Tolani Lake Enterprises, Inc.
Navajo and Hopi Solar-Powered Irrigation Pumping Systems

Final Report

USDA-NRCS Conservation Innovation Grant Award #69-3A75-12-233
September 30, 2012 – March 31, 2016

Overview

This report summarizes the activities, outcomes and lessons learned from the three-year Navajo and Hopi Solar Powered Irrigation Pumping Systems project funded through USDA NRCS Conservation Innovation Grant #69-3A75-12-233. This report is supplemented by a highly detailed report: *Navajo and Hopi Solar-Powered Irrigation Pumping Systems: A Summary of Activities Findings*) that includes for each of the three solar PV pumping systems we installed and evaluated: technical specifications, photographs, sample pre-construction documents, outreach materials, and detailed descriptions of findings, lessons learned, and recommendations.

In summary, we found that properly designed and installed solar PV irrigation pumping systems are reliable, low-maintenance and inexpensive for producers to operate. This technology applied across our region could make a significant contribution to Navajo and Hopi sustainable traditions of farming. However, to succeed, producers will need financial assistance to cover relatively steep front-end costs and technical assistance from a qualified and experienced team to optimize the many interdependent variables involved in integrating a solar PV system with a well, pump, and water storage and delivery system that fits site conditions and producers' needs.

Producers, community leaders and Tribal Soil and Water Conservation District partners are excited about what they have seen over the past three years and want to put similar systems into place across our region. We invite a discussion with NRCS leadership on how best to move this technology from innovation to an approved EQIP practice.

Key Findings

1. Solar photovoltaic arrays work well to pump irrigation quantities of water but off-grid systems must be paired with sufficient water storage or drip irrigation to mitigate their limited mid-day operating window. This is not a significant issue with grid-tied systems which are capable of pumping any time of day.

2. Solar energy, especially applied in remote rural off-grid applications, offers significant advantages to producers. If designed, purchased and installed by a reputable experienced firm, there are minimal maintenance and operating costs after installation. Systems have an estimated 25-year life during which they generate clean power with no fuel inputs and minimal maintenance costs. Solar power eliminates the health and environmental impacts of high-carbon fuels burned by on-site diesel generators or remote utility power plants. In addition, these systems can offer a significant annual financial return to producers participating in voluntary carbon credit markets. Grid-tied systems or those that maximize use of solar power generated year-round have a higher benefit to cost value.

3. Solar tracking technology is not a good fit for remote, windy, dusty sites. Simpler, sturdier, less expensive fixed mount arrays are better suited for remote farm applications. The exception might be with proven systems with assured accessible manufacturer/installer support and equipment warrantee.

4. Although DC pumps are common in small livestock and domestic watering applications, AC pumps are generally more available, more powerful and more cost-effective.

Three Unique Applications of Solar PV Pumping Technology

Tolani Lake Enterprises, Inc. (TLE) worked closely with a broad and diverse group of partners to install and evaluate three unique solar PV irrigation pumping systems designed to meet the needs of farming communities at three selected sites—two on Navajo Nation and one on Hopi land. For each project, we identified a suitable site; secured needed approvals, designed the system, procured equipment, conducted a pump test on the well, installed the PV and pumping systems, and trained staff and local farmers to operate and monitor the installed system. Tribal and community leaders, farmers, ranchers, and community members including youth were closely involved at each site. We celebrated completion of each system with a community gathering and tour where all participants learned about the innovative application of technology and saw the sun pump precious water.

These three unique systems demonstrate a variety of conditions under which solar power can effectively reduce pollution and greenhouse gas emissions while providing reliable, low-cost water for agriculture. Two systems were built to pump small capacity idle wells. The third replaced a 125 hp diesel generator to pump a heavily used mid-size agricultural well. We built two off-grid solar PV direct pump systems and one grid-tied system. The following briefly describes each of the systems, their benefits and limitations, and what we learned.

Year 1: North Leupp Family Farms, Inc.

The first and largest of the three systems was completed in August 2013 at North Leupp Family Farms near Leupp, Arizona about 40 miles east of Flagstaff on the Navajo Nation. This 21.3 kW off-grid system is powered by a solar array consisting of 72- 295 watt panels mounted in 3 rows on posts. Six of these panels are dedicated to power a small greenhouse PV system with a battery bank and inverter system that provides 120 Volt AC power for equipment located in the greenhouse and power shed. Initially a dual tracking system, the array is now fixed in the E-W axis but still has the capacity to be manually adjusted on the North-South axis to optimize the solar gain as the sun angle shifts during the year. The system was designed to pump 360 gallons per minute from a well adjacent to the farm that taps into the alluvial aquifer of the nearby Little Colorado River. The system irrigates on average 20 to 30 acres of the farm's total 100 acres.

To date this system has pumped 10.4 million gallons of irrigation water, 5.2 million gallons per growing season. Performance metrics comparing solar PV to power generated by the 125 KW diesel generator (now a backup power supply) indicate an annual savings of approximately: 1) 376 gallons of diesel fuel; 2) $1,881 in fuel costs; 3) $800 in operating and maintenance costs; and 4) 1.3 tons of atmospheric CO_2.

Lessons Learned at North Leupp Family Farms

Most importantly, we learned that solar PV direct pumping from a well of this size is limited to a window from about 10 am to 3 pm through the growing season. Direct pumping from the sun is limited to a five to six hour mid-day window when the sun is strong enough to run a mid-size (15 hp) pump needed for a well of this size. This is not ideal timing for irrigation. Integrating sufficient water storage into the design is the ideal solution. Storage tanks act like a battery, allowing the pumping system to fill tanks during the day and farmers to access the water in early mornings and evenings for irrigation. Another solution is to pair solar direct PV systems with subsurface drip irrigation to minimize water losses from mid-day watering.

During the project, North Leupp Family Farms completed its NRCS Conservation Plan and submitted an EQIP application that included installation of a drip irrigation system for the section of the farm currently under cultivation. Installation of the drip system was scheduled to follow installation of a new hoop house which meant that starting in 2014, farmers were left to flood irrigate mid-day or pay for fuel to use the diesel generator to irrigate during preferred early morning or evening hours. At the time of this report, the farm has neither water storage nor drip irrigation installed. *This is a significant issue that requires mitigation as soon as possible.*

We also learned from this first installation, that complex tracking systems are not ideal for dusty, windy, remote installations without easy access to technicians trained to program the tracking system. We also discovered that a flow meter and an hour meter should be integrated into system design to measure both the volume of water pumped and system operating time to ideally evaluate performance and cost-effectiveness. We realized this after installation and retrofitted the meters, but were unable to get the hour meter to work properly as a retrofit.

Another lesson learned was that heat build up inside protective structures can be excessive in this region, negatively affecting performance and longevity of electronics and batteries. In this area, summer daytime temperatures frequently exceed 100 degrees building intense heat inside enclosed structures. Insulation and active ventilation or cooling should be integrated into protective structures.

Our final note is that an off-grid solar PV system generates power whenever the sun is shining, offering opportunity to co-locate enterprises to use surplus energy when it is not needed to pump water. Optimizing on-site water storage to fill during mid-day operating hours and through the off-season with tanks or reservoirs sited to gravity feed to the fields is another way to effectively put this surplus power to use.

Years 2 & 3: Hopi Well 63N01

The second system, the smallest of the three, was completed in March 2016 on the Hopi Reservation about 3 miles north of Kykotsmovi, Arizona. This area is central to a farming area serving four Hopi Villages. The system is powered by two solar panels (560 watts) pumping a small well (6 gpm) that taps into an alluvial aquifer linked to the Oraibi Wash a few hundred yards away. The well had historically been pumped with an old-style windmill that was in disrepair when we made the site selection. This system pumps water into two connected storage tanks that farmers can tap from an overhead filling station and faucet. A float switch controls when the well pumps. We designed the system for hauling irrigation water because the Hopi are primarily dry land farmers who carefully locate their fields to most effectively capture scarce rainwater and runoff. They supplement by hand irrigation during dry periods. The modest flow from this well will provide the area's 25 small farms with sufficient water for supplemental irrigation. At the celebration of completion of this system, area farmers and Hopi Tribal leaders talked of extending a water line to pump directly to nearby fields.

Lessons Learned at Hopi

The approval process with The Hopi Tribe took over two years to complete. This pushed siting, design and installation of what was to be the second year system into year three, compressing our workload in the final year. We applied what we learned in the first year to this system and built sufficient storage into its design. Once construction was complete, however, we realized that the height of the overhead filling station outlet determines the level to which the storage tank can be tapped. In times of high demand, this could mean that after the top 2 feet in the storage tank is used, farmers will have to use the hose faucet (about 1 foot above ground level) until the well pump can catch up and refill the storage tank.

Year 3: Dennehotso Chapter

The third system is an on-grid application in Dennehotso, Arizona on the Navajo Nation about 52 miles from the Four Corners. The innovation demonstrated at this site shows how pairing grid-tied solar power with a water delivery system generates clean energy that offsets carbon intensive electricity and allows producers to pump irrigation water 24/7. Grid-tied power gives farmers the advantage of being able to pump outside of peak sun hours, the only time when pumps powered directly by the sun are operational.

The system's 5.04 kW solar array is mounted on the Dennehotso Chapter House roof. Because the Navajo Tribal Utility Authority does not offer net metering (buying excess power from solar customers), the Chapter uses the solar energy generated during daylight hours to run its operations and reduce its utility bill. The system was sized to offset the cost of utility power used during the growing season when farmers are irrigating fields in the adjacent community gardens. This provides optimal benefit to the Dennehotso community in the form of clean power for irrigation 24/7 and reduced energy bills year-round for the Chapter. Any surplus power is fed back into the grid continuing to offset high-carbon power purchased by the utility. The system's production is available online so anyone in the community can monitor the power generated, cost savings and carbon offset at anytime: https://easyview.auroravision.net/easyview/index.html?entityId=8066633 (cut and paste this link into a browser).

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Lessons Learned at Dennehotso

We saw an opportunity at Dennehotso to try something new and set up a grid tied system to work around the mid-day operating limitation of solar direct pumping and benefit the Chapter by offsetting their electric costs during the workday. The challenge here was the distance to the fields from the secure site at the Chapter House where the solar array and well were located. Because there was essentially no elevation change between the well and the field, we designed a storage tank and pressure pump system to move water the roughly 600 feet to the field. Because the pipeline crossed land not controlled by the Chapter, Navajo Nation cultural and environmental review and approval was required for its installation. This was outside the scope of the original project budget and timeline. Thankfully, Dennehotso Chapter was able to contract directly with a consultant to complete the process and a no cost extension accommodated the additional time needed to complete the bidding, contracting, field work, and administrative review and approval. We also experienced delays with the NRCS payment system that stalled construction for several weeks.

Table 1 is a compilation of key specifications, operating parameters, and financial and operational costs and benefits of each of the systems.

Table 1: Summary of the 3 Solar PV Irrigation Pumping Systems

Location and Description	North Leupp Family Farms – Mid-size off grid direct PV pumping system	Hopi Well 63N01 - Small off grid direct PV pumping system	Dennehotso Chapter – Small grid tied pumping system
SOLAR PV SYSTEM			
Modules (panels) Manufacturer/Model/Type	Trina model TSM-295-PA14 multicrystalline cell	Solar World SW 280 monocrystalline cell	Solar World SW 280 monocrystalline cell
Watts per module	295	280	280
# modules	66 / 6[1]	2	18
Total kW	19.47 / 1.77[1]	0.56	5.04
Controller	Sun Pumps model SPV 15000 Solar Pump Variable Freq. Drive	Grundfos model CU 200 SQFlex	Float switch controlled relay
Inverter(s)	Integrated with controller	N/A (DC powered pump used)	18 Enphase M250 micro inverters
Mounting system	Ground pole rack	Top pole rack	Rooftop rack
WELL			
Well Depth (ft)	Approximately 175	157	120
Surface casing diameter (in)	12	6	8
Recommended pumping rate (gpm)	360	6	20

Static water level (ft)	80	73	12
Drawdown depth at recommended pump rate (ft)	80.4	83-88 (estimated)	70
SUBMERSIBLE WELL PUMP			
Motor	Franklin Electric, model 23661391,15 hp, 460 volt AC, 3 phase, 6” diameter	Grundfos MSF 3, 1.4 hp, variable speed, AC or DC	Grundfos ¾ hp, 208-230 volt AC, 3 phase, 4” dia.
Pump Make/Model	Grundfos, model 385S 150-2, 15 horsepower, 8” diameter pump end with a 4” discharge	Grundfos SQ Flex model 6 SQF-2, 3” diameter, 1” discharge	Grundfos model 25S07-05, ¾ hp, 4” diameter, 1 ¼” discharge
Max Daily Water Production (gal/day) and Pumping Rate (gpm)	108,000 gpd (assumes 5 hrs/day), 360 gpm	1800 gpd (assumes 5 hrs/day), 6 gpm	28,800 gpd, 20 gpm
WATER STORAGE & DELIVERY SYSTEM			
# Tanks	0	2 (1 new)	1
Capacity (gals)	0	20,000 total (10,000 new)	10,000
Pressure pump Make/Model	N/A	N/A	Grundfos model CM 5-3, 1.4 hp, 30 gpm
Delivery System	6 inch diameter 700 ft main pipeline to 4” flood irrigation system laterals	Gravity overhead filling station and hydrant	Pressure pump with tank and 3 inch diameter 600 ft pipeline to faucet
GENERAL			
Operating window during peak of growing season	10 am to 3 pm	10 am to 3 pm	24 hours
Completed	August 2013	March 2016	March 2016
Acres irrigated	20 - 30	--	10
Water pumped as of March 2016 (gals)	10,409,000	--	--
COST / BENEFIT			
Approximate Equipment Cost[2]	$79,100	$20,400	$66,500
Well testing	--	$2,500	$2,500
Approximate Installation Cost[2]	$10,500	$8,000	$12,000
Estimated annual/lifetime (25 years) energy cost savings	$1,880 / $47,000	$900 / $22,500[3]	$1,275 / $31,875
Estimated annual/lifetime CO2 emissions reduction (tons)	1.3 / 32.5	2.9/ 72.6	14.2 / 355
Estimated annual/lifetime value of carbon offsets (at $732/ton)[4]	$952 / $23,790	$2,127/ $53,166	$10,394 / $259,860
Simple ratio of lifetime benefits to cost[5]	0.8	2.4	3.6

[1] Six modules were dedicated to the greenhouse PV system (battery bank and inverter system).

[2] Costs are specific to each location and include security fencing, protective structures, and at North Leupp Family Farms includes the greenhouse PV system. Retrofits and in-kind labor are not included in these estimates.

[3] As compared to running the well pump from a 1500-watt generator using 0.33 gal/hr of gasoline, 5 hours/day for a 180 day growing season.

[4] Value of $664/metric ton was determined by Imperial College London and the International Carbon Reduction and Offsetting Alliance in September 2014, this converts to $732/US ton.

[5] Cost-benefit analyses are complex economic assessments that transform future dollars into present values. This number is a simple calculation of the total benefits (energy cost savings plus the value of carbon offsets) divided by the cost (equipment and installation) to allow for a simple comparison between systems.

Accomplishments By Deliverables

1. System design, purchase and installation.

Over the course of the project, we worked closely with our contractor, Westwind Solar Electric, Northern Arizona University Global Engineering Outreach Student Chapter (formerly Engineers Without Borders), North Leupp Family Farms, Inc., The Hopi Tribe and Village Tribal Councils, Hopi Natural Resource and Land Departments, the Navajo-Hopi Partition Land community of Sandsprings, Dennehotso Chapter, Navajo Nation Water Resources, Dennehotso Farm Board, Navajo Mountain Soil and Water Conservation District, the Little Colorado River Soil and Water Conservaiton District and the Hopi Soil & Water Conservation District.

The first system at North Leupp Family Farms was completed as projected in the first year. Due to the complexities of Hopi governing structures involving multiple levels of authorization—central tribal council and administration as well as village officials—securing a site and approval for the year 2 installation took much longer than expected. Once it became apparent that completing that the Hopi installation in year 2 was unlikely, we began to work in parallel with Dennehotso Chapter to begin the process of siting and design. We installed the second and third systems in year three, both of which were completed in March 2016, the last month of the project period.

2. Reports on status of anticipated collaborations with the Coalition's Model Farms and AmeriCorps projects if funded.

Neither project was funded.

3. Performance monitoring protocols and documenting system performance.

The North Leupp Family Farms system pumped 5.2 million gallons of water in each of the 2014 and 2015 growing seasons. We compared operating and maintenance costs of the solar PV system with historical operating costs of the on-site 125 kW diesel generator (now the backup power supply). The system replaced 200 diesel generator operating hours, saved 376 gallons of fuel valued at $1,081, plus an estimated $800 in maintenance costs. This equates to an annual savings of $1,881 and a carbon offset of 1.3 tons. Over an estimated 25-year lifetime, this means a savings of $47,000 and a carbon offset of 32.5 tons.

Similarly, we compared performance of the Hopi off-grid system to the cost of running the pump from a 1500-watt gasoline generator five hours/day over a 180-day growing season. Typical fuel consumption for a generator of this size is 0.33 gallons per hour. Using these figures, the system's estimated annual savings are $900 in operating costs and a carbon offset of 2.9 tons. Over an estimated 25-year lifetime, this means a savings of $22,500 in operating costs and a carbon offset of 72.6 tons.

As of June 22, 2016, the Dennehotso array generated a total of 6,300 KW hours of energy and a carbon offset of 9.6 US tons since it was commissioned on October 19, 2015—on average 788 kW hours per month. Because the system operates year-round and not just when there is demand, its annual production is estimated at 9450 kW hours saving the Chapter an estimated $1,275 in utility charges and a carbon offset of 14.2 tons. Over an estimated 25-year lifetime, this means a savings of $31,875 and a carbon offset of 355 tons.

The value of carbon credits varies, but using the value of $732 per ton ($664 per metric ton) determined by Imperial College London and the International Carbon Reduction and Offsetting Alliance in September 2014, (http://www.naturalcapitalpartners.com/news-media/article/unlocking-the-hidden-value-of-carbon-offsetting), the value of the carbon offset provided by these systems could offer significant returns to producers who choose to participate in voluntary carbon credit markets.

We calculated a simple benefit to cost ratio for each system and found that the grid-tied system had the highest lifetime return. This is partly due to the fact that its system offsets energy costs for the Chapter year-round whereas the off-grid systems are able to produce energy year-round but only offset energy costs during the 180 day growing season. Colocating other energy users or growing yearround in greenhouses would increase the benefit to cost numbers for these systems.

4. Reports on SWCD/College dissemination and outreach on-farm tours,

workshops, after system installations in each year, including numbers of activities and of participants per activity

In total, outreach included presentations to over 900 people at more than 40 events including the three community celebrations at each of the three sites. Because the Hopi and Dennehotso systems were only completed in March 2016, the bulk of outreach events were focused on the first project at North Leupp Family Farms completed in August 2013.

Outreach events included presentations at the Tsaile campus of Dine College; Leupp, Tolani Lake, Birdsprings and Hardrock Chapters; Grazing Committee meetings in Birdsprings, Leupp and Tolani Lake; Chapter Land Use Planning Committees at Leupp and Tolani Lake; and a tribal youth gathering in Sedona, Arizona. TLE solar technicians also provided many on-site tours and presentations to visitors, reservation schools, tribal leadership, youth conservation groups and County leaders. North Leupp Family Farm staff continues to show visitors the system as part of their farm tour. TLE continues to share information about all of the three systems through our website.

5. Culturally appropriate bilingual video-documentation of each system installation and operations.

Three young Navajo filmmakers produced a feature film, *Walking on Water* that tells the story of innovative use of renewable energy as it relates to water conservation and water rights, crucial issues for regional ranchers and farmers. *Walking on Water* has been shown at a variety of reservation venues and is available online at: https://www.youtube.com/watch?v=CoVWL3yJwYo.

Keanu Jones, one of the youth filmmakers, and his new film that included parts of *Walking on Water* were featured in the March 2015 White House Film Festival. (Indian Country Today Media Network.com, March 27, 2015, http://indiancountrytodaymedianetwork.com/2015/03/27/watch-film-earned-18-year-old-director-trip-white-house-159782).

In addition, Paper Rocket Productions, a local Native production company, worked with us to film and produce a six-minute video, *Pumping Water with the Sun on Navajo and Hopi Land*, as an outreach and education tool. It is available online at: https://vimeo.com/171850405/f7e730dd74.

6. At the end of year 1, a manual describing system innovation, design and installation, evaluation and dissemination with updates each year.

Navajo and Hopi Solar-Powered Irrigation Pumping Systems: A Summary of Activities Findings is an in-depth e-manual that includes for each of the three solar PV pumping systems we installed and evaluated: technical specifications, photographs, sample pre-construction documents, outreach materials, and detailed descriptions of findings, lessons learned, and recommendations. It includes the entire Operating and Maintenance manuals for all three systems. It was designed to be a stand-alone resource to assist NRCS and producers interested in this technology to learn from our experience and is provided as a separate document to this report.

7. A project summary presented to State Technical Committees with the goal of including solar pumping as a conservation practice eligible for EQIP.

We are sharing our findings with the Arizona State Technical Committee at their June 29, 2016 meeting in Phoenix, Arizona. We will also provide the committee a copy of this report and the *Navajo and Hopi Solar-Powered Irrigation Pumping Systems: A Summary of Activities Findings.*

8. Participation in at least one NRCS CIG showcase or comparable event

Tolani Lake Enterprises staff and Solar Technician, Tyrone Thompson, presented a poster on this project at the NCRS CIG Showcase at the 70th Annual Soul and Water

Conservation Society Conference: *Coming Home to Conservation, Putting Science into Practice* in Greensboro, North Carolina on July 27, 2015. The poster is included as an appendix in the *Navajo and Hopi Solar-Powered Irrigation Pumping Systems: A Summary of Activities Findings.*

9. **Final project report at the end of year 3.**

   Completed.

Key Challenges

We provide the following as insight for anyone interested in applying this technological innovation.

- Finding agricultural wells of 100 gpm or larger for the project.
  After substantial effort, we were able to identify only one well of this size at North Leupp Family Farms. Records in this region are incomplete and sometimes inaccurate. But with help from our partners, we were ablt to find two smaller wells adjacent to farms of commercial size so could complete the project. This offered an unexpected opportunity to apply and evaluate solar PV pumping technology under a range of conditions.

- Inferior quality solar equipment without warrantee.
  We purchased our first solar equipment from a local supplier who had built and installed 17 dual axis tracking arrays across the US, with one system on Cape Cod reported to have successfully weathered Hurricane Sandy in 2012. The company was not yet in full production, but bid a similar system and we selected it to evaluate dual tracking as one of the technological innovations. We learned later, the company was undercapitalized and did not warrantee its equipment. The metal used to fabricate the array mounting brackets as well as the connecting hardware were lighter grade than needed to hold up under local conditions. In addition, the programmable hydraulic dual tracking system never operated correctly despite repeated reprogramming attempts by the supplier who designed the system. To address these deficiencies, our team transformed the array to a fixed system retaining the option to manually adjust the N-S axis as needed.

- Obtaining tribal approvals.
  Tribal review and approval took a great deal more time and effort than predicted. We discovered that The Hopi Tribe has a long and unhurried process for approving projects, especially when initiated by outside partners. Navigating this process took more than a year to complete, but at the celebration of the new system, Hopi leaders were very pleased with the outcome and expressed gratitude and hope for future partnership. The Navajo Nation cultural and environmental approval process for the Dennehotso pipeline was initiated at completion of the design but took over six months to complete. Both delays affected the project timeline, requiring a six-month no cost extension to complete.

- Monitoring performance.
  Integrating flow and hour meters into the system in the design phase ensures access to essential data for evaluating performance , but these data must be read and documented regularly by local operators, a job that is above and beyond normal duties of farm managers and farmers. Even so, the farm managers and our solar/water technicians were able to document performance at North Leupp Family Farms. We are optimistic that the Hopi Tribe and Dennehotso Chapter and Farm Board will operate, monitor, and maintain their systems, but they will not likely include evaluating system performance as part of their daily operations. Because these two systems were completed in the last month of the project period, we have little performance data to share.