K. Begay, which was supported by Navajo Tribal Utility Authority (NTUA)'s Vircynthia Charley, Melissa Parrish and Deenise Becenti.

Financial support was provided by the Department of Energy, Office of Energy Policy and Systems Analysis and Sandia National Laboratores

Figures

No table of figures entries found.

Disclaimer

This report may discuss information prepared under an agreement with and funded by the U.S. Government and/or information about programs or products independent of the U.S. Government. Neither DOE, the U.S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:

1. warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
2. representation that such use or results of such use would not infringe privately owned rights; or
3. endorsement or recommendation of any specifically identified commercial product, process, or service. Any views and opinions of researchers expressed in this work do not necessarily state or reflect those of the United States Government, its contractors or subcontractors.

1. Introduction

1.1. Background

When Vircynthia Charley was a young girl growing up on the Navajo Reservation in the 1970s, she did not have running water to drink or any system for sewage waste, heat, or electricity. If her grandmother saw her sitting idly, she would tell her to make herself active - go cut and haul wood to heat their hogan (traditional Navajo home) or go herd the sheep. During the days, Vircynthia dutifully took the 50 mile on-way bus ride away to attend public school, then came home and did her chores before trying to do her homework by the light of kerosene lamp at night. After high school, she joined the army and was deployed abroad to defend our country, but was honorably discharge a couple of years later due to injuries from the Desert Storm conflict. She returned to the Phoenix, Arizona area and got a job as an electrician outside of the reservation. She enjoyed putting her knowledge to use and perfected her trade over her fifteen-year career.

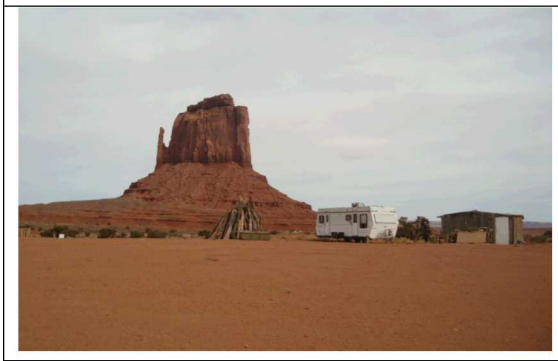
Vircynthia was also exposed to modern amenities such as television, indoor plumbing and heating, which started her heartfelt desire to make these modern comforts available to her Navajo people. Vircynthia maintained this desire to electrify the homes of her neighbors when she joined the Navajo Tribal Utility Authority (NTUA), a Navajo Nation's tribal enterprise, as an electrician in the early 1990s. Originally employed as a journeyman, Vircynthia's responsibilities were responding to service calls, outages, meter reading and unfortunately, shutting off electrical power to those who could not pay their bills. Her assignments and duties continued to grow over time as did her original desire to electrify the homes of her people, the Navajo Nation[23].

	
Source: DOE Site Visit 2018	Source: DOE Site Visit 2018

The Navajo Nation, or Diné Bikéyah (Land of the People), is the largest American Indian reservation in the United States. The reservation extends throughout northeastern Arizona, northwestern New Mexico, and southeastern Utah, totaling 27,000 square miles and about 332,000 Navajos with only approximately less than 45,000 Navajos (13 percent) living off the Navajo Nation. [24]

The reservation is ecologically characterized as a high plains desert and is spotted with mesas and canyons. It contains significant natural resources, including surface water and groundwater, range lands, forests, irrigated farmlands, lakes, fish and wildlife, as well as substantial reserves of coal, oil and natural gas, wind and outstanding solar resources. With over 270 sunny days a year, the Navajo Nation is the largest contiguous premium solar resource area in the West with over 424 square miles of prime development area[1], equating to over 3 GW in solar PV potential.[2] However, the Navajo Nation has designated land use plans throughout the Nation with minimal non-allocated land for development.

Historically, Navajo's economy was based on farming, hunting and grazing of livestock. The Navajo people have traditionally practiced a herding lifestyle that requires large tracts of land to support grazing livestock such as sheep and cattle, leading to a traditional dispersed population. As a result, non-electrified homes could exist anywhere from 1 to 45 miles away from the electrical grid.[3] Consequently, it is often cost-prohibitive to provide utility services to individual homes on much of the Navajo Nation.

	
Source: DOE Site Visit 2018	Source: DOE Site Visit 2018

The Navajo Nation is the least electrified of all Indian lands; the Navajo reservation accounts for 75% of un-electrified Indian households[4]. An estimated 32% of Navajo Nation's inhabitants lack electricity[5].

[1] Arnold Leitner, Fuel from the Sky: Solar Power's Potential for Western Energy Supply, report for National Renewable Energy Laboratory, July 2002, NREL/SR-550-32160.

[22] Doris, E., Lopez, A., Beckley, D., Geospatial Analysis of Renewable Energy Technical Potential on Tribal Lands, NREL, 2013, DOE/IE-0013

[3] Cata, Nora, Sustainable Rural Electrification: Residential Solar Energy on the Navajo Nation, Sandia National Lab, 2012.

[4] U.S. Energy Information Administration. Energy Consumption and Renewable Energy Development Potential on Indian Lands. SR/CNEAF/2000-01. April 2000. Table ES

[5] Testimony by the Navajo Nation to the Regulatory Commission Washington, DC 20426, Grid Reliability and Resilience Pricing, Docket No. RM 8-1-000, October, 2017.

The cost to electrify off grid homes with line extensions could be approximately $35,000 single-phase or $60-80,000 three-phase per mile.[6] At this rate, it could cost as much as $350 million over a period of ten years to provide electricity to off-grid Navajos.[7] The Navajo Tribal Utility Authority (NTUA), which services the majority of the Navajo Nation, can afford the cost of construction including right of way costs in areas with a population density of more than eight homes per mile. Below that number, the costs fall on individual families who cannot afford the electrical line extension to electrifying their home.

1.2. Definition of US Energy Access

Energy access refers to those Americans that do not have electricity because they lack grid-tied power or distributed resources.

There are approximately half a million Americans without basic electricity service, or who live in energy poverty. Energy poverty is defined as the "inability to cook with modern cooking fuels and the lack of a bare minimum of electric lighting to read or for other household and productive activities at sunset"[8]. Most of these people live in overseas territories and on American Indian reservations.[9,10] In fact, tribal lands have the highest rates of un-electrified homes in the contiguous United States and Alaska.

According to the International Energy Agency (IEA), modern energy services are crucial to human well-being and to a country's economic development[11]. The IEA asserts that access to modern energy is "essential for the provision of clean water, sanitation, and healthcare and for the provision of reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunication services". The graph below illustrates the link between electricity and the Human Development Index. From an economic development standpoint, electricity has been reported to increase literacy rates[12] which has an effect of improved economic growth, lower poverty, less crime, self-empowerment, and disease prevention.

Figure 1: Per Capita Energy Consumption and HDI Value[13]

[6] Battiest, Terry. "Navajo Tribal Utility Authority Solar Program System Data and O&M Initiative for DOE Solar Technologies Database." Tribal Energy Program intern research paper, Sandia National Laboratories, 2007. SAND #2010-7617 P.

[7] Bain, Craig, Crystal Ballentine, Anil DeSouza, Lisa Majure, Dean Howard Smith, and Jill Turek. "Navajo Electrification for Sustainable Development: The Potential Economic and Social Benefits." American Indian Culture and Research Journal 28, no. 2 (2004): 67-79.

[8] UN Development Programme, Energy Services for the Millennium Development Goals, in pursuance of UN Millennium Development Goals (New York, 2005).

[9] World Bank. World Development Indicators 2015: Access to electricity (% population). Last updated July 2015. http://data.worldbank.org/data-catalog/world-development-indicators. Accessed 15 July 2016.

[10] U.S. Energy Information Administration. Energy Consumption and Renewable Energy Development Potential on Indian Lands. SR/CNEAF/2000-01. April 2000. Table ES-3.

[11] International Energy Agency, World Energy Outlook 2017, Paris, France, 2017. http://www.worldenergyoutlook.org/resources/energydevelopment/

[12] Akanksha Chaurey and Tara Chandra Kandpal, "Assessment and evaluation of PV based decentralized rural electrification: An overview," Renewable and Sustainable Energy Reviews 14 (April 2010): 2266-2278.

[13] United Nations, Development Programme, Fighting Climate Change - Human Solidarity in a Divided World: Human Development Report, prepared by Amie Gaye, 2007/2008.

1.3. Economic Opportunities

The Navajo Nation is among the lowest socio-economic indicators for any geographic region in the United States. According to the NTUA, the latest statistics indicate the Navajo Nation has an unemployment rate of approximately 48.5%— nearly nine times the current U.S. average—and 38% of the Navajo people live below the poverty line. The average per capita income on the Navajo Nation as of the 2010 census is $10,695, as compared to the U.S. average per capita income of $48,377.

With a focus on Kayenta, Arizona which is Navajo Nation township, the population size is 4,700 people. Of working age adults, 52.8% of the population did not work in 2017. Nearly two thousand people are in poverty (below the federal poverty level) and an additional 1,000 are in deep poverty (less than half of the federal poverty level).

1.4. Housing Stock Availability and Background

An estimated 25% of homes on the Navajo Nation are traditional Navajo dwellings called hogans. Most housing is comprised of mobile homes, modular buildings, and standard homes. It is estimated that 31% of all homes lack complete plumbing, 28% lack kitchen facilities, 38% lack water services, 32% lack electricity, 86% lack natural gas services, and 60% lack landline telephone services. The Navajo Nation also lacks a modern 911 emergency system[14]. In Kayenta, AZ, of the 1,240 homes, 700 are rental units and over 300 are mobile homes.

1.5. Navajo Tribal Utility Authority

That Navajo Tribal Utility Authority (NTUA) is a non-profit distribution utility founded in 1959 to address the absence of utilities on the Navajo Nation. It is the largest multi-utility enterprise owned and operated by an American Indian tribe and currently serves approximately 41,259 electric customers, 39,323 water, 14,105 waste water customers, 7,929 natural gas customers, and 205 photovoltaic customers. It provides electric distribution and transmission, communications, natural gas, water, wastewater and power generation, including photovoltaic (solar), services for the Navajo people at a reasonable cost. The tribal utility authority, an enterprise of the Navajo Nation, operates under a tariff rate and offers one of the lowest electricity rates throughout the western United States.

NTUA's objectives are:

- To promote employment opportunities on the Navajo Nation, and
- To improve the health and welfare of the residents of the Navajo Nation.

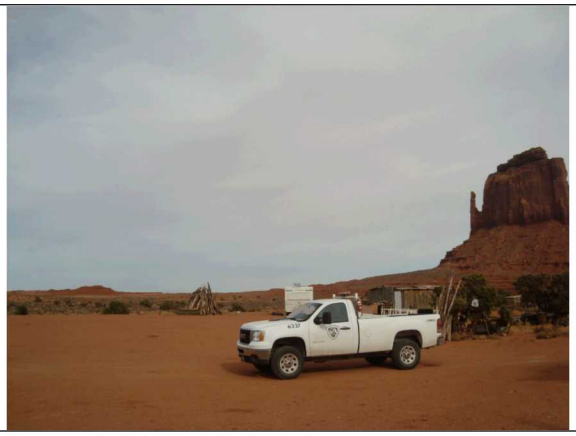
NTUA has a workforce of 722 regular employees, and 8 temporary employees. Of these numbers, over 97% percent are of Navajo Descent.

---

[23] Beyond the Grid - Solar power on the Navajo Nation video. Arizona State University film project by Courtney Columbus, Katrin Mehler, Brittany Nixon, and Lisa Marie Schlesinger https://vimeo.com/194008631

[23] http://navajotimes.com/news/2012/0112/012612census.php

[14] NTUA, 2017.

	
Source: DOE Site Visit 2018	Source: DOE Site Visit 2018

2. Description and History of the Solar Energy Program

Historically, the Navajo Nation and other rural tribal reservations had largely been overlooked during the 1930's Rural Electrification Act (REA) which had originally been put in place to electrify unreached rural areas. The vast land, the rugged areas and the dispersed traditional homes result is the challenge of large number of un-electrified homes on the Navajo Nation. Solar photovoltaic electricity generation is one viable and straight-forward solution to this rural electrification dilemma.

In 1993, NTUA was awarded a $350,000 grant funded by the Western Power Authority in partnership with the DOE to conduct a solar energy pilot. Vircynthia Charley volunteered and was responsible for installing 40 stand-alone energy units of either 240 watts or 260 watts in homes that were too far from the grid to be connected. Sandia National Laboratories assisted with the proposal development process and provided technical assistance. The array output of 1.3 kWh/ day was too small to power much more than very simple lighting during the day. Customer tariff charges of $40/month combined with the grant monies did not cover the maintenance costs of these small systems, but the experience set the foundation for solar use to increase energy access for remote areas.

In 1999, NTUA received a $2 million loan from USDA's Rural Utility Service (RUS) to purchase 200 systems with 640 Watt solar power generated[15]. These units were distributed by NTUA via a customer lease purchase agreement which should have assisted in paying back the RUS loan. The concept was for PV units which would be installed in homes ready with internal electrical wiring completed which met

[15] Begay, Sandra, "Native American Sustainable Energy Systems – Navajo Solar Electric Case Study", presented at the Arizona Governor's Tribal Energy Meeting, Arizona, 2005.

[27] Final Report: DOE Cooperative Agreement DE-FG02-04CH11240 between DOE and NTUA, March 2007 https://digital.library.unt.edu/ark:/67531/metadc897820/m2/1/high_res_d/947555.pdf

industry standards. The self-contained solar PV units included pre-wired two angle adjustable mounted PV panels (tilt for summer and winter sun), the balance of the system (invertors, charge controllers) and lead-acid batteries all mounted on a metal skid which was placed on a flat bed trailer by a fork lift. The concept was for drag, drop, plug and play – deliver and place the PV system south facing after trenching and connecting from the home to the solar PV electrical unit, then the system is ready to generate electricity for the home.

With this large procurement of solar PV system, NTUA soon discovered the system's photovoltaic cells had a manufacturing error that caused the systems to overheat. Customers paid $95/month for approximately 1.6 kWh of output, but were frustrated that they could not microwave or refrigerate food without the panels overheating. Although 200 units were purchased with the RUS funds, NTUA was did not install the full lot. The manufacturer was initially not responsive to NTUA's requests to replace panels, so Vircynthia and her team loaded up the panels and drove to manufacturing plant in Phoenix; they would not leave until the company agreed to X-ray the panels and confirm the manufacturing defect. The manufacturer eventually replaced the faulty PV panels, but customer trust had eroded regarding this sets of solar PV units. It would take time to re-establish the quality of the PV systems.

Over the next eight years from 2002-2010, NTUA was awarded funding through a cooperative agreement, the Navajo Electrification Demonstration Program (NEDP)[27] between the DOE, specifically the Solar Energy (Solar) Program and eventually from the DOE Office of Electricity (OE) funding. The creation was through a congressional earmark sponsored by former New Mexico Senator Jeff Bingaman and Senator Pete Domenici to support the Navajo Nation. From the final report of the NEDP, "Under the sponsorship of United States Senators, Jeff Bingaman and Pete Domenici, Congress passed Public Law 106-511, Section 602. P.L. 106-511 passed by the House on October 19, 2000 and by the Senate on October 24, 2000. The legislation authorized the Navajo Electrification Demonstration Program to be funded $15,000,000 per year for five years. President Clinton signed the Bill into Law on November 13, 2000. Public Law 105-611 allows for rural electrification of Navajo People's homes that request for electric services. The funding was originally designated for solar installations; but given its purpose of rural electrification, it was eventually used for grid extensions for eligible customers before the funding was expended

The DOE-NEDP funding allowed NTUA to change solar vendors and to procure a hybrid solar energy kit of 880W solar panels combined with small wind turbine and battery system. Their business model was adapted to have a tariff fee for operations and maintenance costs that is in place today. Even today, customers are not charged any initial costs and are only required to pay a set monthly tariff. The new business model allowed NTUA to maintain ownership of the PV systems and regain customer trust in the PV program. In addition, NTUA with the support of Sandia National Laboratories technical assistance, standard operating procedures and operating and maintenance schedules for the systems was created. NTUA also developed customer education curriculums for both customers and customer services representatives.

Vircynthia was a pioneer of the NTUA solar energy program, but these efforts were in addition to her many other electrician duties. Today, she is the NTUA Kayenta District Manager. She and her staff are

responsible for all the utilities in her district: electricity distribution, natural gas, telecommunication, water, and waste water infrastructure. The solar PV energy program model that she helped to develop with over 100 installations in Kayenta has been replicated other districts. All of NTUA has benefited from lessons learned.

Dates	Funding	Amount	Customer Price/Month	Array Output	Total kWh/day	# of Units	Manufacturer (Integrator)
1993	DOE - WAPA	$350,000	$40	240 W 260 W	1.3	40	Solar Mart
1999 - 2001	USDA – RUS	$2,000,000	$95	640 W	1.6	200	Photo Com. / Kyocera
2002-2003	DOE – NEDP	$800,000	$75	880 W hybrid small wind (Phase I)	2.0	40	SunWize (NADAC)
			$145	880 W hybrid LP gas generator (Phase I)	2.0	4	SunWize (NADAC)
2003-2010	DOE – NEDP	$1,150,000	$75	880 W hybrid small wind (Phase II)	2.0	63	SunWize (Ducommon Tech.)
2010 – Present	DOE		$75	1080 W hybrid small wind + refrigeration unit	~3.0	65	Sacred Power

In spite of the success, the NTUA solar energy program does not pay for itself. The $75/month or $145/ month tariff that customers pay, dependent on system size, does not fully cover the total system cost. In addition, there are high but fundamental operation and maintenance (O&M) costs involved with replacing batteries every 2-5 years due to constant draining or overuse of the systems and adding equipment such as refrigerators. The cost for the solar program is financially supported by NTUA's other utility service portfolios, such as NTUA wireless as well as through the larger, grid connected electric rate base.

2.1. Insights from Customer Interviews

On February 16, 2018, the research team visited NTUA customers to discuss their perception of the solar PV electrification program. The following insights were gained from these visits.

Customer A

The first customer interviewed lives in a three bedroom, 20 year-old manufactured home with 9 other members of his family, including his young grandson and three other children. Although his salary is above 120% of AMI, he spends 40-50% of his income on housing costs. The family has lived in their current home for ten years with little or no power. They primarily used flashlights for lighting and coal and wood stoves for heating. The customer has the largest solar system available through NTUA – 1300 Watts – and can still only use the system for lighting and refrigeration, but he is glad that he has the ability to keep food and medicine cool.

Customer B

The second visit was to an elderly, self-employed artisan who made approximately $20,000 per year from selling her traditional rugs. She lives in a trailer in the Monument Valley Tribal Park where no utilities are located; she hauls wood and water for daily use. Twice a week, she pays $60 in gas and fees to cut and haul wood to her home for heating during the winter. Her only energy assistance is a donation of two armfuls of wood and a pile of coal which she received once a year. She also purchases propane for her stove. Through the solar energy program, she has electric lights and can stay up after the sun goes down to weave wool rugs. She can also refrigerate the medications needed for her eyes and ears. She pays $70 per month for her solar lighting and refrigeration and, although the process was quick and easy for NTUA to install, she is frustrated that the system is limited and cannot handle the addition of extra appliances such as a microwave or a coffee maker.

2.2. Barriers addressed by Program

The goal of the NTUA program is to address barriers to off-grid electrification throughout the Navajo Nation. These barriers include:

1. Insufficient access to capital
2. Low credit scores/lack of credit history
3. Remote nature of the communities
4. Early technology issues with PV systems leading to lower customer confidence with the systems

By providing low cost, subsidized energy systems, NTUA has addressed the first two barriers. Creating off-grid solutions with consistent O&M on these systems allows remote communities to access power where line extension is economically unfeasible. Finally, rebuilding trust with new, more advanced systems has broken down barriers related to early technology challenges for residential PV electrification systems.

However, additional barriers exist including the growth of electrical use or consumption for modern electronics especially for younger Navajo members. For example, the current suite of available electrification products only allows customers to utilize limited basic needs of lighting and refrigeration. Some customers have noted that they would like a greater selection of technology sizes to allow for additional electronics and appliances such as microwaves, computers, televisions, satellite service and so on. While the NTUA program has made great strides in bringing PV electricity to remote areas with consistent operations and maintenance (O&M), additional programs may be needed to address electrification needs that will allow Navajo tribal members living in remote areas to enjoy the same digital access that their less rural counterparts have available. This level of remote electrification will require creative financial solutions to be economically sustainable.

3. Conclusion

In the current phase of the off-grid solar energy program, NTUA procured solar hybrid systems from a tribally owned and operated solar manufacturing company. With approximately 200 NTUA units utilized and a tremendous need for affordable off-grid units, there are opportunities for other tribally owned off-grid solar PV system businesses and other non-profit residential system installations. At NTUA, there are two solar PV positions - a renewable energy specialist and renewable energy engineer which support all of NTUA's renewable energy projects. There are numerous electrical PV operation and maintenance semi-annual assignments, and customer service interactions by trained staff to support the solar renewable energy program. In addition, there is an opportunity to create design and manufacturing jobs of solar panels or assembly of solar systems in addition to energy efficiency education to meet the needs of the rural un-electrified communities in the US and beyond.

3.1. Opportunities to scale

This case study has focused on the role of NTUA to bring power to a specific region within the US, but there are over 1.3 billion people around the globe who lack access to electricity and millions more need access to a reliable grid. The needs of these rural and remote communities that have never been connected to a formal grid and that may not be covered by a utility service territory are often similar to remote tribal communities and islanded territories of the US.

Many emerging market communities are currently using kerosene and candles for their lighting needs which can be far more expensive than solar PV energy systems in the long run. Remote communities in Africa collectively spends $17 billion on low technology lighting options and Asia spends nearly another $10 billion (See **Error! Reference source not found.**). In addition, technologies that are designed for off-grid markets are well suited to resilience needs for extreme weather events, such as distributed solar systems combined with microgrid extensions. Off-grid communities in emerging markets would be a prime market for US exports of plug and play technologies that could deliver off-grid access to power. In fact, the recent $80 million debt finance of M-Kopa, the British solar energy company which is intended to help the company expand its reach from 500,000 households to 1.5 million homes over the next three years, is illustrative that this industry is maturing.

The plug and play solar energy business model replicated a strategy of leapfrogging technology similar to the success of cellular phone technology which was able to leapfrog the innovation pathway instead of traditional phone landlines. However, cellular phones are relatively inexpensive and require little maintenance or education for use; where as some of the challenges associated with the early NTUA's solar program were due to a manufacturing error with one type of system and business model, which ultimately was addressed. Consumer education is on-going with a focus on the cycle of PV energy generation or battery charging specifically to support operation and maintenance of the system and

longevity of the battery system. NTUA moved to a tariff model for O&M fees rather than the previous lease-to-own model to control the supply chain of models in use. The collaboration and partnership with Sandia National Laboratories helped NTUA to procure better PV systems and improve O&M practices.

There is an opportunity pioneer research on innovative PV systems technologies to meet the needs of off-grid access and extreme weather events simultaneously. These technologies could be piloted in US communities to meet the national security goal of energy access and possibly for small emergency power during black-out events, and the piloted strategies could be used for national solar and micro-grid manufacturing.

References

Annex

List of Interviewees and Contact Information

Vircynthia Charley, Kayenta District Manager, Navajo Tribal Utility Authority, P.O. Box 170, Fort Defiance, AZ 86504 (928) 729-5721 vcharley@ntua.com

Melissa Parrish, Acting Supervisor, Navajo Tribal Utility Authority, P.O. Box 170, Fort Defiance, AZ 86504 (928) 729-5721 mparrish@ntua.com

Deenise Becenti, Public Relations Director, Navajo Tribal Utility Authority, P.O. Box 170, Fort Defiance, AZ 86504 (928) 729-5721 deeniseb@ntua.com