# JEMEZ PUEBLO SOLAR POWER STUDY

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ABSTRACT

Northern Arizona University (NAU) and the Southwestern Indian Polytechnic Institute (SIPI) conducted a pre-feasibility study for utility-scale solar power on the Jemez Pueblo in New Mexico. Student groups at NAU and SIPI analyzed four different 40-MW solar power projects to understand whether or not such plants built on tribal lands are technically and financially feasible. The NREL System Advisor Model (SAM) was employed to analyze the following four alternatives: fixed, horizontal-axis photovoltaic (PV); fixed, tilted-at-latitude PV; horizontal, single-axis tracking PV; and a solar-thermal "power tower" plant. Under supervision from faculty, the student teams predicted the energy production and net present value for the four options. This paper presents details describing the solar power plants analyzed, the results of the SAM analyses, and a sensitivity analysis of the predicted performance to key input variables. Overall, solar power plants on the Jemez Pueblo lands appear to pass the test for financial feasibility.

## 1. INTRODUCTION

Northern Arizona University (NAU) and the Southwestern Indian Polytechnic Institute (SIPI) were sponsored by the American Indian Science and Engineering Society (AISES) and the American Indian Higher Education Consortium (AIHEC) to perform a student-centric renewable energy project with application at the Jemez Pueblo in New Mexico. Funding for the project was provided by the US Department of Energy's American Indian Research and Education Initiative (DOE-AIREI) program, with technical support from the Sandia National Laboratories. The main purpose of the funding was to support Native American engineering students in analysis of a real-life problem that could also benefit a partner tribe, in this case the Jemez Pueblo. In response to this opportunity, NAU's Tribal Clean Energy Resource Center, which is part of NAU's Institute for Tribal Environmental Professionals, partnered with the Engineering and Engineering Technologies program at SIPI and created four student-led projects focused on analysis of the technical and financial feasibility of a utility-scale solar photovoltaic (PV) power plant on Jemez tribal lands.

[1] Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security administration under contract DE-AC04-94AL85000.

As a mechanism for economic development, the Jemez Pueblo is interested in investigating the potential to develop a utility-scale solar power plant on the Southwest corner of the "Holy Ghost" section of the reservation trust land. In particular, Jemez was interested in knowing if it is possible to build and operate and solar power plant that interconnects to the transmission system, for sale of electrical energy to customers off the reservation. The Holy Ghost site is within approximately five miles of transmission lines, with no known wildlife or cultural resources that require protecting, no wells or buildings, and as grazing land, it is likely suitable for solar power development. Thus the goals of the student projects were to evaluate the suitability of solar resource and four different technology options for solar power plants development. With approval of the Jemez personnel, the student teams selected the following four technology options:

1. Fixed-axis, horizontal solar PV
2. Fixed-axis, tilted (at latitude) solar PV
3. 1-axis tracking, horizontal solar PV (rotate around N-S axis on a daily basis)
4. Concentrating solar, molten salt "power tower" thermal power plant (CSP)

The sections that follow will describe the Holy Ghost location and the solar resource available at the site, the SAM analysis tool and common assumptions applied to all four technology options, the four system configurations and results from the analyses.

## 2. <u>HOLY GHOST SITE AND SOLAR RESOURCE</u>

The Jemez Pueblo reservation is located in the State of New Mexico, in Sandoval County. The Jemez tribe has approximately 3,400 tribal members with a substantial 58% living on the reservation. New Mexico is one of the six Southwest states in the United States with a high solar resource potential [1]. The annual latitude-tilt irradiance at the site is approximately 6.4 kWh/m$^2$/day [2]. Fig. 1 displays the solar irradiance levels in the state of New Mexico and highlights Sandoval County. The blue tinted section on the map overlays the location of the proposed "Holy Ghost" solar site on the reservation.

Zooming in on the highlighted blue box in Fig. 1 leads to the photos displayed in Fig. 2. The land is at an approximate elevation of 5600 feet and is a dry hot climate, typical of the Southwest US. The site is located in the foothills of the Jemez Mountains but is reasonably flat. This area of the reservation is trust land is currently used for cattle grazing.

## 3. <u>SYSTEM ADVISOR MODEL</u>

The NAU and SIPI student teams utilized the National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM) [3]. SAM is a renewable energy performance and cost model designed to facilitate decision making for people involved in the renewable energy industry. The model uses updated technology and financial data from NREL's database combined with performance and cost models to determine system performance based upon a number of criteria. Example criteria include site location, PV modules, inverter selection, panel orientation, etc.

To model the energy production and cost performance of a renewable energy system, SAM relies upon several data resources, such as solar and wind data sets. Several project specific input variables are required from the user, many of which have reasonable default values. A list of example input variables, taken directly from the SAM website [3] are shown below:

- Installation costs including equipment purchases, labor, engineering and other project costs, land costs, and operation and maintenance costs.
- Numbers of modules and inverters, tracking type, derating factors for photovoltaic systems.
- Collector and receiver type, solar multiple, storage capacity, power block capacity for parabolic trough systems.
- Analysis period, real discount rate, inflation rate, tax rates, internal rate of return target or power purchase price for utility financing models.
- Building load and time-of-use retail rates for commercial and residential financing models.
- Tax and cash incentive amounts and rates.

Each of the four solar technologies/configurations investigated had a nameplate capacity of 40 MW. For the purpose of defining the solar resource and site location, the "Holy Ghost" location was determined to be at latitude 35.71°W and longitude -106.95°. For the three PV options, the PV module selected from the NREL database was a Prism Technology B 245. This module is made from 60 mono-

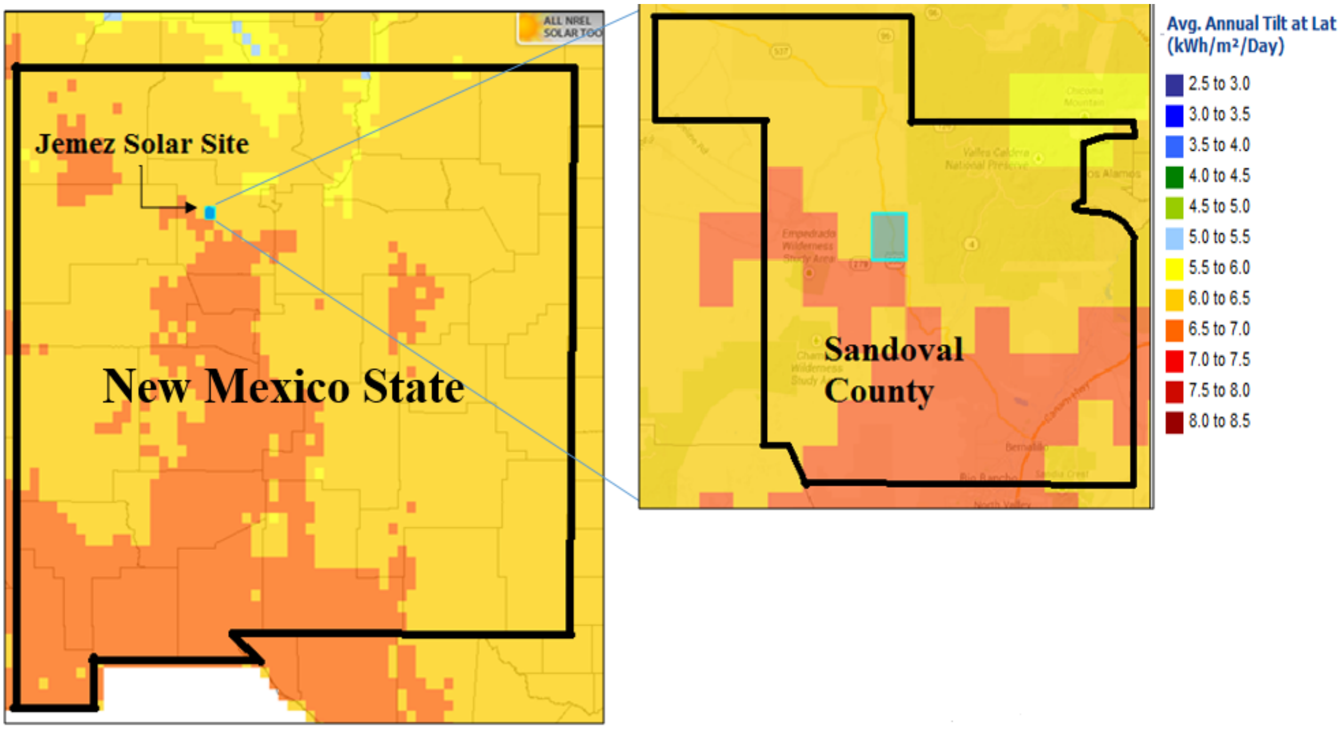


Fig. 1: Annual solar global horizontal irradiance level in Sandoval County, New Mexico, as provided by the NREL Solar Prospector [2]. The blue cell highlighted in the county image overlays the Holy Ghost site.

Fig. 2: The area of the proposed "Holy Ghost" solar project, located on the Jemez Pueblo reservation. The blue box on the left corresponds to the small blue boxes in Fig. 1, showing satellite image of the site. (photo credits: Google Earth (left), Mehrdad Khatibi (right).

crystalline silicon cells, and is rated at 245W, 15.6% efficiency, producing 8.1A at 30.1V at max power. The module was chosen because it is available and manufactured in the Southwest and is representative of typical module performance and cost. The inverter used in this analysis was the Satcon Technologies 1.25 MW, 480V inverter, model EPP-1250-1000-52085-320X-U-x. Similar to the PV module, the inverter was selected as having typical performance and cost in its class. Consistent with the SAM suggested default values, the PV system costs were assumed to be identical between the three PV options (for a 40MW plant, the installation costs are $76.6M). In reality, it is expected that the single-axis tracking system will have a higher installation cost, but that the difference will not be a dominant factor in choosing among the alternatives.

SAM financial calculations are conducted in one of two modes: either specify a PPA (power purchase agreement) price to value the energy produced, or set a desired internal rate of return (IRR). Utilizing this information and details about the system configuration and location, assuming a project lifetime of 25 years and a debt payoff period of 20 years, SAM calculates the annual energy production, net present value (NPV), capacity factor, levelized cost of energy (LCOE) and other outputs values. For the purposes of this project, a PPA price was specified at a "central" case of $0.12/kWh of purchased energy. Table 1 displays a summary of the financial inputs common to all four technology options considered.

TABLE 1: SUMMARY OF SAM FINANCIAL INPUTS COMMON TO ALL FOUR TECHNOLOGY OPTIONS ANALYZED.

| SAM Financial Inputs | Value |
|---|---|
| PPA price ($/kWh) | 0.12 |
| PPA escalation rate (%/yr) | 1 |
| Debt fraction (%) | 50 |
| Loan rate (%) | 7 |
| Real Discount Rate (%/yr) | 8.2 |
| Loan term (years) | 20 |
| Analysis period (years) | 25 |
| Inflation rate (%/yr) | 2.5 |
| Federal income tax rate (%/yr) | 35 |
| State income tax rate (%/yr) | 7 |
| Sales tax (% of installed cost) | 5 |
| Annual insurance rate (% of installed cost) | 0.5 |
| Assessment Percent (% of | 100 |
| Property tax (%/yr) | 0 |
| Construction financing | Yes |
| Percent of installed cost (%) | 100 |
| Up-front fee (% of principal) | 1 |
| Months prior to operation | 6 |
| Annual interest rate (%) | 4 |
| Federal investment tax credit (% | 30 |
| Depreciation | 5-yr MACRS |
| Time of delivery factors | none |

## 4. SYSTEM CONFIGURATIONS AND SAM MODELING RESULTS

### 4.1 PV system alternatives

Regardless of the PV system configuration (fixed horizontal, fixed tilted, or 1-axis tracking), if utilizing the system components described in the previous section to generate a nameplate capacity of 40 MW, 163,240 modules are required, arranged in strings of 22 modules, with 7,420 strings in parallel. Thirty inverters are required. The footprint of the plant is estimated to be 158 acres or about 4 acres per MW. This is about 1/2 to 1/3 of many PV plants in the field today. As mentioned previously, the total installation costs for these systems are $76.6M.

For each of the PV system configurations considered, profiles of monthly energy production and the first year energy estimates are shown in Fig. 3. The energy production and NPV for each system is also summarized in Table 2. It is worth noting that the fixed-axis, tilted at latitude configuration produces 20% more energy that the fixed, horizontal axis system, and the 1-axis tracking system produces 41% more. The NPV for each configuration is substantially positive, ranging from $16.2M to $34.3M, with the 1-axis tracking system being the highest. Given the assumed real discount rate of 8.2%, these NPV values suggest further consideration of a utility-scale PV plant by the tribe is likely merited. It is important to mention that there will be significant costs associated with connecting these PV plants to the transmission grid, likely on the order of $10M to $15M. These costs will directly reduce the NPV of each alternative, and will be important to resolve in detail in any future study.

TABLE 2: SUMMARY OF ENERGY OUTPUT AND NET PRESENT VALUE (IN MILLIONS) OF THE FOUR SOLAR POWER PLANT OPTIONS CONSIDERED.

| Power Plant Configuration | First Year Energy (GWh) | NPV ($) |
|---|---|---|
| Fixed-axis, horizontal PV | 68.1 | 16.2M |
| Fixed-axis, tilted at latitide PV | 81.7 | 25.1M |
| 1-axis tracking, horizontal PV | 96.1 | 34.3M |
| CSP power tower ($0.12/kWh PPA) | 225.2 | -24.2M |
| CSP power tower ($0.20/kWh PPA) | 225.2 | 79.0M |

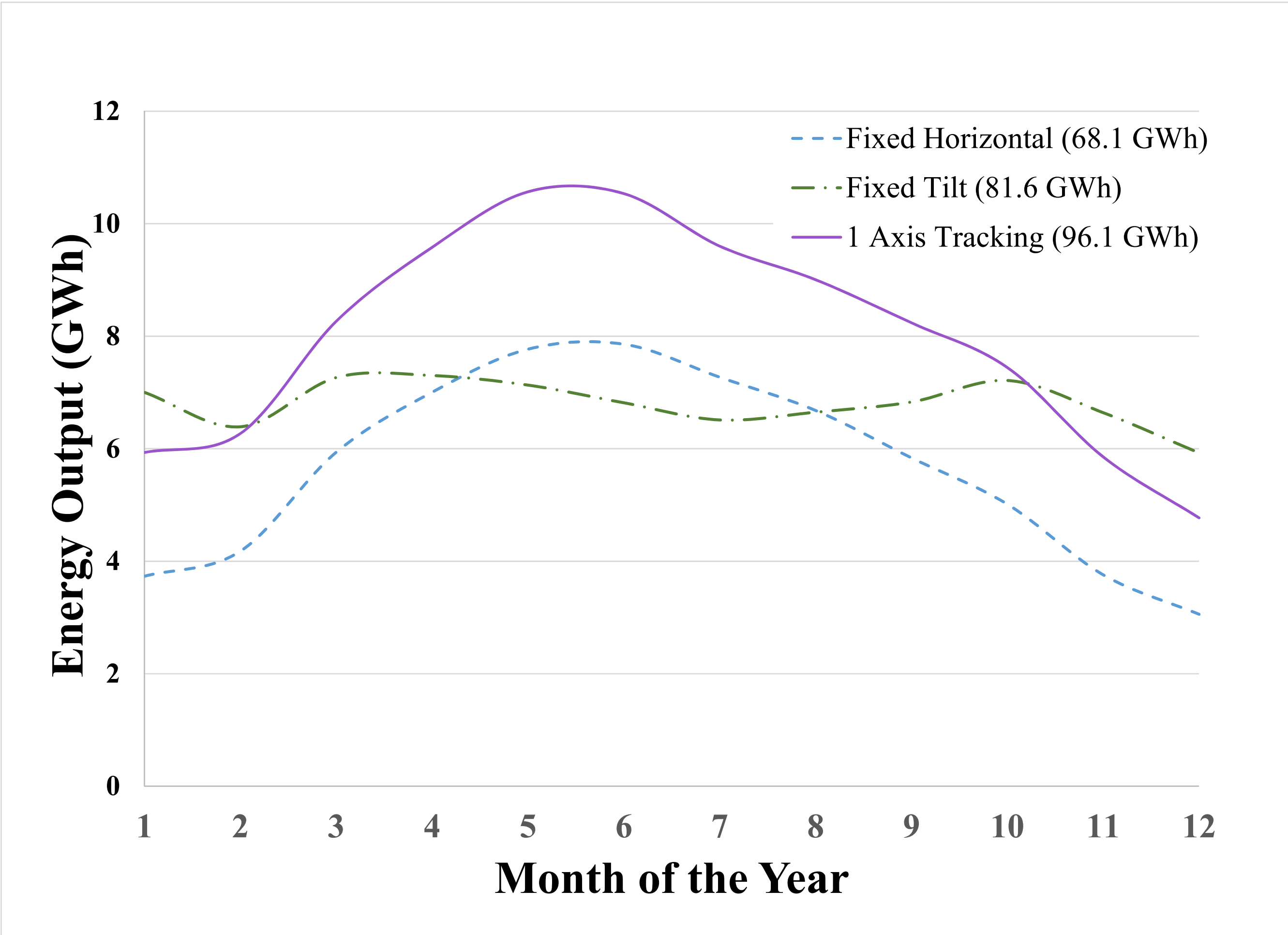


Fig. 3: Monthly energy profiles and year 1 energy output for the three different 40 MW PV power plant configurations. Expected first year energy production is for each technology is included in the legend.

4.2 CSP molten salt "power tower" thermal power plant

The CSP plant selected for study was a molten salt power tower with 10 hours of storage. For a description of the underlying model of the system, including the components and layout, see the publication by Turchi and Heath [4]. Using mostly the default values provided by SAM, such as losses due to soiling, component availability, etc., it was determined that the plant footprint covers 1,953 acres. This is an order of magnitude greater than that required for the PV, and due to the fact that the irradiance capture system (the mirrors and receiver) are purposely oversized so that energy can be captured for storage during the day while at the same time allowing the plant to produce at full capacity. Concerning the plant configuration, SAM outputs indicate that 8,929 heliostats (mirrors) of 12.2-m in height and width are required to capture the necessary solar energy. The height of the tower is 203-m, incorporating a receiver height of 20-m. Because the energy capture system in much larger than the PV plants, the energy output from the CSP plant is over twice that of the 1-axis tracking PV system. A detailed list of the outputs for the CSP plant as compared to the PV alternatives is provided in Table 3, including the NPV and first-year energy output that was reported in Table 2. Also provided in Table 3 are the levelized cost of energy (LCOE); the internal rate of return (IRR); the minimum debt-service coverage ratio (DSCR) for projects with the commercial power purchase agreement; and the annual capacity factor which is an indicator of annual production as a fraction of rate capacity.

The installation cost of the system, including the storage system and steam power plant needed to generate the electricity is $580M. Similar to the land requirement, the installation cost of the power tower is also an order of magnitude higher than for the PV plants. Although much more complex and costly than a PV plant of same nameplate capacity, the CSP plant can provide energy on-peak, can be dispatched, and has a much higher capacity factor and capacity value than the PV, thus making its energy more valuable. Note in both Tables 1 and 2 that results are listed for PPA rates for the CSP of $0.12/kWh (the central case) and $0.20/kWh. The higher PPA price was included to reflect the fact that the energy from the CSP plant has a higher value to the utility than that from a PV plant.

TABLE 3: SUMMARY OF KEY OUTPUT VALUES FOR THE FOUR SOLAR POWER PLANT OPTIONS CONSIDERED.

| Power Plant Configuration | First Year Energy (GWh) | NPV ($) | LCOE Real ($/kWh) | IRR (%) | Minimum DSCR | Capacity factor (%) | Annual water useage ($m^3$) | Total land area (acres) |
|---|---|---|---|---|---|---|---|---|
| Fixed-axis, horizontal PV | 68.1 | 16.2M | 0.11 | 25.4 | 1.95 | 19.4 | - | 158 |
| Fixed-axis, tilted at latitide PV | 81.7 | 25.1M | 0.11 | 30.9 | 2.37 | 23.3 | - | 158 |
| 1-axis tracking, horizontal PV | 96.1 | 34.3M | 0.11 | 36.3 | 2.83 | 27.4 | - | 158 |
| CSP power tower ($0.12/kWh PPA) | 225.2 | -24.2M | 0.14 | 3.63 | 0.92 | 73.9 | 73,642 | 1,953 |
| CSP power tower ($0.20/kWh PPA) | 225.2 | 79.0M | 0.23 | 22.1 | 1.62 | 73.9 | 73,642 | 1,953 |

One detractor for implementing the CSP plant is the requirement for large amounts of cooling water for the thermal power plant. SAM outputs indicate that 73,642 $m^3$ of water (equal to 59.7 acre-feet) is required each year for cooling. Since the Jemez tribal lands are in the desert southwest, finding the cooling water could be challenging and cost prohibitive.

## 5. SENSITIVITY ANALYSIS

Several judicious assumptions must be made when selecting the values of input parameters to the SAM model, from basic decisions about system design to more nuanced decisions about financing. These choices can affect the eventual calculation of the energy output and/or the NPV. Thus it is important to conduct a sensitivity analysis of the results to possible errors in the selected input.

The results of such an analysis are shown in the spider-plot displayed in Fig. 4. This figure was created for the 1-Axis tracking system, and displays the sensitivity of the net present value (in $millions) to changes in the values assumed for the central case (represented as the "fraction of central case") on the horizontal axis. Consistent with the values presented in Tables 1 and 2, the NPV is 34.3M for the central case. Input values for the central case are shown in the legend for each parameter that is varied. First let's consider the impact of changes to the PPA price, as represented by the solid, brown line that slopes up steeply from the left to the right. As displayed, if the PPA price is one-half of the central case, or $0.06/kWh, the NPV falls to about $4M. If the PPA price doubles to $0.24/kWh, the NPV climbs to in excess of $95M. Perhaps what is most important about his line is its steep slope. It indicates that changes in the PPA price strongly influence the NPV, and thus will be a very important factor in the financial success of the PV power plant.

All three of the PV plants considered (fixed, horizontal; fixed, tilted; and 1-axis tracking) have similar looking spider plots. The NPV is most sensitive to the PPA price and the real discount rate. Though not shown, it is worth noting that when analyzing the NPV sensitivity to the PPA price of the fixed, horizontal system, the NPV goes below zero if the PPA price is reduced to $0.06/kWh. A spider plot was not created for the CSP plant.

6. FUTURE ANALYSIS

The analysis conducted by the student teams at NAU and SIPI suggest utility-scale solar development may be beneficial for the Jemez Pueblo. Given the opportunity, the student teams would pursue the additional tasks listed below:

- Determine feasibility and cost of transmission interconnection
- Conduct an optimization on plant size, configuration, and financial aspects of the project
- Create visualization of a solar array at the Holy Ghost site
- Improve:
  - Estimates of installation costs
  - Estimates of operation and maintenance costs

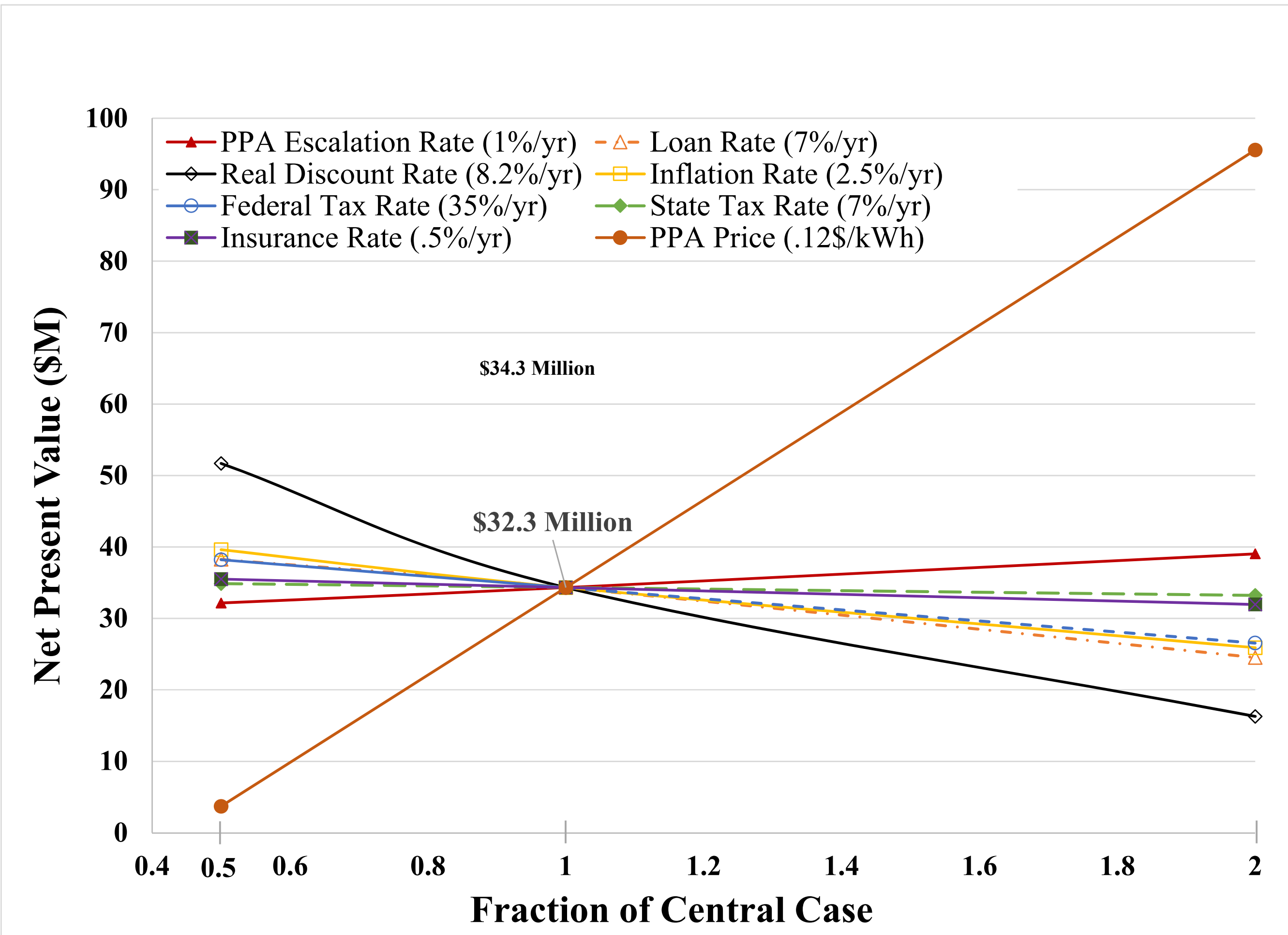


Fig. 4: 1-Axis tracking system sensitivity plot of the net present value (in $millions) plotted versus fraction of the central case value for several input parameters. First year energy production and NPV are 96.1 GWh and $34.3M for the central case. Input values for the central case are shown in the legend for each parameter that is varied.

- Tune the financial inputs to be less general and more specific to Jemez tribe
- Research potential incentives for the Jemez Pueblo, as well as the tax incentives already present in the SAM model, and use those that apply

- Research potential customers for power

## 7. CONCLUSIONS

The purpose of this project was to engage undergraduate Native American students in a real-life engineering analysis that could also benefit a partner tribe, in this case the Jemez Pueblo. This goal was certainly achieved, as demonstrated by the quality work produced by the students. The student teams at SIPI and NAU employed the NREL System Advisor Model to evaluate the technical and financial feasibility of four different utility-scale solar power plant alternatives: three PV systems (fixed, horizontal axis; fixed, titled at latitude; and horizontal, 1-axis tracking) and one CSP power tower with 10 hours of storage. Results demonstrated that all three PV power plant options yielded a positive NPV (ranging from $16.2M to $34.3M) and may warrant further investigation by the tribe. Of these systems, the 1-axis tracker is preferred based upon the NPV. A sensitivity analysis was conducted and showed similar results for each PV configuration, demonstrating that the NPV is most sensitive to the PPA price and real discount rate. The CSP power tower system yielded a large, positive NPV ($79M) when the PPA rate was $0.20/kWh, and a negative NPV (-$24M) at the central case PPA rate of $0.12/kWh. Due to its storage, however, the CSP power production will have a higher value to a purchasing utility, and therefore a higher PPA rate is a possibility. An additional factor when considering CPS is the large amount of water consumption required for power plant cooling. In each of the four alternative solar power plants considered, the cost of interconnecting to the transmission system will be a major cost, and will need to be considered in any future study, along with determining if there is available transmission capacity to connect a power plant to the grid.

## 8. ACKNOWLEDGEMENTS

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