SAND Number 2009-0232 P

NORTH LEUPP FAMILY FARMS PROJECT - SUSTAINABLE AGRICULTURE SYSTEMS USING PHOTOVOLATIC CELLS AND SMALL WIND

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Albuquerque, NM
August 2008

I. INTRODUCTION

NORTH LEUPP FAMILY FARMS BACKGROUND INFORMATION

The North Leupp Family Farms (NLFF) is a community-based, non-profit, volunteer-driven farm supporting sustainable agricultural for more than 20 years. Established in 1985, NLFF is located approximately two miles north of the town of Leupp, Arizona, located on the southwest side of the Navajo Reservation as shown in Figure 1. A closer view of the Leupp area is shown in Figure 2. Before the use of conventional irrigation methods used in present day agriculture, the people of the surrounding Leupp area had only dry farming methods available. The use of irrigation on NLFF began over 20 years ago during an extended drought, when the Navajo Nation Government implemented a basic surface irrigation system using a well drilled during a road construction project. Later, the Seventh Generation Fund and a non-profit native entity sponsored the farm for ten years and upgraded the surface irrigation system to a drip irrigation system. Israeli farmers and engineers designed the drip irrigation system and piping. When the Navajo Nation withdrew from the Seventh Generation Fund it adapted the drip irrigation system to its present day form.

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[1] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United Sates Department of Energy's National Nuclear Security Administration under contract DE-AC-04-94AL85000.

Figure 1: Map of Navajo Nation including Leupp on the southwest corner (source:http://www.klaustueshaus.com/travel/usa/usa2002/usa2002day07.html).

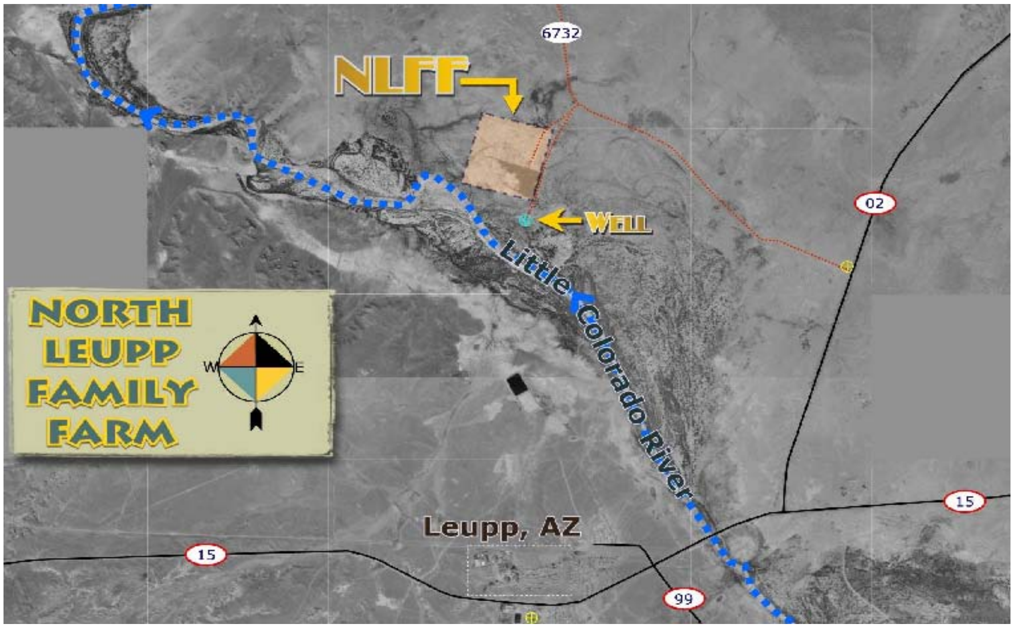

Figure 2: Aerial View of Leupp area (source: http://leuppfarm.googlepages.com/aboutnlff).

Community involvement, under the guidance of NLFF Board of Directors, and the use of traditional farming practices have helped retain the water and land rights necessary to maintain the Navajo livelihood of this community. With the trends of obesity, diabetes, and overall unhealthy lifestyles on the rise in Native Americans populations, establishing healthy practices is the NLFF is top priority. By establishing and promoting healthy foods and active lifestyles; ensuring communal food security; and strengthening traditional methods of farming and ranching in its community, the NLFF continues to develop and present solutions for addressing the difficulties that many Navajo people face today.[2]

PROJECT OBJECTIVES AND OVERVIEW

This study focused on two primary interest areas: (1) gathering sufficient past and current data to calculate the amount of renewable energy generation needed for current and future development at NLFF; and (2) outlining concerns, effects, and costs associated with each renewable energy system design. The renewable energy system will be small-commercial scale, not utility-scale.

Objectives inherent in this process include determining current operating requirements, developing methods for objectively comparing operation variations, selecting a finite number of possible design scenarios to examine, and proposing farm-specific optimizations for the selected scenarios. Successful simulations will require actual, real-world data that can be estimated or used as input data to validate models and calculations.

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[2] Leupp Chapter House. *Leupp Land Use Plan*. Leupp, Arizona: Leupp Chapter, 2005.

Necessary data for these analyses include water usage and schedule, fuel consumption, current irrigation setup, well site information, and power load estimations.

PROJECT PANEL

Four organizations were instrumental in completing the project objectives. Grand Canyon Trust (GCT), Sandia National Laboratories (SNL), and NLFF personnel completed the original analyses and generated summaries. Documentation from the Leupp Chapter House *Strategic Land Use Plan* accommodated in developing methods that best fit the needs of the community. Sandia National Laboratories through the U.S. Department of Energy (DOE) Tribal Energy Program provided management that guided all efforts and ensured that the research resulted in a useful study and potentially applicable system design scenarios. Detailed past and current data of the well drilling site was inaccessible. Consequently, estimated well data was obtained from some of the members of the GCT, the Leupp Chapter House *Strategic Land Use Plan*, and NLFF personnel. The NLFF board comprises the following members: Dennis Walker- President, Bill Edwards- Vice President, Valencia Herder Secretary/Treasurer, Hank Willie- Member at Large, and Stacey Jensen- Farm Manager.

REPORT ORGANIZATION

This report includes the following sections:

- NLFF Irrigation System
- Wind and Solar Characterization
- System Design

- Analysis and Comparison
- Future Development
- Conclusions
- Reflections

II. NLFF IRRIGATION SYSTEM

AREA BACKGROUND

Meteorological data has been collected for the past 30 years in the area of Winslow, Arizona, which is located 25 nautical miles southeast of Leupp, Arizona. Winslow has approximately the same climate conditions as Leupp. For this reason, meteorological data from Winslow (*e.g.,* annual precipitation levels) are used for this study.

The farming season includes a crucial three-month growing from June through August. Figure 3 shows the 30-year average of temperature and precipitation levels. Note the correlation between the maximum temperature and vital growing periods. Further projections predict that temperature is on-the-rise for the future. The effects of recent drought years and the noticeably low levels of precipitation demonstrate how significant irrigation is to a successful harvest.

Figure 4 shows a maximum 30 percent chance of .01 inches of precipitation in any given 1-day period. The probability that the area will receive 0.50 inches of rain in any single day remains under 5 percent, excluding the monsoon season (July through September) where the probability reaches just under 10 percent. The graph curves were smoothed with a 29-day running mean filter.

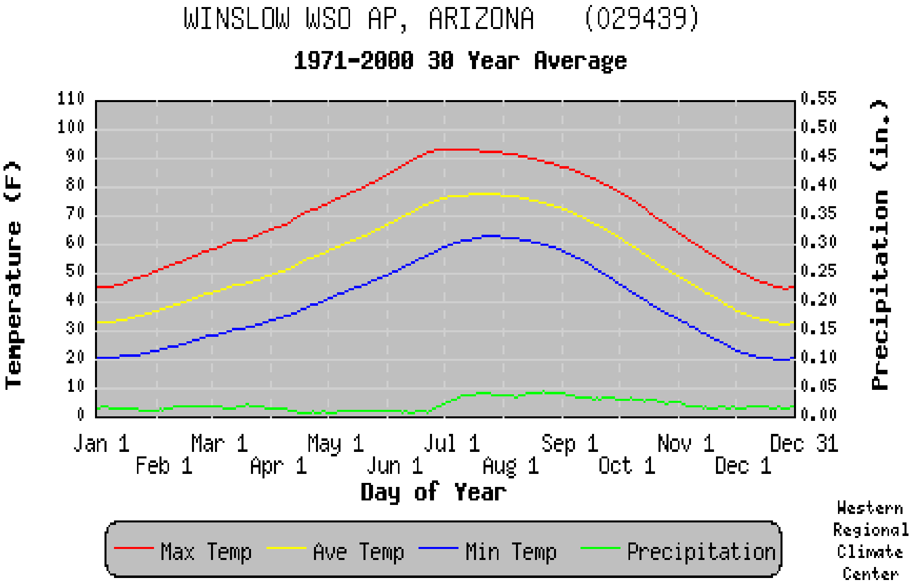

Figure 3: Temperature variation and yearly precipitation for 30-year average data (source: http://www.wrcc.dri.edu/summary/Climsmaz.html).

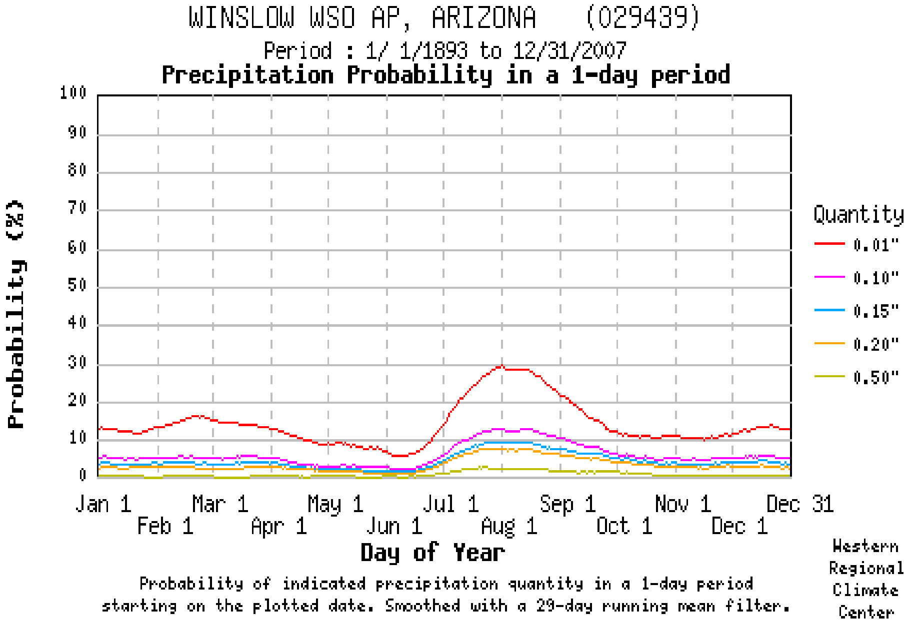

Figure 4: Probability of different amounts of precipitation in a 1-day period using 14 years of past data (source: http://www.wrcc.dri.edu/summary/Climsmaz.html).

SYSTEM COMPONENTS

The irrigation system was designed by Israeli engineers and covers 96.5 acres. The system incorporates surface (or furrow) irrigation in which the water is pumped to the surface from a deep well. The water runs through an underground main line system to T-spout connectors that surface near the edge of the field. The majority of the main line is underground to reduce the effects of wear from the elements. The farm regularly supports between 30 and 40 families. Currently, 28 families each receive one half-acre plot of land to sow A maximum of four plots can be irrigated at any given time and a minimum of three hours is required to water the plots. Each plot is regularly irrigated three times per week during the start of the season[3]. Figure 5 shows the layout of the farm, including the well site just south of the field.

Notice that the current plots of land that are being used (*i.e.*, the green sections of the field) are near the main water lines. The AC pump was reduced from a 40-hp to a 7.5-hp pump, which reduced the flow rate from and resulted in a noticeable pressure head loss and flow rate in the field. Water that is directed to the fields through the main line diverges to sub-line PVC piping to the fields as shown in Figure 6. A small section of the field has drip irrigation, but because the relative size of this section is so small compared to the rest of the field, it is assumed to be negligible for this analysis.

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[3]. NLFF Field Visit. 7 July 2008. Interview with farm personnel.

Figure 5: Satellite view of NLFF showing the well area and fields (source: http://www.mapquest.com).

Figure 6: Section of sub-line watering a plot in the field.

A three-phase Olympian power generator is used to supply approximately 5 kW of constant power to the AC submersible pump which pumps water to the surface from a depth of approximately 100 feet. Generator power use was estimated by reading the voltage and amperage while the unit was operating. The startup surge power was estimated at just over 15 kW. The well's main line is diverted in several directions. The first diversion is to the fields. A second diversion fills a nearby open water storage tank that local livestock ranchers use to fill their water trucks. A final diversion runs to a nearby enclosed water storage tank used to pump water to Tolani Lake for cattle ranching (several additional pumps of unknown size are used on this line).

Figure 7 shows the 4-inch galvanized steel piping exiting the well. After the main line diverges to the field, the galvanized steel is replaced by PVC (*i.e.*, hard plastic). A total length of 4,854 feet of PVC piping diverts the water to the field. Figure 8 shows how the main line is routed from the well site to the field with distances between reference spouts and field boundaries labeled.

Figure 7: Main line at well site diverging to the fields and storage units.

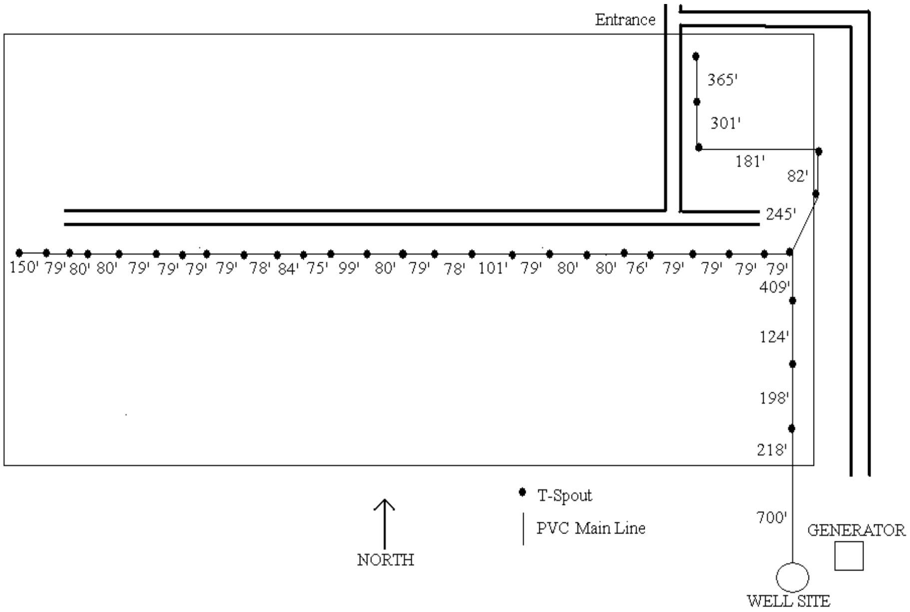

Figure 8: Diagram of main line running from well site to the field with respective distances labeled.

A summary of irrigation system components is provided in Table 1. The values in the table were interpolated for a typical 100-day growing season assuming constant values. Many of these values were measured or estimated. For instance, the flow rate from the well was approximated by using a container of known volume (a 5 gallon bucket) and measuring the fill time. A mean value of 2.9 seconds with a standard deviation of 0.73 was calculated from eleven samples. The standard deviation measures how widely spread the values in the data set are to the mean value. Data points that are near to the mean have a small standard deviation; while a data set that is far from the mean has a large standard deviation. Equal data values have a standard deviation of zero.[4]

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[4] "Standard Deviation ". Wikipedia. August 2008 <http://en.wikipedia.org/wiki/Standard%5Fdeviation>.

Table 1: NLFF Irrigation System Components

NLFF System Components				
Location:	35 degrees 19' N 111 degrees 00' W			
Elevation:	4681 ft			
Olympian Power Systems Generator				
Model	Rated Power	Standby Power	Rated Voltage	Phase
D125P1	156.3 kVA	125 kW	480/277 V	3
Rated Frequency	Rated Current	Fuel	Fuel Consumption Rate	Fuel per Season
60 Hz	188 A	#2 Diesel	2 Gal/hr	1000-2000 Gal
Main Line and Sub-line				
Material	Section Lengths	Piping Diameter	Total Length of Piping	Spout Sections
PVC / Galvanized Steel	10-20 ft	4 Inches	4854 ft	32
Well Site and Pump*				
Gould's Model	Franklin Electric Motor	Voltage	Maximum Amperage	Frequency
225H07-2	7.5 Hp	460 / 380 PH3 V	11.9 / 12.6 A	60 / 50 Hz
Flow Rate	Draw-down Level	Static Water Level (ft)	Surface Elevation (ft)	Frictional Losses for PVC (ft)
100 gpm**	N/A	75**	-7	20.3
Frictional Losses for Galvanized Steel (ft)	Total Static Head	Total Dynamic Head	Well Casing Inner Dia.	Water Source
1.3	N/A	120 ft**	8 Inches	C Aquifer
Field Properties				
Irrigation System	Crops	Water Requirements (gal / acre)		
Surface / Furrow	Traditional Corn, Squash, and Melons	2571		

*The pump listed is an old pump that was taken out prior to the current pump.
**Values were estimated from local wells or approximated from pump charts.

SYSTEM CONSTRAINTS

NLFF is subject to significant operational constraints that affect the process and production of the farm, and which are usually reflected in the year's crop yield. These constraints are due to current irrigation system design and are summarized below.

- **High field labor—**beginning in mid-February, the ground is plowed and disked. Beginning in the middle of May, seeds are planted and watering begins. Every morning and evening, three hours are required to arrange the pipes according to the required plots. The farm requires at least two people working every day checking for cracks or leaks, and maintaining furrow ditches.
- **High associated fuel costs**—during the peak growing season (June through August) fuel consumption rates range from 10 to 15 gallons of diesel per day. Diesel is purchased from the local station regularly; at the date of this study diesel fuel cost $5.00 per gallon. In a normal growing season, the cost of operation can reach $7,500.
- **Low outlet head pressure**—when the water reaches the field, the water pressure head is low, resulting in only 3 or 4 plots watered in the morning and evening or four acres per day.
- **Poor equipment availability**—access to new agriculture equipment is nearly unattainable. The available donated or borrowed equipment is undersized and sees long hours in the fields. Currently there is only one tractor available and it is owned by one of the local farmers.
- **High water use**—the furrow irrigation system requires approximately 24,000 to 36,000 gallons of water each day, depending on system run time.

- **Minimal windbreak**–as a result of the local climate (high winds and temperature), small tamaris (tamarisk or salt cedar) trees have grown along the north edge of the fields. Evapotranspiration (evaporation from the plant surfaces and soil combined with transpiration from plant leaves, which describes the total water escaping from the field to the air[5]) levels are high due to high winds and temperature, low humidity, and high levels of solar energy.
- **No storage—**because the diesel generator belongs to the Navajo Nation Water Department, when water needs to be pumped to cattle at Tolani Lake, the farm stops operating for up to three straight days.

These operational constraints govern the farm's production ability. The bounding limits on production vary seasonally, monthly, and sometimes daily.

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[5] Rogers, Danny, and Mahbub Alam. "What is ET?". June 2008 <http://www.oznet.ksu.edu>.

III. WIND AND SOLAR CHARACTERIZATION

NLFF is seeking to use wind and solar energy to power the well pump given that the cost of diesel has risen drastically in the past year. Leupp is known to have a great wind and solar resources. While the combined characteristics of wind and solar generation are of prime importance, it is also worth investigating the wind and solar resources individually to gain an understanding of their variability; cloud cover is minimal and high spring winds could possibly provide benefits for future development. Additionally, extending an electricity line approximately two miles would enable NLFF to sell excess renewable energy back to the Navajo Tribal Utility Authority (NTUA) through a net metering system and renewable energy certificates (RECs).

WIND POTENTIAL

Statewide, Arizona does not hold uniform, large-scale wind potential as vast as, for example, the Midwestern U.S. but certain areas hold high opportunity. In 2002 Northern Arizona University (NAU) hired TrueWind Solutions to create annual, seasonal, and monthly maps of average wind power density and wind speeds using 30 years of historical data and a modified weather forecasting program. Using NAU’s Sustainable Energy Solutions interactive wind map, high-resolution wind energy resource maps of the Leupp area were created for each of the four seasons. Table 2 shows the annual wind power density and wind class definition.

Table 2: Standard Wind Power Class Definitions at 30 m and 50 m

Standard US Wind Class Definitions						
	30 m			**50 m**		
Wind Class	Wind Speed (m/s)	Wind Speed (mph)	Wind Power (W/m^2)	Wind Speed (m/s)	Wind Speed (mph)	Wind Power (W/m^2)
1	0-5.1	0-11.4	0-160	0-5.6	0-12.5	0-200
2	5.1-5.9	11.4-13.2	160-240	5.6-6.4	12.5-14.3	200-300
3	5.9-6.5	13.2-14.5	240-320	6.4-7.0	14.3-15.7	300-400
4	6.5-7.0	14.5-15.7	320-400	7.0-7.5	15.7-16.8	400-500
5	7.0-7.4	15.7-16.5	400-480	7.5-8.0	16.8-17.9	500-600
6	7.4-8.2	16.5-18.3	480-640	8.0-8.8	19.9-19.7	600-800
7	8.2-11.0	18.3-24.6	640-1600	8.8-11.9	19.7-26.6	800-2000

The theoretical amount of power in the wind at any given wind speed is given by the following equation:

$$P = \frac{1}{2}\rho A V^3 \left(Watts\right) \qquad [1]$$

where ρ represents the density of air at the given location. Density is a function of pressure and time. Thus, as elevation increases, density decreases. In contrast, as temperature is decreases, density increases. *A* represents the total swept area of the rotor blades of the wind turbine. *V* is the velocity of the wind in meters per second (m/s). As a result of the cubic velocity in the power equation, a slight increase in wind speed increases the theoretical power significantly. Consequently, the power density class velocities differ by only modest wind velocities. Wind power density represents the theoretical amount of power captured by the wind for a given rotor and swept area given by the equation:

$$WPD = \frac{1}{2}\rho V^3 \left(Watts / m^2\right) \qquad [2]$$

For example, an area at sea level has an average air density of 1.2 kilograms per meter cubed (kg/m^3). The average wind velocity for the area is 6 m/s. The resulting wind power density is 130 W/m^2.

As in every system there are going to be inefficiencies. To account for these inefficiencies, Equation 1 can be modified as follows:

$$P = \frac{1}{2} A \rho V^3 \eta_g \eta_b (Watts) \qquad [3]$$

The terms η_g and η_b account are introduced to account for the manufacturer's efficiency of the generator and bearings/gearbox, respectively. [6] Thus, when procuring a wind generator detailed specifications (including the bearings and gearboxes details) are very important to the performance of the system.

Using the high-resolution wind energy resource maps of Arizona and aerial photos of the Leupp area, the farm's wind resources can be approximated. Figure 9 shows the annual average wind power density areas near NLFF. Figure 10 and Figure 11 show spring and summer and fall and winter, respectively.

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[6] Twidel, John, and Tony Weir. *Renewable Energy Resources, Second Edition.* New York: Taylor & Francis, 2007.

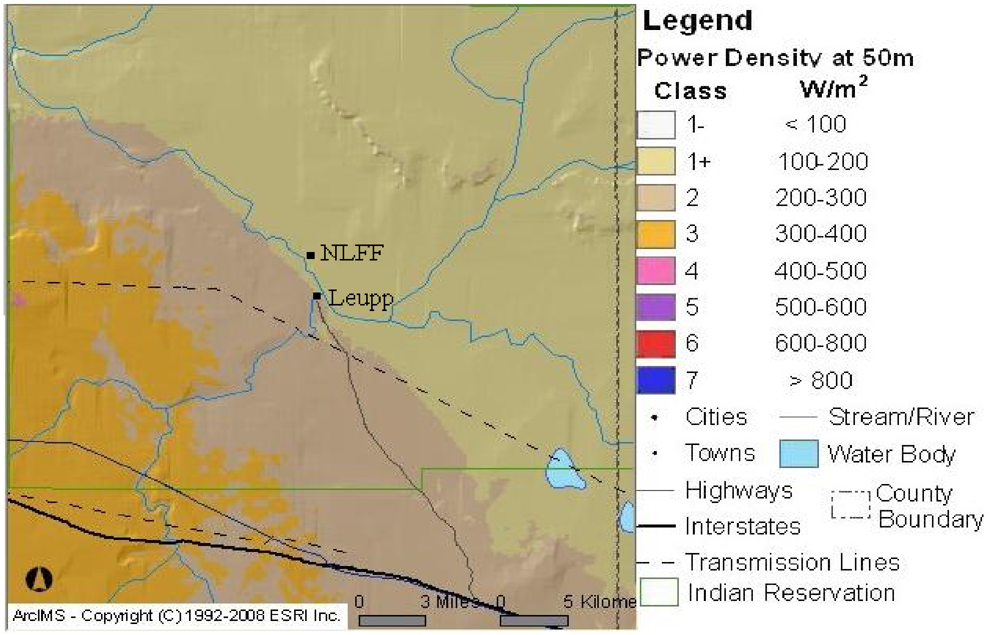

Figure 9: Annual wind power density for Leupp area (source: http://wind.nau.edu/maps/).

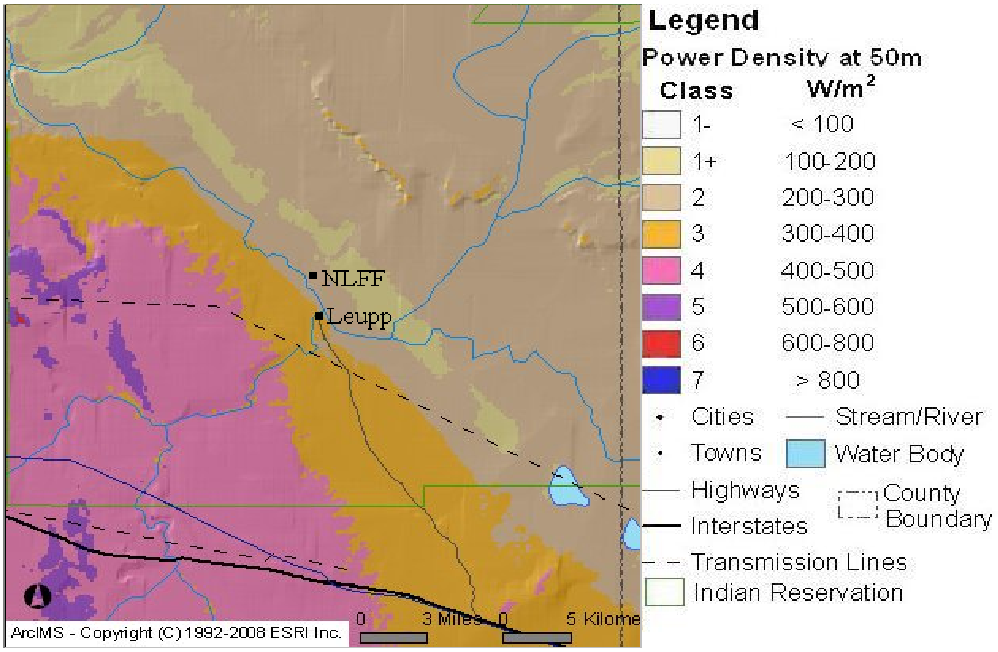

Figure 10: Spring wind power density plot for Leupp area (source: http://wind.nau.edu/maps/).

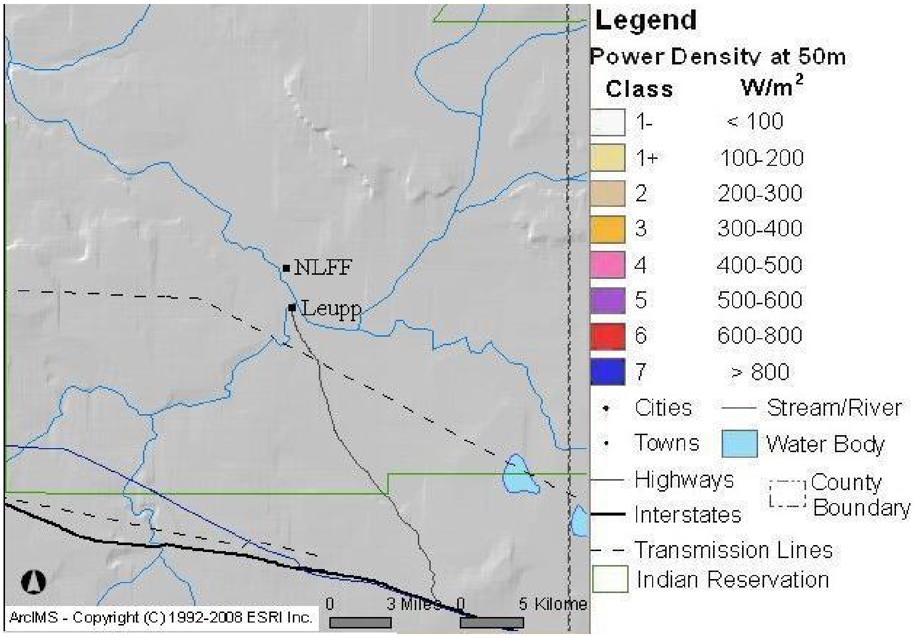

Figure 11: Wind power density for summer, fall, and winter in Leupp area (source: http://wind.nau.edu/maps/).

As illustrated above, the seasonal wind power density for the Leupp region has some astounding results. While spring weather teeters near a Class 3 (orange), wind power density resources for summer, fall, and winter result in nominal Class 1 wind (gray). Though occasional windy days may occur outside the spring season, non-spring seasons are insignificant. Results from the average annual wind power density illustration indicate that NLFF is on the boundary of a Class 2 wind power density resource. Thus, small or community-scale wind turbines should not be overlooked; high spring winds could provide additional power for future development (such as a greenhouse).

SOLAR POTENTIAL

Arizona is known for high temperatures and dry climates. Engineers at the National Renewable Energy Labs in Golden, Colorado, modeled solar radiation using hourly values of direct beam and diffuse horizontal solar radiation values from the National Solar Radiation Database. This data can be used for designing solar energy systems. For this study, data from taken the *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors* (*The Red Book)* for the city of Flagstaff, Arizona, was used (Leupp Arizona is only 35 nautical miles west of Flagstaff and its latitude differs by less than a degree).[7] The manual provides tables of sun hours corresponding to fixed tilt, single-axis tracking, and dual-axis tracking flat-plat collectors. One full-sun hour is defined as being exposed to a solar intensity equal to 1000 W/m^2. Table 3 shows average sun hours for different fixed tilt angles for flat-plat collectors oriented true south. Due to variations in the earth's magnetic field, a compass will not point towards true north or south. The difference between magnetic north and true north is called the magnetic declination. This angle can be found on numerous charts and depends on the region. Leupp has a west declination angle of 13º, which must be subtracted from the compass reading to determine true azimuth.

Table 3: Sun Hours Available for Fixed-axis Systems Corresponding to Month and Tilt Angles

Fixed Tilt (º)	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Ave. Year*
0	3.1	4	5.1	6.3	**7.2**	**7.7**	**6.4**	5.9	5.4	4.4	3.3	2.8	5.1
Minus15 from Lat	4.4	5.2	5.9	**6.8**	7.2	7.4	6.2	**6.1**	6.1	5.6	4.7	4.2	5.8
Lat	5.2	5.8	**6.2**	6.7	6.7	6.7	5.8	5.9	**6.3**	6.1	5.4	4.9	6
Plus15 from Lat	**5.6**	**6.1**	6.2	6.2	5.9	5.7	5	5.4	6	**6.3**	**5.8**	**5.4**	5.8
90	5.3	5.3	4.6	3.6	2.6	2.2	2.2	2.8	3.9	4.9	5.1	5.1	4
Tilt at Max	***15***	***15***	***Lat***	***-15***	***0***	***0***	***0***	***-15***	***Lat***	***15***	***15***	***15***	***6.3***

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[7] "Solar Radiation Data Manual ". National Renewable Energy Labs. June 26, 2008 <http://rredc.nrel.gov/solar/pubs/redbook/HTML/>.

By graphing each fixed-tilt angle and the corresponding sun hours, the maximum amount of sun hours for each month can be determined. Figure 12 and Figure 13 show this relationship.

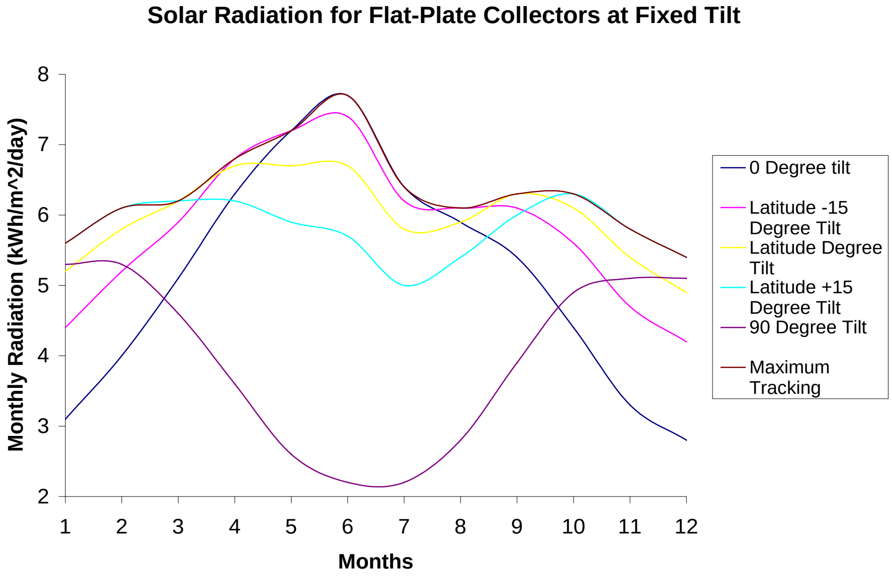

Figure 12: Monthly sun hours *vs.* tilt angle for fixed-axis systems.

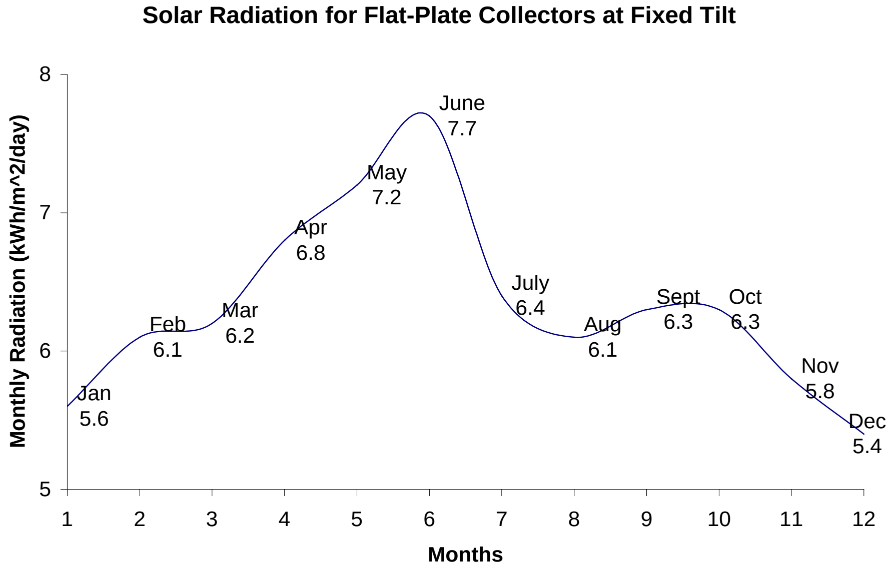

Figure 13: Monthly maximum sun hours available for fixed-axis systems.

By adjusting the tilt every month according to the maximum sun hours available, the total annual average sun hours can be increased by 8 percent. Allowing a single-axis tracking device along the east-west axis, a 30 percent minimum increase is available compared to fixed-axis devices as shown in Table 4.

Table 4: Sun Hours Available for Single-axis Tracking systems by Month and Tilt Angle

1-Axis Tracking (Deg)	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Ave. Year*
0	4.8	6	7.4	9.1	10.1	**10.8**	**8.6**	8.2	7.9	6.8	5.2	4.4	7.5
Minus15 from Lat	5.8	6.9	8	**9.5**	**10.2**	10.7	8.6	**8.4**	8.5	7.6	6.2	5.4	8
Lat	6.4	7.4	**8.3**	9.4	9.9	10.3	8.3	8.3	**8.6**	8	6.7	6	8.1
Plus15 from Lat	**6.8**	**7.6**	8.2	9.1	9.4	9.6	7.8	7.9	8.4	**8.1**	**7**	**6.4**	8
Tilt at Max	***15***	***15***	***Lat***	***-15***	***-15***	***0***	***0***	***-15***	***Lat***	***15***	***15***	***15***	***8.4***

By graphing each fixed-tilt angle for the single-axis tracking device and the corresponding sun hours, the maximum amount of sun hours for each month can be determined (see Figure 14 and Figure 15). Adjusting the tilt every month according to the maximum sun hours available increases total annual average sun by 25 percent. In the analysis below, two scenarios (fixed- and single-axis tracking) were evaluated to compare the costs associated with the number of solar panels and to better capture the impact of solar over an entire year. The amount of power output does not increase, but system cost differs.

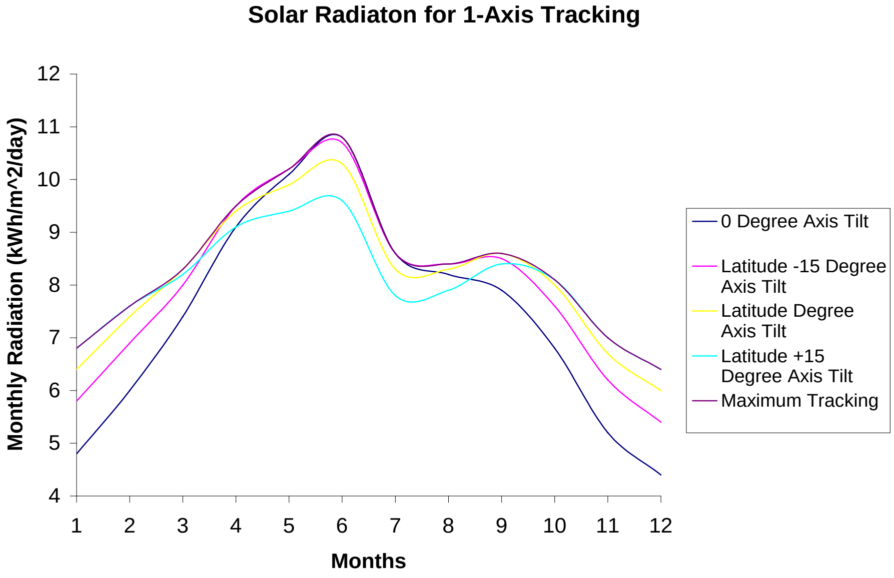

Figure 14: Monthly sun hours for various to tilt angles for a single-axis tracking system.

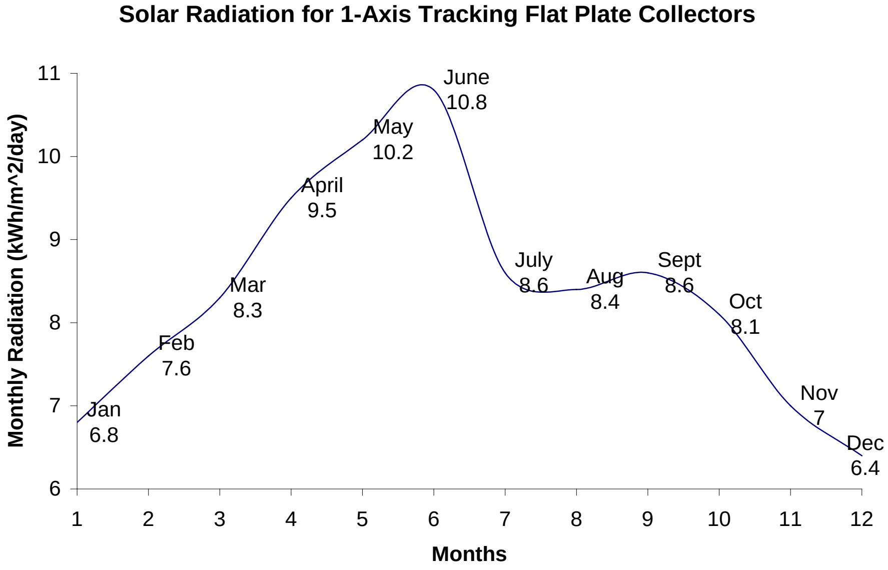

Figure 15: Maximum monthly sun hours for a single-axis tracking systems.

IV. SYSTEM DESIGN

The intent of the original design was to collect the necessary data from the current system such that an example solar system could be compared. Due to time constraints and data collection difficulties, the exact specifications of the current system had to be estimated using past well pump data and local well information. Using the listed components from Table 1, the following five baseline scenarios were established:

1. Continue ‘as is’ without further modifications to the system
2. Install a PV system to run the existing AC pump
3. Install a new PV system that includes a new DC pump
4. Extending the grid
5. Install a small wind turbine system.

OVERVIEW OF PHOTOVOLTAIC CELLS AND WIND TURBINES

Photovoltaic (PV) cells create electricity from the sun’s energy. To understand the energy transfer at a subatomic level requires an understanding of how PV cells are constructed. The base material of PV cells is silicon. An atom of silicon has four valence electrons each sharing electrons with neighboring silicon atoms in covalent bonding. A PV cell has layers of positive-charged and negative-charged pairs. To produce a negative-charged side of a PV cell, the cell is doped with different types of atoms that have five valence electrons (*e.g.*, phosphorus atoms). When introduced into pure silicon, the phosphorus atoms occupy a lattice position within the silicon structure, which forms an n-type (or negative) semiconductor. In contrast, when producing the positive side of a PV cell, the silicon is doped with atoms such as boron, which have only three valence electrons. To take the place of the fourth missing electron, a positively-charged hole forms creating a p-type semiconductor. The structure of n- and p-type semiconductors is shown in Figure 16.

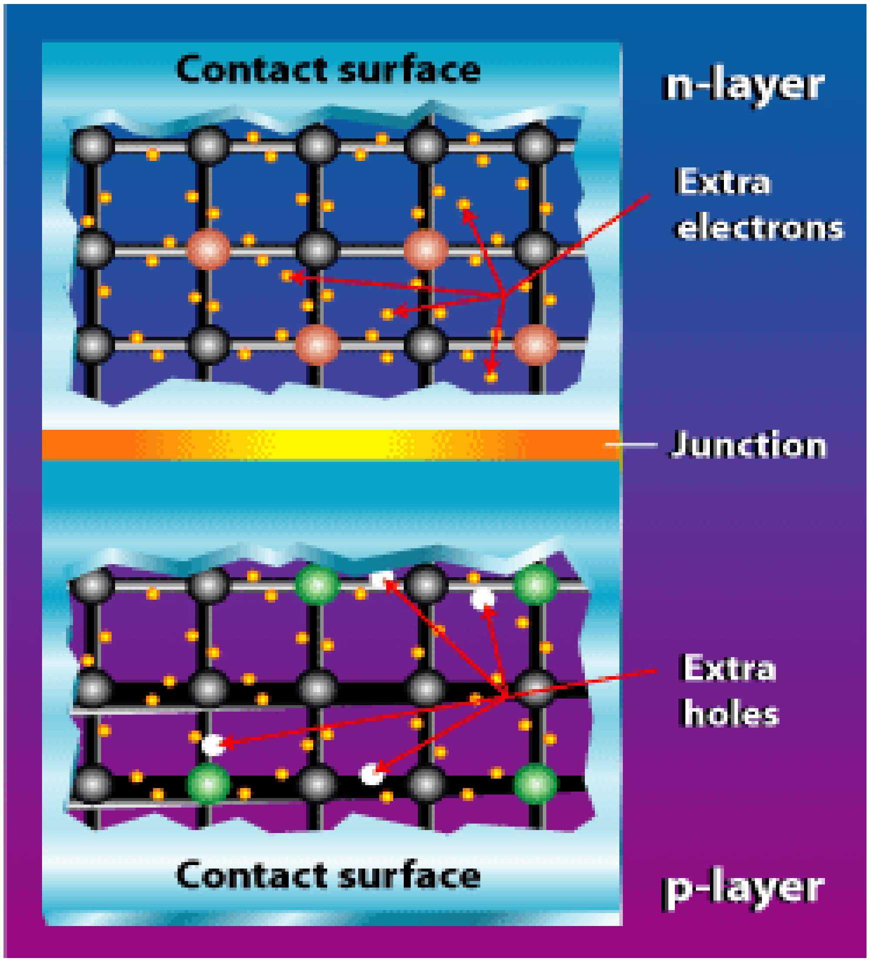

Figure 16: PV cell with n-type and p-type layers (source: http://www1.eere.energy.gov/solar/photoelectric_effect.html).

When photons from solar radiation pass into a PV cell, the kinetic energy is transferred from the photons to the valence-level electrons. The flow and formation of expelled negatively charged electrons are attracted to the positively charged holes in the p-type semiconductor which creates electricity.[8]

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[8] "Photovoltaic Basics". U.S. Department of Energy. June 2008 <http://www1.eere.energy.gov/solar/pv_basics.html>.

To extract energy using wind turbines, blades similar in shape to those of an airplane wing foil are used. These wind turbine blades create pressure differences as the wind flows over the blades causing the blades to rotate. By creating and using this mechanical energy to drive a shaft connected to a generator, electricity can be produced.[9] As shown in Figure 17, a utility-scale wind turbine has many complicated components. In a small wind turbine, however, the system is more basic and is built to be reliable year in and year out.

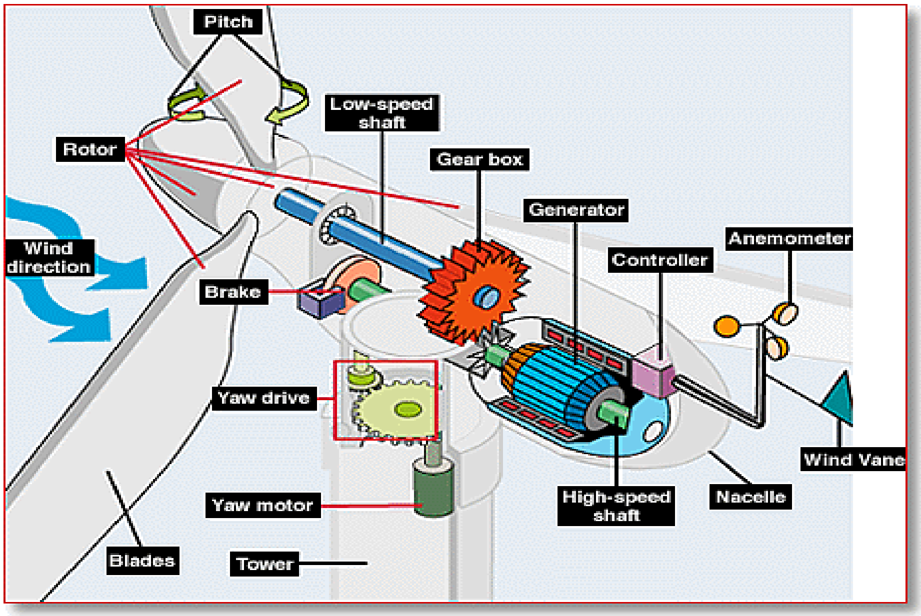

Figure 17: Wind turbine components of a utility-scale wind turbine (source: http://www1.eere.energy.gov/windandhydro/wind_how.html).

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[9] Twidel, John, and Tony Weir. Renewable Energy Resources. 2nd Ed. New York: Taylor & Francis, 2007.

LIFE-CYCLE COST ANALYSIS

Complexities in selecting a suitable generation system design required limiting the number of possible solutions. To neutrally compare operation variations, each possible system design scenario was analyzed based on performance (would it meet the farm's needs), initial cost, economic value, and life expectancy. The following five baseline scenarios were evaluated for a 20-year lifetime:

1. Continue 'as is' without further modifications to the system
2. Install a PV system to run the existing AC pump
3. Install a new PV system that includes a new DC pump
4. Extending the grid
5. Install a small wind turbine system.

By analyzing each scenario separately, a final community-based solution can be selected from either a single scenario or a hybrid of two or more scenarios.

To give real costs over the life of the system, a life-cycle cost (LCC) analysis was performed for each of the five scenarios. LCC analysis includes the total expenses incurred over the life of the system. This analysis compares the different power options and determines the most cost-effective system for each design scenario. Each LCC evaluates the effects of using different components with different reliabilities and system component lifetimes. Each scenario will have different initial costs, operating and maintenance (O&M) costs, and repair and replacement costs. In an LCC analysis, analysis consists of finding the present worth of any expense expected to occur over the reasonable life of the system. To ensure accurate results, all systems were matched to the current pump or pumping requirements. The life-cycle cost of a project can be calculated using the following formula:

$$LCC = C + M_{pw} + E_{pw} + R_{pw} - S_{pw} \qquad [4]$$

In the above formula, *pw* indicates the present worth for each factor. C is the capital costs of the project or the initial capital expenses. *M* is the sum of the yearly scheduled maintenance. *E* is the sum of energy cost of the system. Energy costs are calculated separately from operation and maintenance to incorporate different fuel inflation rates. *R* is the sum of the replacement and repair costs. *S* is the salvage value of the system or its net worth at the end of the life-cycle period. In calculating future costs, these must be discounted because of the time value of money. A dollar today is worth more today than a dollar one year from now because the one dollar today can be invested and interest can be earned.

It is also important to discount future cost due to the inherent risks of future events not occurring as projected. Using single and uniform present worth multiplier factors, future costs can be discounted. Inflation must also be accounted for in the investor’s nominal rate of return to get the net discount rate. Inflation is the tendency of prices to rise over time. For example, if the nominal investment rate was 8 percent, and the general inflation rate was assumed to be 3 percent over the life-cycle cost period, a net discount rate would be 5 percent. To account for future fuel cost rises (for example if the cost of diesel fuel was expected to rise 2 percent faster than the general inflation rate), a net discount rate of 3 percent would be used to calculate the present worth of future fuel costs. For the scenarios being analyzed in this report, a net discount rate of 5 percent was used. A net discount rate of 3 percent was used to account for diesel fuel inflation[10].

Scenario One (use the existing generator and pump) - In this “business as usual” scenario, the current generator was used and values were estimated for a 20-year lifetime. Table 5 shows the LCC the current diesel generator used at NLFF. It was assumed that the diesel generator will need to be replaced at year 12. As shown the total LCC of the generator system over its 20-year lifetime is just over $100,000. Figure 18 shows each present value element for the system as a percentage of the total LCC. Diesel fuel is accounted for in the O&M costs.

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[10] Risser, Vern. *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices*. Albuquerque, NM and Las Cruces, NM: Sandia National Laboratories, Southwest Technology Development Institute, Daystar, Inc. Revised July 2003.

As shown in the Figure 18, over 70 percent of the costs are associated with O&M and are largely due to diesel fuel consumption.

Table 5: LCC Analysis on Existing Generator System

Economic Analysis
Life-Cycle Cost Analysis
Point Design: Diesel Generator

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC Cost (%)
1. Capital Costs:				
Generator		$30,000	$30,000	22%
Installation		$1,000	$1,000	1%
A – SUBTOTAL		$31,000	$31,000	23%
2. Operation & Maintenance				
Annual Inspection		$125	$1,558	1%
Oil Change (2/yr)		$100	$2,492	2%
Fuel*		$7,500	$93,465	70%
B - SUBTOTAL (O&M)		$7,725	$97,515	73%
3. Replacement	(Year)			
Generator rebuild	12	$10,000	$7,840	6%
C - SUBTOTAL (Replacements)		$10,000	$7,840	6%
4.Salvage				
D - 20% of original cost		-$6,000	-$2,262	-2%
TOTAL LIFE-CYCLE COST (A + B + C + D)			**$134,093**	**100%**

* Fuel use was calculated by: (fuel consumption rate in gallons per minute) × (operation time in hours) × (days used per season) × (price per gallon of diesel)

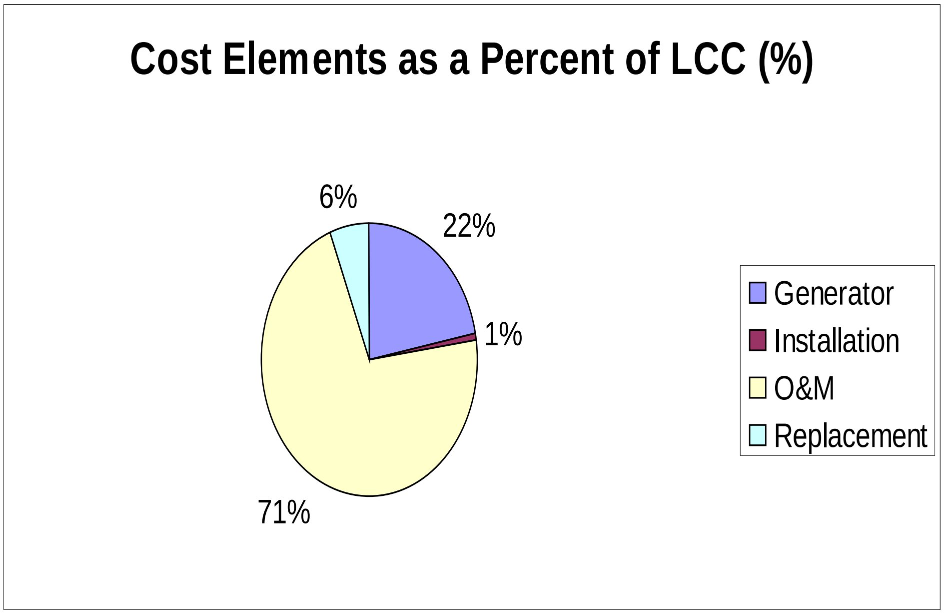

Figure 18: LCC cost elements as a percentage of the total system.

Currently, the oversized diesel generator has a fuel consumption rate of 2.5 gallons per hour. Because the farm is organic (no pesticides or fertilizer are used) the generator is the major environmental concern. Burning up to 15 gallons of diesel per day has a large impact on the surrounding environment. In a typical 100-day growing season, 15 metric tons of carbon dioxide equivalents (MT_eCO_2) are dispersed into the surrounding atmosphere. Diesel burned in a combustion cycle releases many gases that differ in their ability to absorb heat in the atmosphere. Some of these gases have a higher global warming potential (GWP). GWP is defined as the cumulative effects of a gas over a specified time and results from the emission of a unit mass of gas relative to a reference gas.[11] Table 6 lists common byproducts of fossil fuels and their corresponding GWPs. Carbon dioxide is the gas to which other gases are referenced. For example, one mole

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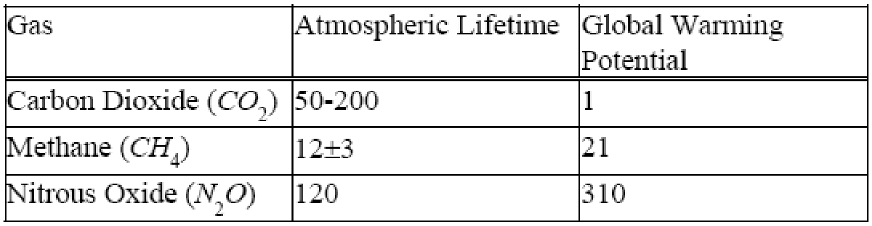
[11] "Greenhouse Gas Emissions". U.S. Environmental Protection Agency. July 2008. <http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions.html>.

(unit of measurement) of nitrous oxide has the equivalent global warming potential to 310 moles of carbon dioxide.

Table 6: Common green house gases and their corresponding global warming potential.



Gas	Atmospheric Lifetime	Global Warming Potential
Carbon Dioxide (CO_2)	50-200	1
Methane (CH_4)	12±3	21
Nitrous Oxide (N_2O)	120	310

Scenario Two (use a PV array to run an AC pump)—In the second scenario, a PV system was sized to run only the current AC submersible pump. To minimize costs, a 2-axis tracking device was implemented, which eliminated the need for the extra PV panels associated with fixed and single-axis tracking devices. Twelve 175-W panels were used for the calculations. Because AC pumps require an almost constant power input, eight 6-V, deep-cycle batteries were also incorporated in the system. Balance of system (BOS) consisted of the inverter, a charge controller, and the necessary wiring.

Table 7 shows the LCC analysis for this system. As the results show, the costs to run the existing pump are considerably lower than running the current diesel-only system.

Table 7: LCC Analysis for Dual-axis PV Array Powering the AC Pump

Economic Analysis
Life-Cycle Cost Analysis
Point Design: Dual-Axis PV Array for Current AC Submersible Pump

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC Cost (%)
1. Capital Costs:				
Array		$9,900	$9,900	30%
BOS		$6,784	$6,784	20%
Battery Bank		$2,880	$2,880	9%
Tracker		$5,500	$5,500	17%
Installation		$1,000	$1,000	3%
A - SUBTOTAL		$26,064	$26,064	78%
2. Operation & Maintenance				
B - Annual Inspection		$150	$1,869	6%
3. Replacement	(Year)			
Battery Bank	5	$2,880	$2,258	7%
Battery Bank	10	$2,880	$1,768	5%
Battery Bank	15	$2,880	$1,385	4%
Rebuild Inverters	10	$2,500	$1,535	5%
Controller	10	$500	$307	1%
C – SUBTOTAL (Replacements)		$11,640	$7,254	22%
4.Salvage				
D - 20% of original costs		-$5,213	-$1,965	-6%
TOTAL LIFE-CYCLE COST (A + B + C + D)			**$33,222**	**100%**

Figure 19 shows the cost elements as a percentage of the system’s LCC. As in most PV pumping systems, the PV array will have the majority of the capital costs associated with the overall system. However, the battery bank is assumed to be replaced every 5 years.

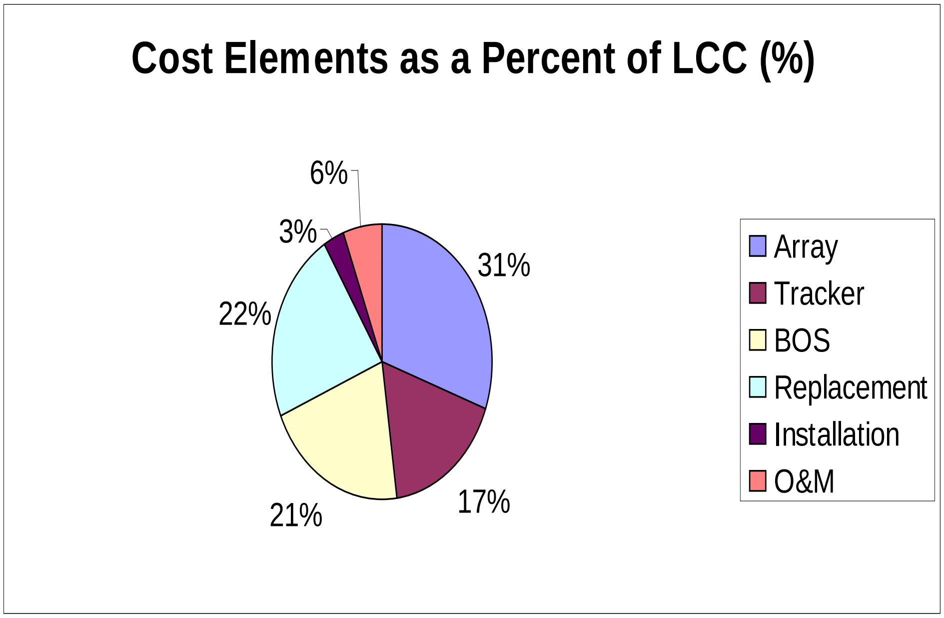


Figure 19: LCC cost elements as a percentage of the total AC pumping system.

Scenario Three (use a PV array and a new, larger DC pump)—In this scenario the existing AC pump is replaced with the largest commercially available DC pump that would meet the farm’s total pumping requirements. The pump is both AC and DC capable, if a back-up generator is used and has a maximum rated output of 40 gallons per minute. Figure 20 shows the daily and monthly water output of the system assuming full sun every day. At maximum output in July, the pump can produce 24,000 gallons of water per day. The 7-kW PV array uses 36 panels and a fixed-axis mounting system oriented at 35° due south. Table 8 shows the LCC analysis for this system. The total cost implementing the DC pump/PV system is just under $45,000.

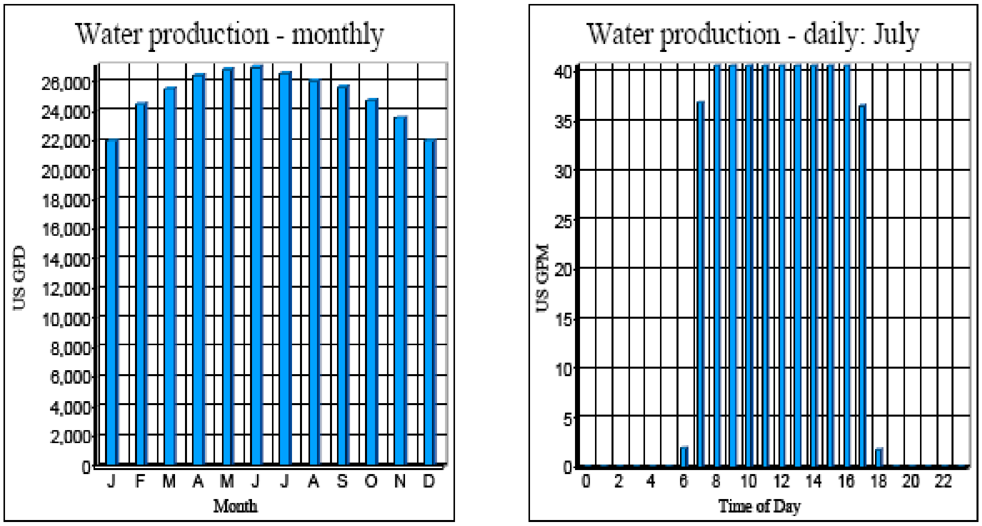


Figure 20: Daily and monthly water production from PV-powered DC pump.

Table 8: LCC analysis for Fixed-tilt PV array Powering a DC Pump

Economic Analysis
Life-Cycle Cost Analysis
Point Design: Fixed-Axis PV Array for DC Submersible Pump

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC Cost (%)
1. Capital Costs:				
Array		$29,700	$29,700	67%
Pump		$1,450	$1,450	3%
Mounting		$2,430	$2,430	5%
BOS		$6,784	$6,784	15%
Installation		$2,500	$2,500	6%
A - SUBTOTAL		$42,864	$42,864	96%
2. Operation & Maintenance				
B - Annual Inspection		$150	$1,869	4%
3. Replacement	(Year)			
Pump	5	$1,450	$1,137	3%
Pump	10	$1,450	$890	2%
Pump	15	$1,450	$697	2%
Controller	10	$500	$307	1%
C - SUBTOTAL (Replacements)		$4,850	$3,032	7%
4.Salvage				
D - 20% of original costs		-$8,573	-$3,232	-7%
TOTAL LIFE-CYCLE COST (A + B + C + D)			**$44,533**	**100%**

Figure 21 shows the LCC elements are shown as a percentage of the total system. As shown, the PV array accounts for 65 percent of the system's total lifetime costs, because it had to be sized to run the larger pump. It was assumed that the pump would be replaced every 5 years.

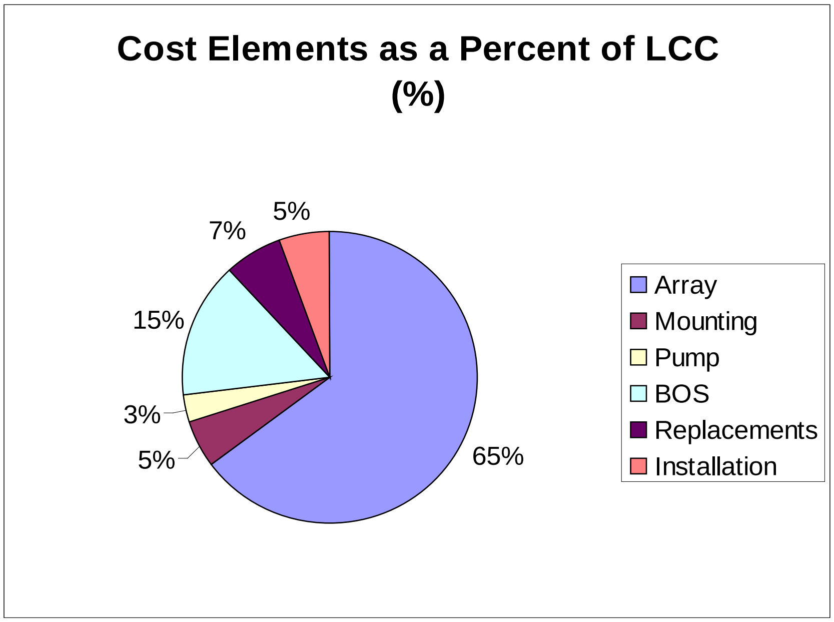


Figure 21: LCC cost elements as a percentage of the total PV/DC pumping system.

Scenario Four (extend the utility grid)—In the fourth scenario, the utility grid would be extended approximately 2 miles from the town of Leupp to the farm. To power existing loads, a three-phase (higher voltage) utility line would have to be installed. A single-phase line could be extended if the existing pump is replaced with one or more single-phase replacement pumps. It is estimated that the extension will currently cost $10,000 to $30,000 per mile. This analysis assumes the worst-case cost of $30,000 per mile. To calculate the pump's electrical load the following assumptions were used: a 100-day growing period, 6 hours of electric use per day, and an average cost of electricity of

8.5 cents per kWh. Table 9 shows the LCC analysis for the utility grid extension—the cost is approximately $60,000.

Table 9: LCC Analysis for Utility Grid Extension to Power Well Pump

Economic Analysis
Life-Cycle Cost Analysis
Point Design: Utility Grid Extension

Item	Dollar Amount ($)	Present Worth ($)	Percent Total LCC Cost (%)
1. Capital Costs:			
Installation	$60,000	$60,000	97%
A – SUBTOTAL	$60,000	$60,000	97%
2. Operation & Maintenance			
Electricity Cost	$400	$4,985	8%
Yearly Inspection	$100	$1,246	2%
B - SUBTOTAL (O&M)	$500	$6,231	10%
3. Replacement			
C – Line should last 20+ yrs	N/A	N/A	N/A
4.Salvage			
D – 20% of original costs	-$12,000	-$4,524	-7%
TOTAL LIFE-CYCLE COST (A + B + C + D)		**$61,707**	**100%**

Figure 22 shows the LCC elements as a percentage of the total system cost. The costs of the different phase pumps were not considered because the necessary pump sizes were not available from the Water Department. The bulk of the costs are associated with installation. It was assumed that the utilities' system components are contained in the installation costs.

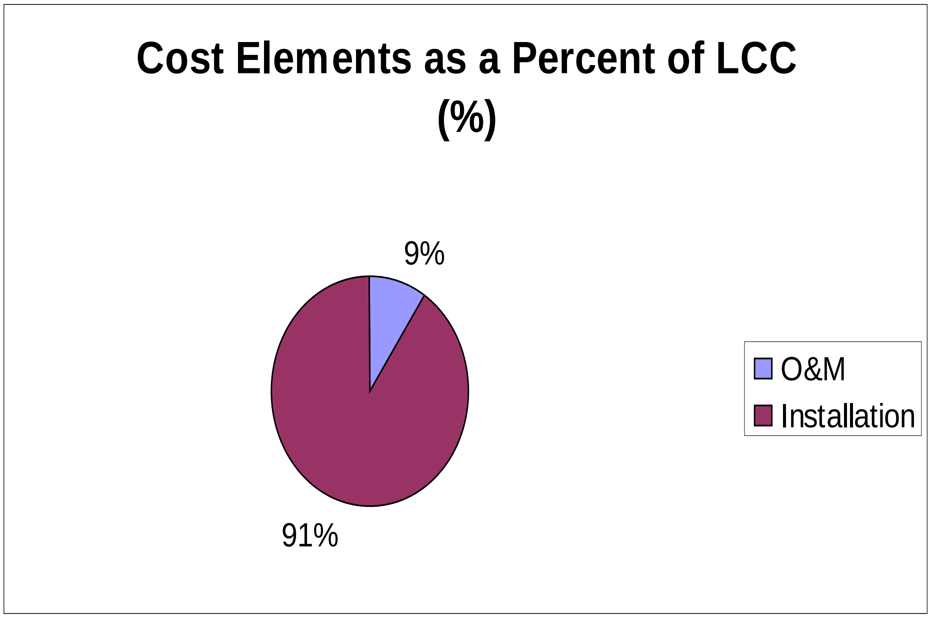


Figure 22: LCC cost elements as a percentage of the total utility grid extension.

Scenario Five (install a small wind turbine to power the existing pump)—In the final design, one of the largest, commercially available residential wind turbines was analyzed and sized to run the well's existing AC submersible pump. The 1.5-kW wind turbine has an integrated inverter to produce grid-ready power. A wind turbine's performance chart and wind resource data maps were used to estimate the power produced. The performance energy chart is shown Figure 23.

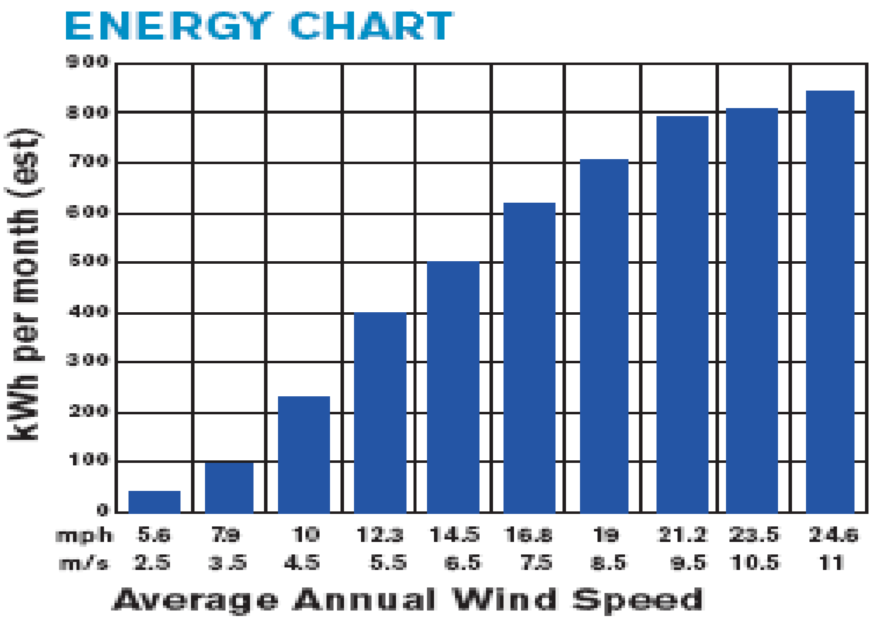


Figure 23: Skystream energy chart corresponding to different wind speeds (source: http://www.skystreamenergy.com/).

To estimate the output for a specific location requires knowing the average annual wind speeds. By comparing the wind speed to the highest corresponding kWh per month, the turbine's monthly output can be estimated. Table 10 shows the wind energy production values calculated from the Leupp area wind resource maps.

Table 10: Estimated Seasonal Wind Energy Using Skystream Wind Turbine

Estimated Wind Energy Production			
Time of Year	Wind Speed m/s	Wind Power W/m 2	Power Produced kWh/month
Annual Average	6.7	150	500
Spring Average	8.4	300	700
Other Average	4.6	50	230

Using annual average wind speed values, the total power produced is 500 kWh per month. Using the estimated load values from the generator, ten wind turbines would be required to run the existing AC pump. The LCC for a single Skystream wind turbine is shown in Table 11. The total LCC for a single Skystream wind turbine is approximately over $10,000. The tower cost is for a 33-foot mono-pole lattice tower, one of the largest mono-pole towers readily available. Larger towers are available but, due to high construction costs, are not feasible.

Table 11: LCC Analysis for a Single Wind Turbine

Economic Analysis
Life-Cycle Cost Analysis
Point Design: 1.5-kW Skystream Wind Turbine

Item		Dollar Amount ($)	Present Worth ($)	Percent Total LCC Cost (%)
1. Capital Costs:				
	Skystream Wind Turbine	$4,875	$4,875	46%
	BOS	$387	$387	4%
	Tower	$4,298	$4,298	41%
	Installation	$1,000	$1,000	10%
	A - SUBTOTAL	$10,560	$10,560	100%
2. Operation & Maintenance				
	B - Annual Inspection	$60	$748	7%
3. Replacement				
	C - Should last 20+ yrs	N/A	N/A	N/A
4.Salvage				
	D - 20% of original costs	-$2,112	-$796	-8%
TOTAL LIFE-CYCLE COST (A + B + C + D)			**$10,511**	**100%**

Figure 24 shows the LCC elements as a percentage of total system cost (for a single wind turbine). As shown, the tower and turbine LCC for one wind turbine far outweigh other costs. Indeed, together they comprise 81 percent of the total system cost.

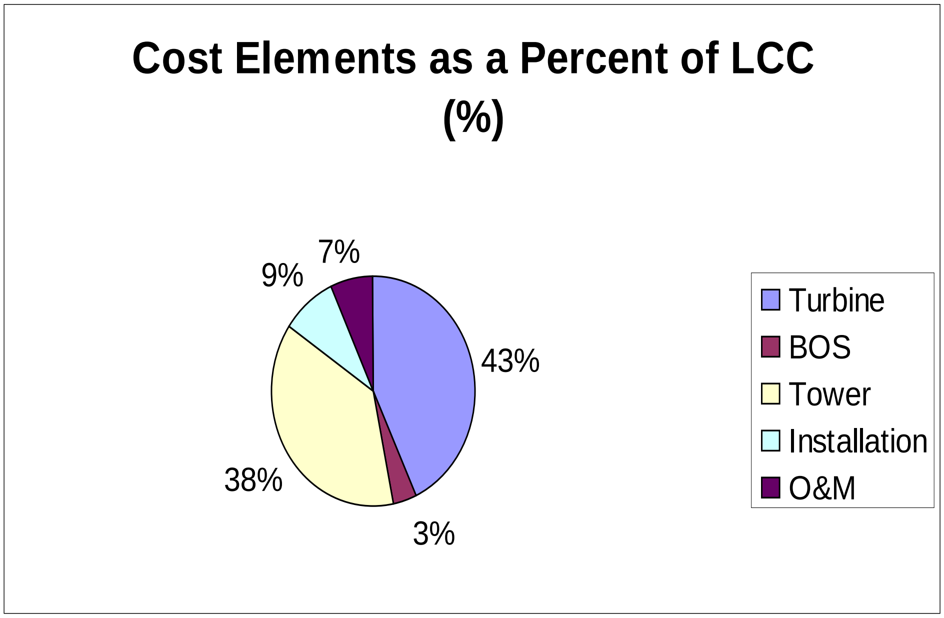


Figure 24: LCC cost elements as a percentage of the total system cost for a single wind turbine.

V. ANALYSIS AND COMPARISON

Analysis and comparison of each design scenario was done in two parts. First, the LCCs of the different designs were compared. Second, non-cost benefits and drawbacks for each system were examined to highlighting other important considerations.

An LCC analysis for each of the design scenarios was conducted. Figure 25 shows the relationship of the each system's costs to the costs of the other systems. Design scenario two, the dual-axis PV system powering the existing AC submersible pump is the lowest cost option. To adequately compare the design scenarios, however, the benefits and drawbacks of each system must be analyzed in addition to cost. In the following discussion, each design scenario is categorized as either one that can offset the total power production of the generator *and* the total associated loads on the farm (including the unknown watering loads from the Navajo Nation Water Department that provide water to Tolani Lake) or one that can power only the load from the main well's existing AC pump. Design scenario one and four can be selected to power the total systems loads. The rest will fall under powering the well pump load.

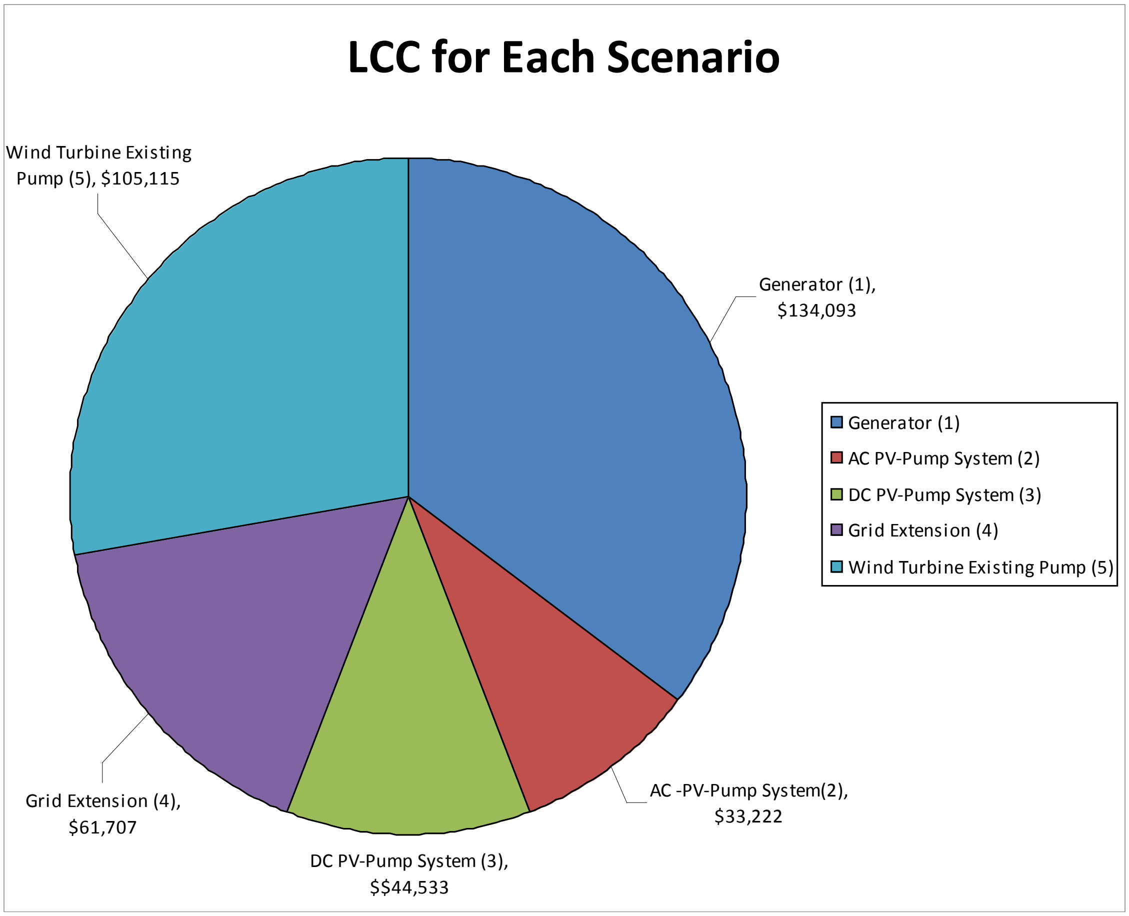


Figure 25: Total LCC corresponding to each design scenario.

“WHOLE LOAD” SCENARIOS

Scenario Two (PV arrays powering the existing AC pump) have the following benefits:

- Low life-cycle costs.
- Expandability. If the BOS (inverter, charge controller, *etc.*) is oversized, it will be easy to expand the PV array and the system can be grid-tied.
- Batteries provide some storage when sunlight is unavailable and assist with the start-up power surge. Farm workers could assist with battery maintenance.
- Dual-axis tracking minimizes the number of PV panels and the area required for system installation.

Drawbacks include the following:

- High maintenance—The batteries will have to be serviced every two to three months, replaced every five years, and kept well away from the elements and insulated. They also have a long charge time.
- System can become complicated quickly and watering can only be done part of the day to allow for battery recharge time. Batteries will provide only minimal storage.
- Replacement costs can be high if multiple components need to be replaced at one time.

Scenario Three (PV arrays powering a new, larger DC pump) have the following benefits:

- Simple system design with few main components and low maintenance.

- PV pump can be powered by an AC system, such as a back-up generator, if necessary.
- Low replacement costs.

Drawbacks include the following:

- No water or energy storage.
- PV array requires a large area for installation and a large amount of panels.
- Due to the low flow rate, the system would have to run constantly every day to meet the necessary water requirements.
- If overcast skies are present, overall daily water output could drop as much as 90% because pumping depends exclusively on the sun.
- Expanding the PV array will not increase pump output.
- This system is not ready to be grid-tied.

Scenario Five (wind turbines powering the existing AC pump) have the following benefits:

- The Leupp area has good wind resource during the spring and the wind often blows at night.
- Low- to no-maintenance system design.
- Low cost (for a single turbine).

Drawbacks include the following:

- Wind is not constant or reliable during non-spring months.
- The system has no water or energy storage. Watering would depend on wind and there would be no way of regulating the watering schedule.

- Multiple wind turbines would take up large area.
- The system is economically unfeasible for multiple turbines.

“PUMP LOAD ONLY” SCENARIOS

Scenario One (using the existing pump and generator “as is”) has the following benefits:

- The generator can power the multiple high loads associated with the AC pumps.
- High flow rate.
- Water storage is available and can provide water to the field when necessary.

Drawbacks include the following:

- Noisy operation.
- High fuel consumption.
- High pollution rate.
- When the system only powers well pump, it is largely oversized.
- High (and continuously rising) fuel costs.
- High replacement and maintenance costs for the generator.

Scenario Four (utility grid extension) has the following benefits:

- Lower LCC than the existing system.
- Utility grid can power the multiple high loads associated with the AC pumps and the power is reliable.

- Renewable energy systems (if installed) can be tied to the grid. With net-metering in place, system would sell back unused power to the utility and other financial incentives (*e.g.,* RECs) are available.
- High flow rate.
- Water can be provided to field when necessary.
- Low maintenance costs.
- Power could be extended to nearby residents who have no power for their homes.

Drawbacks include the following:

- Electricity comes from fossil-fuel-based generation (not environmentally friendly).
- The utility line extension process could take a long time to complete.

The results of this study can be interpreted in many ways and, depending on the farm's future development plans; each design scenario could play a role. For example, when evaluating the grid connection scenario the ability to connect renewable energy devices to the grid should be considered because it will offer additional benefits. Assuming a 100-day growing period, 6 hours of pump use a day results in approximately 3500 kWh of electricity use per season for the farm. Using the National Renewable Energy Laboratories (NREL) PWATTS program to analyze different sized grid-connected PV systems; AC energy output can be simulated for the Leupp area. [12] The PWATTS program assumes unobstructed sun radiation throughout the year.

Figure 26 shows the AC energy output versus PV array sizes for fixed- and single-axis tracking. As shown, a linear relation develops as the PV array size increases. For example, to offset the 3500 kWh pump load used during a growing season, either a 1-kW single-axis array or a 2-kW fixed-axis is needed.

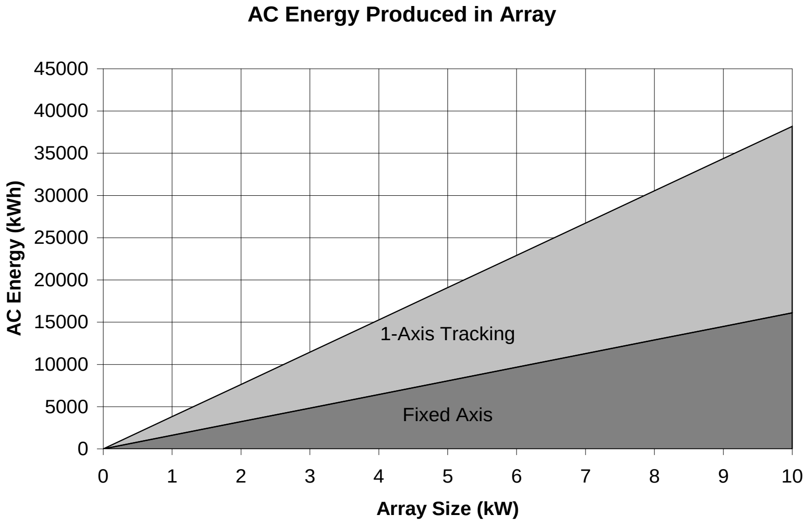


Figure 26: Annual AC electricity produced by different sized PV arrays and tracking systems.

The PWATTS program can also calculate the value of offsetting grid-purchased electricity (energy value profits). Figure 27 shows the energy value profits for different array sizes and tracking devices. Again, the graph shows a linear relation between array size and dollars earned. After deducting the 3500 kWh pump load, a 4-kW array would yield approximately $175 and $1000 in additional profits for fixed-mounting and single-axis tracking, respectively.

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[12] "A Performance Calculator ". NREL. August 2008 <http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/>.

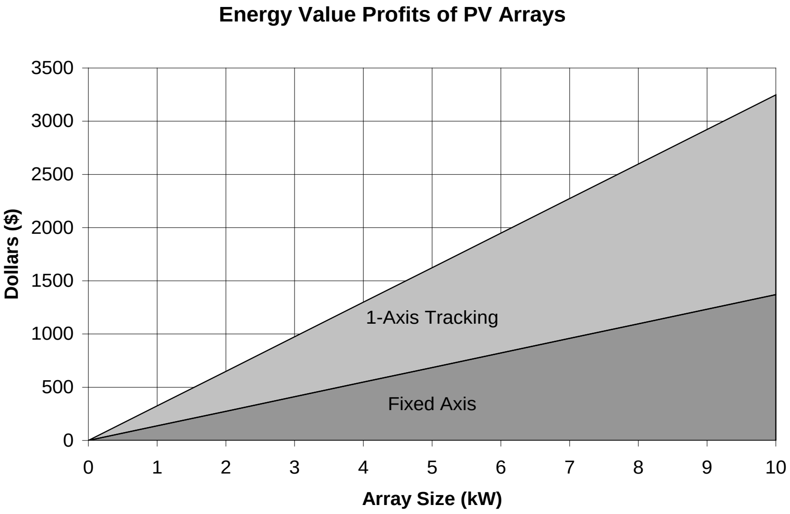

Figure 27: Electricity profits produced by different sized PV arrays and tracking systems.

VII. FUTURE DEVELOPMENT

NLFF's long-term goal is sustainable agriculture and development. By ensuring proper planning and sizing of equipment, the farm will be able to expand sustainably for all future needs.

SCHEDULED PLANNING AND DATA RECORDING

Presently, the NLFF provides enough produce for local families; this year is the first that the farm has allocated a small section of the field for cash crops (produce to be sold to the public). Planning the future development of the farm is essential to identifying the renovations necessary to eliminate fossil-fuel-based water pumping. Accurate planning, however, will require collecting a great deal of data about current conditions on the farm and should include compiling a detailed log of day-by-day weather, water, field, and fuel data taken during the growing season to use as a baseline. Table 12 shows an example of a data log. It is also essential to record the experimental cash crop yields and profits to determine what amount of land must be planted for future growth of this part of the farm.

Table 12: Daily Log

NLFF Log Book	
Date:	7/11/2008
Current Weather:	Sunny/Windy
Temperature:	85 F
Wind Speed:	20 mph SW
Plots Watered:	2 through 10
Soil Conditions:	Dry
Diesel Usage:	10 Gallons
Hours Irrigated	5 Hours
Consumption Rate:	2 Gal/Hr
Water Flow Rate:	80 gpm
Total Water:	24,000 G
Water Per Acre	3000 Gal/Acre

By collecting data daily, future planning and development can be adjusted according to specific requirements. For example, in July 2007, 150 more gallons of diesel were used than in the previous month. Consequently, NLFF can now expect this increase and plan for the additional fuel demand for July 2008. In a recent visit to the farm, it was noted that water requirements were reduced because the plants had matured. This reduction affects pump use and should be accounted for in future planning. Additionally, a small non-operational weather station was noted near who originally operated the weather station and to determine what would be required to return it to operation. The specifications of the current system (*e.g.*, pump model and output) should be also recorded. The farm's layout, including plot numbers and plants grown in each plot, should be documented and used to develop a crop rotation plan. Understanding the capacity of the land will ease the pressure for further development and will allow the farm to produce to the highest level.

GREENHOUSE

Further development plans include building a greenhouse to raise seedlings for early planting. This will enable the farm to have multiple harvests and further develop its cash crops. To determine how many days the greenhouse might need be heated requires estimating the average number of heating degree days for the year. A “degree day” is defined as the difference between the day’s average temperature and 65 ºF. If the average temperature is below 65 ºF, it is considered a heating degree day, and if above, it is considered a cooling degree day. For example, if the high for the day was 60 ºF and the low was 30 ºF, the average would be 45 ºF. Subtracting the average from 65 ºF would count as 20 heating degree days or 20 ºF multiplied by 1 day[13].

Figure 28 shows the Leupp area’s local average heating degree days. Looking at the graph, the heating degree days for the Leupp area begin in September and last until June. If a forecast of the day’s highs and lows were available, a calculation of the necessary fuel oil or source of energy (such as a solar thermal heater) could be planned. Heating degree days are also a good way to see if new investments in heating improvements, such as new insulation, are paying off. By comparing use from past degree heating days with to the electricity or heating use of the improved system, a sense of enhancement can be

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[13] “Degree Heating Day". Wikipedia. August 2008 <http://en.wikipedia.org/wiki/Heating_degree_day>.

obtained. Past heating degree days can be easily obtained through the National Weather Service or a Regional Climate Center.

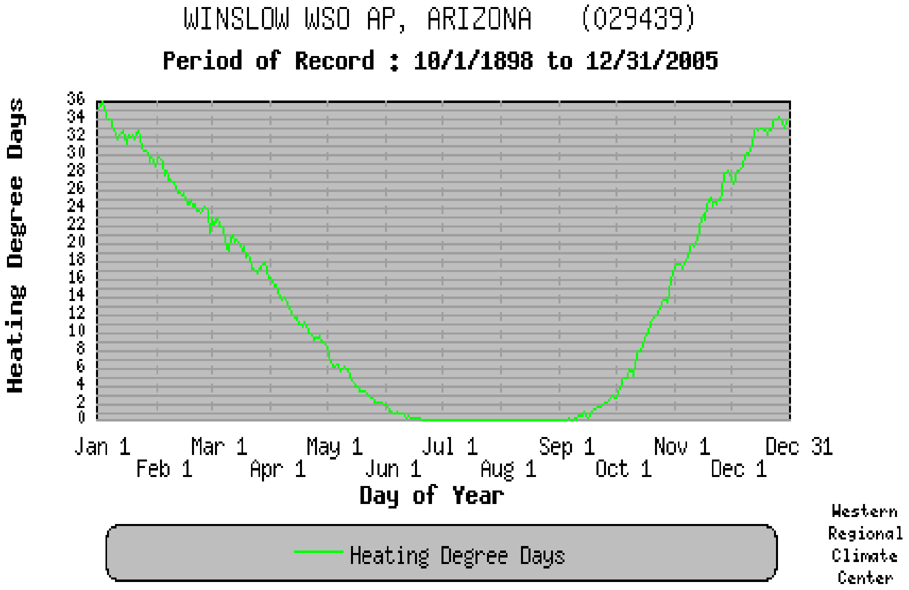

Figure 28: Average number of heating degree days for Leupp area (source: http://www.wrcc.dri.edu/summary/Climsmaz.html).

DRIP *VS.* SURFACE IRRIGATION

In today's agricultural world, it is more important than ever to use water and energy resources sensibly by irrigating wisely. Drip irrigation gives precise control over when and where water is delivered. Water is applied directly to the soil and the plant's root zone without wetting the plant or non-target areas, regardless of wind. Many farms that have converted their conventional furrow irrigation to drip irrigation have received the following benefits:[14]

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[14] Burt, C.M. and S.W. Styles. 2000. Drip and micro irrigation for trees, vines, and row crops. Irrigation and Training and Research Center (ITRC), BioResource and Agricultural Engineering Department, California Polytechnic State University, San Luis Obispo, CA 93407. ISBN 0-9643634-2-9.

- Reduced energy and water consumption resulting from precise water distribution. Precise distribution also improves weed and crop disease control and reduces the environmental effects of run-off.
- Improved crop yield, quality, and uniformity. Increasing the consistency of water distribution to the entire field increases crop yields and quality. Additionally, more land can be used because water is less of a limiting factor.
- Reduced field-labor time and cost. Once the system is installed, field-labor (*e.g.*, that required to move irrigation pipes, etc.) will be minimized until the harvest.

The performance parameters of drip irrigation differ from other irrigation systems. Regardless of the type of drip system, its performance is typically characterized by—

- Low water flow rate (usually measured in gallons per hours per length);
- Long watering periods (hours rather than minutes due to low water flow rates);
- Water pressure between 10-30 psi for most emission devices.
- Filters (mesh filters are required to remove mineral or organic materials from the water to avoid plugging emitter passages); and
- Automated operation.

Each emission device is designed to deliver a uniform amount of water to ensure even distribution. There are three different basic types of drip emission devices:

- **Drip tape** incorporates a series of relative inexpensive emission devices into a thin-walled tube. These tubes vary in thickness and emission device spacing to accommodate different terrain and crops. Drip tape can be installed below or above ground and is ready to install without additional emission devices.

- **On-line emitters** are small devices (usually made of plastic) that emit a small stream. This flow creates a wetting circle the size of which depends on soil type, flow rate, and water scheduling. Each emitter must be inserted by hand to the sub-lines of polyethylene tubing.
- **In-line emitters, or drip line,** are small plastic emitters pre-inserted into the line. This saves the end-user labor time but the emitters are not serviceable and may be in undesirable locations.

When determining the system's water requirements, several factors must be considered including plant size, soil type, wind conditions, solar radiation, ambient temperature and humidity, and growth stage. Drip irrigation is sometimes costly, requiring drip lines to be replaced every 5 to 8 years, but the benefits of increased yields and decreased labor should outweigh the costs.

FINANCIAL INCENTIVES

Many Arizona utilities (including Arizona Public Service Company, Salt River Project, and Tucson Electric Power) currently offer renewable energy financial incentives for their customers. These incentives include tax credits, utility rebates, net metering programs, green power networks, and RECs. Due to tax exemptions and the NTUA program, none of these incentives are currently available to the Navajo Nation, but an incentive program is currently being planned by NTUA. As the need for more green energy and renewable energy portfolio standards increases, every utility should have a plan to give its customers the opportunity of using small-scale renewable energy and incentives to further encourage customers to take advantage of this opportunity. By extending the grid to the NLFF, net metering and RECs could be provided to the Navajo Nation.[15]

Net metering allows the customer to sell unneeded electricity back to the utility. Net metering is monitored in one of two ways: either by a meter that is able to spin in either direction or by using two meters, one to measure the electricity sent back to the grid and the other to measure the electricity coming from the grid. For example, Tucson Electric Power will buy back electricity at $0.09 per kWh for up to 10 kW. The net excess generation is credited on the following month's bill.[16]

RECs (also called green tags, green certificates, or tradable renewable certificates) are issued to represent environmental benefits resulting from renewable energy that offsets emissions from fossil-fuel-based generation. For example, if a company produces 100 metric tons of CO_2 to generate 1 MWh of electricity those emissions can be offset by 1 MWh of electricity produced from a renewable source (resulting in zero net emissions) if the polluting company purchased an equivalent REC. RECs are tradable environmental commodities representing proof that electricity was generated from an eligible green energy resource. These certificates are sold separately from the net metered electricity

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[16] "Arizona Incentives for Renewable Energy and Efficiency". NC State University. July 2008 <http://www.dsireusa.org/>.

produced. Customers can acquire green tags without having to change utilities and do not have to have direct access to green power through their utility.[17] For example, if NLFF were to implement a 4-kWh, fixed-tilt PV system, it could generate 4 MWh of electricity during the non-growing season for which it could acquire and re-sell RECs.

Some funding is available through the United States Department of Agriculture under the Farm Security and Rural Investment Act of 2002. The Renewable Energy Systems and Energy Efficiency Improvements Program under Title IX, Section 9006, presently funds grants, loan guarantees, and direct loans to ranchers and farmers (agricultural producers) or rural small business to purchase renewable energy systems and to make energy efficiency improvements that help rural farms and ranches cut high energy costs and consumption. [18] Further information can be found on the rural development page of the government website.

VIII. CONCLUSIONS

The goal of this work was to investigate renewable energy resources in the NLFF area to determine where the best opportunities for renewable energy systems to be implemented with the approximated and given data taken from the farm. The LCC analysis results indicated that the best option to power only the current pump would be with a dual-axis tracking system that includes a battery bank for energy storage. The LCC analysis also indicated that to power the entire system load, including the Navajo Nations Water

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[17] "Green Power Markets". U.S. Department of Energy. July 2008 <http://www.eere.energy.gov/greenpower/markets/certificates.shtml?page=0>.

[18] "Section 9006: Renewable Energy and Energy Efficiency Program". USDA. July 2008 <http://www.rurdev.usda.gov/rbs/farmbill/index.html>.

Department's pumping loads would most likely require extending the grid; adding grid-tie renewable energy systems could be added to offset the some of the loads. These grid-tied systems would include the potential to sell electricity back to the utility to earn financial incentives (RECs, etc.). It was also determined that the farm must start recording current weather, use, planting, and labor data to develop a baseline for planning and future development.

In terms of recommended future actions, the following are advised:

- Use the information provided in this report to better understand what renewable energy options are available and develop a strategic plan for farm development.
- Collect sufficient data to develop a baseline description of the farm including well data, crop yields, and cash crop profits.
- Further estimate the potential cost savings from implementing renewable energy systems (*e.g.*, utility-scale concentrated solar).
- Attend local agriculture seminars.
- Complete a "request for quote" for the utility grid extension through NTUA.
- Work with the Navajo Nation Water Department to decide what future actions should be taken when the generator needs to be replaced. Working with NTUA will accelerate the process of financial incentives being offered to the Navajo Nation.
- Encourage more local community involvement.
- Finally, continue working with Sandia National Laboratories and the local university for further consulting.

VIII. REFLECTIONS

This internship has been one of the most motivating and unsurpassed experiences of my life. The summer opportunities were diverse and ranged from working, conversing, and experiencing what the top engineers and leaders in the country have planned and are developing for local and nationwide energy problems, to developing a better understanding of current renewable energy projects on tribal lands and the difficulties they have encountered, to examining the need for more tribal groups to become champions in leading their nations to the renewable energy world and setting examples other nations can follow, and finally, to helping address the need for young, educated Native Americans to become proactive in using their higher education to the best of their abilities and providing a better world for all of us to live in. In today’s society, many feel that education is needed to make money and buy earthly possessions; I believe that education is a privilege that should be used to create better people that help transform our world into a better place that everyone can enjoy. The combination of field visits to tribal lands, participating in renewable energy workshops and talking to tribal leaders has offered me a new perspective that university learning could never provide. I have become inspired to continue my education in further hope the knowledge and experiences I will gain will help underprivileged tribes become a sovereign nation. This summer has been a hands-on and in-person experience from touring the Navajo and Hopi Nations off-grid systems and wind development sites, to viewing the tourist attractions incorporating off-grid renewable energy systems of the Hualapai Nations in Grand Canyon West, and viewing the wind and eco-lodge development of the Cahuilla Nation in southern California. In our most recent seminar, we traveled to the Hopi Reservation located in

Northern Arizona where a group of diverse nations and educational background came together to install an off-grid PV system on a residential home. On the final day after the installation was complete, seeing the homeowner turn on the lights for the first time was rewarding than anything I have ever felt. This project has made me feel a similar manner knowing one day the farm could become energy independent implementation of renewable energy system on the farm. The people of Leupp have kept the rich Navajo cultural alive through community evolvement and operations under the guidance of NLFF Board of Directors and the Leupp Chapter House. These traditional farming practices have helped retain water and land rights preserving the Navajo livelihood. By encouraging to the public eat healthy, have active lifestyles, ensuring communal food security, the traditional livelihoods of agriculture and livestock practices will continue to develop and present solutions addressing the difficulties many of the Navajo people face.

Special thanks goes to the local families who participate and help out on the farm: Stacey Jensen; Eddie Thompson; Jackie & Carrie Thompson; Dennis, Justin, Willie, and Tyrone Thompson; Bill Edwards; Raymond & Elsie Phelps; Loretta Jones; Burnell Jones, Keanu Jones; Jacques Seronde; Brandon Montour; and Louie McCabe. Thanks also to the members of the Grand Canyon Trust for providing financial and local support to the farm and to Ben Jones and his family who helped collect much of the data that was needed to develop this report. I would also like to thank the Sandia National Laboratories staff who provided technical support for this project, especially Sandra Begay-Campbell, and the other interns for their moral support and making this internship a memorable experience.