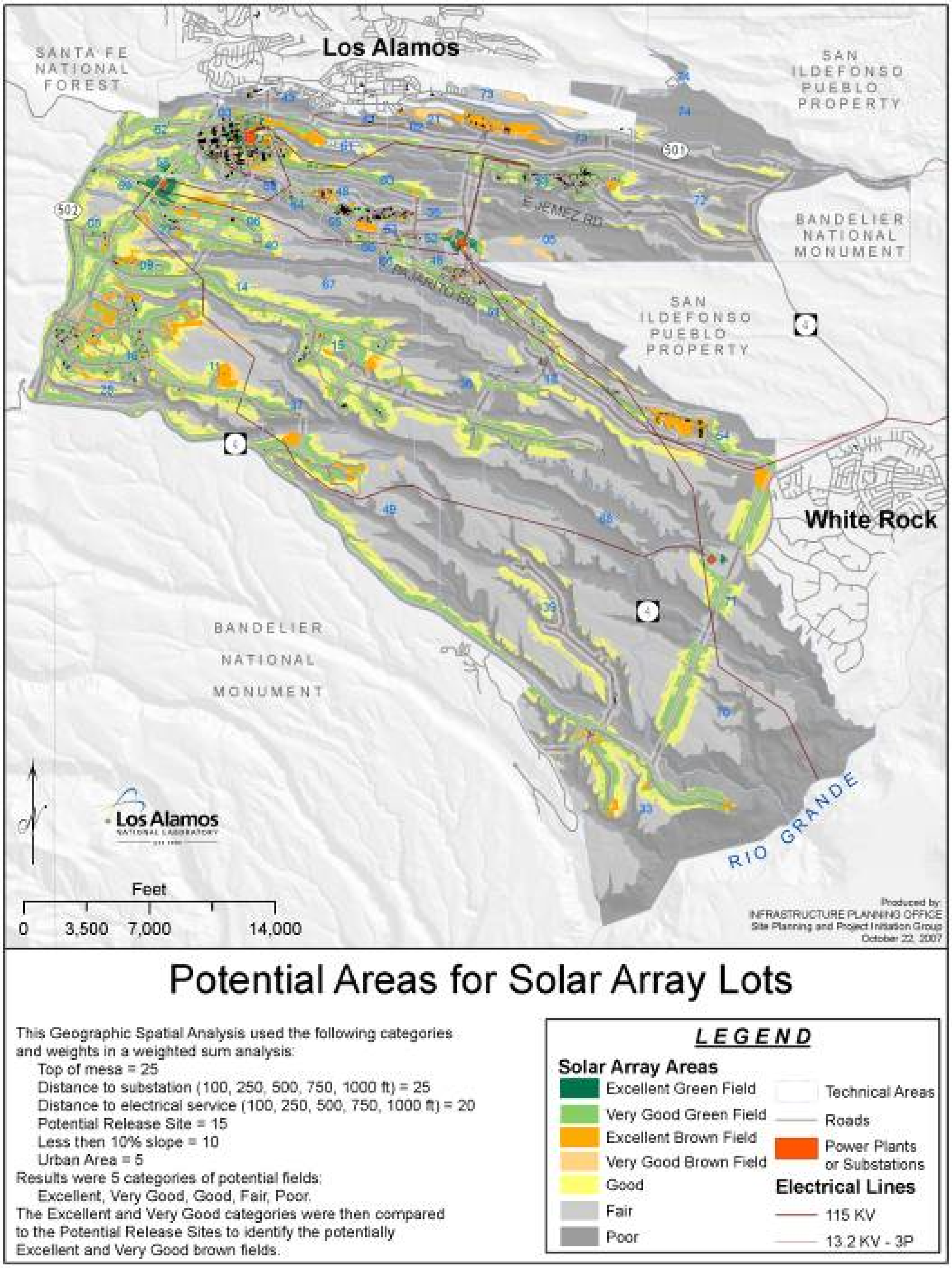

DOE Los Alamos National Laboratory – PV Feasibility Assessment NREL Final Report

LA-UR-16-22342

Cover Sheet Information

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SITE VISIT DATE:	December 6, 2007
SITE VISIT TEAM:	Otto Van Geet (NREL) William Jones (LANL) Isaac Valdez (DOE) John Arrowsmith (Dept of Public Utilities, County of Los Alamos)
DATE OF REPORT:	August 12, 2015
PROJECT NAME:	DOE LANL – PV Feasibility Assessment

Table of Contents

Acknowledgement

This work was sponsored by the Department of Energy Federal Energy Management Program (FEMP) as part of the Transformational Energy Action Management (TEAM) Initiative directed by Anne Crawley, Renewable Energy Projects Manager. Input for this report was provided by William Jones (LANL), John Arrowsmith (Dept of Public Utilities, County of Los Alamos), Isaac Valdez (DOE) and others. Alicen Kandt and Donna Heimiller of NREL conducted a previous screening of LANL.

1 Executive Summary

This report summarizes solar and wind potential for Los Alamos National Laboratory (LANL). This report is part of the "Los Alamos National Laboratory and Los Alamos County Renewable Generation" study.

As part of the Department of Energy's Transformational Energy Action Management (TEAM) Initiative, the DOE Los Alamos National Laboratory (LANL) Facilities were visited on December 6, 2007 by NREL and LANL staff. The purpose of this visit was to determine the potential for PV installations at the LANL site. The entire campus was considered in this analysis, and many potential system locations were identified: 9 different ground mount locations with total available land up to 1,000 acres (500 usable acres), 5 roof-mounted systems on 5 buildings totaling up to approximately 110,000 ft^2 of available roof area.

An economic analysis was updated on April 8, 2015 for four of the nine ground mount locations with up to date electricity costs, incentives, and photovoltaic installed costs. The four ground mount locations were identified as being the best candidates from a siting and environmental perspective by LANL staff. The new techno-economic parameters that were used in the analysis are provided in Table 1. The estimated 2018 utility rate, projected installed costs for 2018 and the projected 2018 federal tax credit were used in the analysis, assuming the system would be installed in 2018.

Table 1 - Fixed Tilt System Characteristics Per Site

Category	Fixed Tilt Case	Single Axis Tracking Case
Weather File	Sante Fe	Sante Fe
Power Density (Watt/ft2)	4	3.3
Tilt (deg)	20	0
Azimuth (deg)	180	180
DC to AC Derate	0.81	0.81
Tracking	Fixed	Single Axis
Year to Year Decline	0.50%	0.50%
Installed Cost ($)	$2.00	$2.10
Analysis Period (yrs)	25	25
Inflation Rate (%)	0.10%	0.10%
Real Discount Rate (%)	3%	3%
Nominal Discount Rate (%)	3.10%	3.10%
Incentives	None	None
Electric Rate ($/kWh)	0.06093	0.06093
Annual Escalation Rate (%)	2.65%	2.65%

The System Advisor Model (SAM) model was used for this analysis.[1] The system size, installed cost, annual energy production, and energy cost savings of a ground mount fixed tilt and ground mount single axis tracking system were analyzed at all four locations and are provided in Table 2 and Table 3.

Table 2 - Fixed Tilt System Characteristics Per Site

Metric	Option A	Option B	Option C	Option D
System Size (kW)	29,447	19,863	8,712	12,720
Installed Cost ($)	$44,170,500	$29,794,500	$13,068,000	$19,080,000
Annual Energy Prod. (kWh)	37,952,416	25,600,190	11,228,357	16,394,020
Energy Cost Savings ($/yr)	$2,312,441	$1,559,820	$0	$998,888

Table 3 – Single Axis Tracking Characteristics Per Site

Metric	Option A	Option B	Option C	Option D
System Size (kW)	24,293	16,387	7,187	10,494
Installed Cost ($)	$38,868,000	$26,219,200	$11,499,200	$16,790,400
Annual Energy Prod. (kWh)	37,150,208	25,059,912	10,990,760	16,048,009
Energy Cost Savings ($/yr)	$2,263,562	$1,526,900	$669,667	$977,805

The economics for the fixed tilt case and single axis tracking case, assuming LANL purchased the systems outright and didn't capture any local or federal tax based incentives is provided in Table 4.

Table 4 - PV System Economics for LANL Direct Purchase Case

Category	Fixed Tilt Case	Single Axis Tracking Case
Payback (years)	24.57	21.61
LCOE Nominal (cents/kWh)	7.26	6.49
LCOE Real (cents/kWh)	7.18	6.42
Capacity Factor (%)	14.70%	17.50%
First Year Prod. (kWhac/kWdc)	1,289	1,529

The economics for the single axis tracking systems are slightly better than the fixed tilt array, with a nominal LCOE of 6.49 cents/kWh. As noted above the estimated 2018 electric rate is 6.093 cents/kWh, and the LCOE of the fixed tilt and single axis tracking case are both slightly higher than the 2018 electric rate. Although the nominal LCOE is slightly higher, these values are just estimates and indicate that the LCOE of a PV system should be very competitive with the local utility rates in 2018. In addition the direct purchase case, a power purchase agreement case was analyzed which included the federal tax credit of 10% (which is the estimated federal tax credit rate in 2018) and local production based incentive for tax paying entities of

[1] SAM model: https://analysis.nrel.gov/SAM/

$0.027/kWh. The economic assumptions for the power purchase agreement case are provided in Table 5.

Table 5 – Power Purchase Agreement Economic Assumptions

Category	Fixed Tilt and Single Axis Tracking Case
Debt Fraction	40%
Loan Term (yrs)	20
Loan Rate (%)	5%
Real Discount Rate (%)	8%
Federal Tax Credit (%)	10%
Production Incentive ($/kWh)	0.027

The economics for the fixed tilt case and single axis tracking case, assuming the systems were installed via a power purchase agreement (PPA) are provided in
Table 6.

Table 6 – Power Purchase Agreement Economics

Category	Fixed Tilt Case	Single Axis Tracking Case
First Year PPA Price (cents/kWh)	7.31	6.33
LCOE Nominal (cents/kWh)	9.14	7.91
PPA Escalation Rate (%/yr)	2.65	2.65
Internal Rate of Return (%)	8.00%	8.00%

In this case the first year PPA price for the single axis tracking system is very close to the estimated 2018 electric rate and the PPA is assumed to escalate at the same 2.65% as the electric grid. This indicates that a PV system will be very competitive with grid purchased electricity in 2018 and should be considered for implementation. The installation of a large PV system of this magnitude would also position LANL as a leader within DOE for implementing onsite renewable energy systems and help the DOE labs meet their federal renewable energy mandates.

If LANL were to implement single axis tracking PV systems on Options A through D they would realize the following benefits:

- ***PV Installation Capacity:*** *58.6 MW*
- ***Year One Electricity Savings:*** *89,248,889 kWh/yr*
- ***Year One Cost Savings:*** *$5,437,935*
- ***Percent of Energy Met by PV:*** *17.18% of (DOE+LANL county energy use)*

2 Site and Utility Information

2.1 Compliance Requirements

A variety of agencies and regulations will necessarily interact when a PV project is in consideration at this federal site. The National Environmental Policy Act (NEPA) requires federal agencies to integrate environmental values into their decision making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet this requirement federal agencies prepare either an Environmental Assessment and, if needed, a detailed statement known as an Environmental Impact Statement (EIS). The Environmental Protection Agency (EPA) reviews and comments on EISs prepared by other federal agencies, maintains a national filing system for all EISs, and assures that its own actions comply with NEPA.[2]

2.2 Utility and Cost Data

LANL gets its electricity from Los Alamos County Utilities. The peak load occurs in the summer in the afternoon, the peak is 62.7 MW LANL plus 17.2 MW Los Alamos County = 80 MW total. The minimum loads occur in the spring and fall when the weather is mild. Loads always peak mid to late afternoon and match solar resource well.

- **Latitude/Longitude:** 35°52'57.67 N/106°18'50.47 W
- **Electric Utility:** Los Alamos County Utilities
- **Annual Electricity Consumption:** 451,126 MWh/year
- **Peak Load:** 62.7 MW LANL + 17.2 MW Los Alamos County = 79.9 MW total
- **Electricity Cost:** $38,385,804/year ($0.0739/kWh)

The average hourly weekday and weekend demand for March and August 2014 is provided in Figure 1 - Figure 4. The Los Alamos County demand is shown in orange, the Los Alamos National Lab demand is shown in grey and the total demand is shown in blue. Although there is a slight reduction in demand on weekends and a slight variation from month to month, in general the demand profile is very consistent from day to day and month to month.

[2] The National Environmental Policy Act: http://www.epa.gov/compliance/nepa/index.html

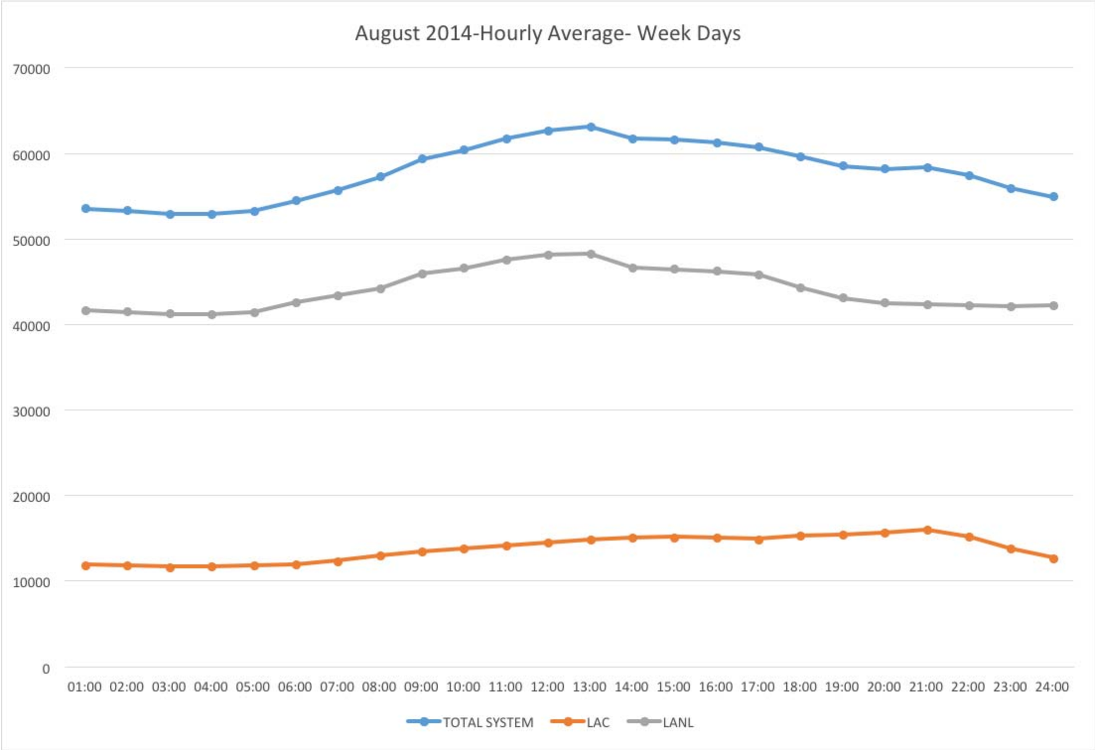

Figure 1 - August 2014 Hourly Averages - Week Days

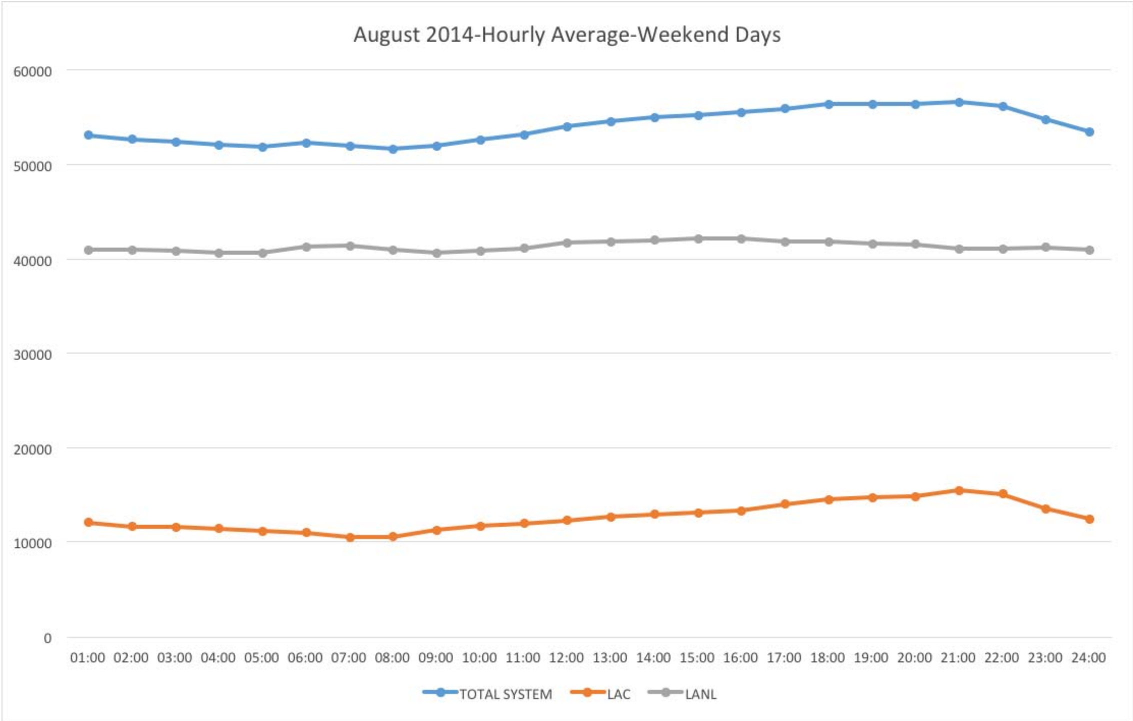

Figure 2 – August 2014 Hourly Averages - Weekends

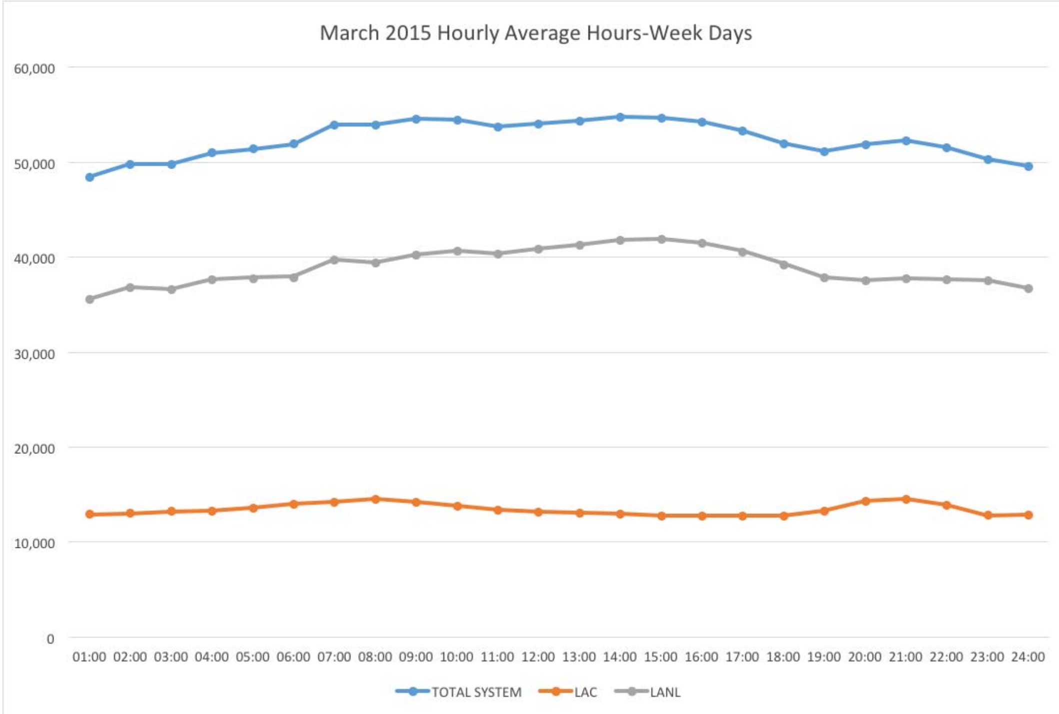

Figure 3 - March 2015 Hourly Averages - Weekdays

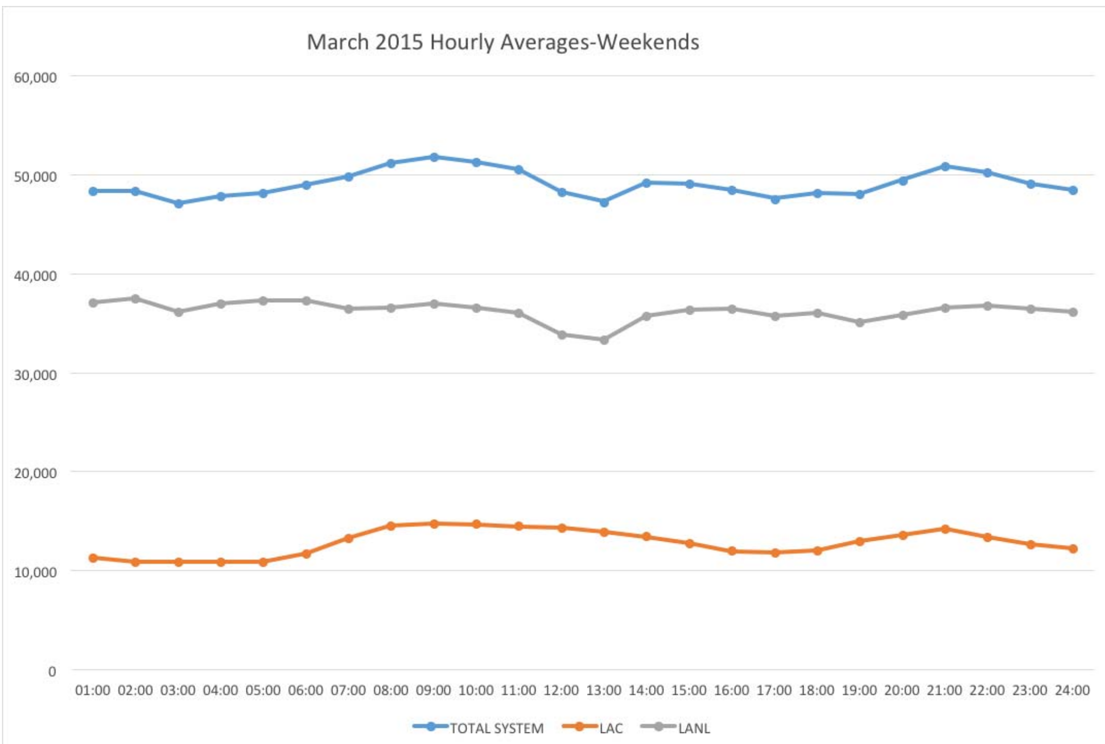

Figure 4 – March 2015 Hourly Averages – Weekends

3 Incentives and REC Markets

Incentives offered by federal and state governments, local utilities, and private organizations have a huge effect on renewable energy project economics, and need to be taken into account when considering renewable energy project economics.

A few incentive options are potentially available for a PV project at LANL. Some of these programs require a tax-paying entity to own the system. The following applicable incentive and rebate information was queried from the Database for State Incentives for Renewable Energy:[3]

- The Energy Policy Act of 2005 (EPAct 2005) included a 30% Federal investment tax credit for the installation of PV systems. The 30% federal investment tax credit is only available for tax paying entities or systems financed through a power purchase agreement and the total credit is being reduced from 30% to 10% at the end of 2015. For this analysis a 10% investment tax credit was applied to all PPAs'
- IRS rules provide a five-year accelerated depreciation for renewable installations, including PV. MACRS analysis is built into SAM.

New Mexico Production Tax Credit

The New Mexico Energy Production Tax Credit (PTC) provides tax credit against the corporate income tax of $0.027/kWh for up to 200,000 MWh/yr of solar energy. This is only applicable to the power purchase agreement case and would not be eligible if the site decided to purchase the system outright.

Economic Scenarios

For this report, two cost scenarios were calculated for each potential system: (1) no incentives or REC sales included and (2) all federal, state and local incentives (i.e. those listed in the bulleted list above and the New Mexico Production Tax Credit). The economics of a system purchased outright without federal incentives was calculated over a 25 year period, and the power purchase agreement option with the federal and local incentives was calculated over a 20 year period. These different cost scenarios are used to calculate economic parameters such as levelized cost of energy (LCOE).

[3] Database of State Incentives for Renewables and Efficiency: http://www.dsireusa.org

4 Photovoltaics

PV Systems

Photovoltaics are semiconductor devices that convert sunlight directly into electricity. They do so without any moving parts and without generating any noise or pollution. They must be mounted in an unshaded location; rooftops, carports and ground-mounted arrays are common mounting locations. PV systems work very well in the sunny Los Alamos climate, the average annual solar resource is about 5.4 kWh/m2/day.

Under full sun, each square meter of PV area produces about 100W of direct current (DC) electricity, although, this efficiency depends on the type of collector, the tilt and azimuth of the collector, the temperature and the level of sunlight. An inverter is required to convert the DC to alternating current (AC) of the desired voltage compatible with building and utility power systems. The balance of the system consists of conductors/conduit, switches, disconnects and fuses. Grid-connected PV systems feed power into the facility electrical system and do not include batteries. Figure 1 shows the major components of a grid connected PV system and illustrates how these components are interconnected in a grid-connected PV system.

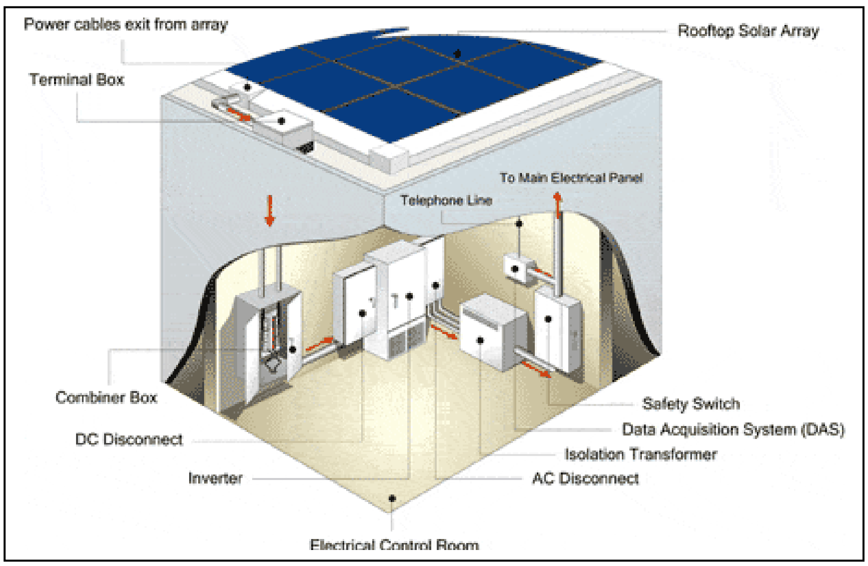

Figure 5 – Depiction of Major Components of Grid Connected Photovoltaic System (from Powerlight.com)

PV System Components

The PV system considered here has the following components:

- PV arrays, which convert light energy to DC electricity
- Inverters, which convert DC to alternating current (AC) and provide important safety, monitoring and control functions

PV Array - The primary component of a PV system, the PV array, converts sunlight to electrical energy; all other components simply condition or control energy use. Most PV arrays consist of interconnected PV modules that range in size from 50 to 300 peak watts. Peak watts are the rated output of PV modules at standard operating conditions of 25°C and insolation of 1,000 W/m2. Since these standard operating conditions are nearly ideal, the actual output will be less under typical environmental conditions most of the time. PV modules are the most reliable components in any PV system. They have been engineered to withstand extreme temperatures, severe winds and impacts. ASTM E 1171-93 imposes temperatures from -40 to +85 C, damp heat 85 C, 85%RH, humidity freeze 85%RH, -40 C and thermal Shock -40 to 110 C in 20 min. ASTM E 1038-93 subjects modules to impacts from one-inch hail balls at terminal velocity (55 mph) at various parts of the module. PV modules have a life expectancy of 20–30 years and manufacturers warranty them against power degradation for 25 years. The array is usually the most expensive component of a PV system; it accounts for approximately two-thirds the cost of a grid-connected system. There is large choice of PV manufacturers; although, it is recommended that the PV be approved by CEC.[4]

Inverters - PV arrays provide direct current (DC) power at a voltage depending on the configuration of the array. This power is converted to alternating current (AC) at the required voltage and number of phases by the inverter. Inverters enable the operation of commonly used equipment such as appliances, computers, office equipment and motors. Current inverter technology provides true sine wave power at a quality often better than that of the serving utility.

Inverters are available that include most or all of the control systems required for operation including some metering and data-logging capability. Inverters must provide several operational and safety functions for interconnection with the utility system. The Institute of Electrical and Electronic Engineers, Inc (IEEE) maintains standard *"P929 Recommended Practice for Utility Interface of Photovoltaic (PV) Systems"* which allows manufacturers to write "Utility-Interactive" on the listing label if an inverter meets the requirements of frequency and voltage limits, power quality, and non-islanding inverter testing. Underwriters Laboratory maintains "*UL Standard 1741, Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems"* which incorporates the testing required by IEEE 929 and includes design (type) testing and production testing. There is large choice of inverter manufacturers; although, it is recommended that the inverter be approved by CEC.[5]

The PV panels will come with 25-year performance warranty; the inverters come standard with a five or ten-year warranty (extended warranties available) and would be expected to last 10-15 years. A location for the inverter along with the balance of the system equipment should be specified.

For the analysis of the feasibility of photovoltaics at LANL, the SAM software program was used.

[4] Consumer Energy Center: http://www.consumerenergycenter.org/cgi-bin/eligible_pvmodules.cgi
[5] Consumer Energy Center: http://www.consumerenergycenter.org/cgi-bin/eligible_inverters.cgi

Operations and maintenance (O&M) costs are assumed to be $12/kW per year for tracking PV and for fixed PV.

The installed cost estimates were calculated based on the Annual Technology Baseline Utility Scale PV system installed costs projections for 2018, which estimate utility scale PV system installation costs at $1.5/Watt.[6]

[6] Annual Technology Baseline, http://www.nrel.gov/analysis/news/2015_first_atb_cost_perf_data.html

5 Ground Mounted PV

Single axis tracking PV rotates the PV from east to west tracking the sun across the sky. Single axis tracking provides about 20% more annual energy than fixed tilt PV. Dual axis tracking provides about 30% more annual output than fixed tilt PV but has a lower power density than single axis tracking at 10 acres per MW vs 6 acres for single axis. Dual axis tracking is also more complicated and the long term O&M is unknown. If a PPA is used with O&M provided by vendor than dual axis tracking should be allowed, otherwise it should not.

Figure 6 - Single Axis Tracking PV at Alamosa CO

Figure 7 - Dual Axis Tracking PV at Alamosa CO

5.1 Potential for Ground-Mounted PV Systems

The entire campus was considered in this analysis, and many potential system locations were identified: 4 different ground mount locations with total available land up to 406 usable acres. The installed capacity could be as large as 58.6 MW.

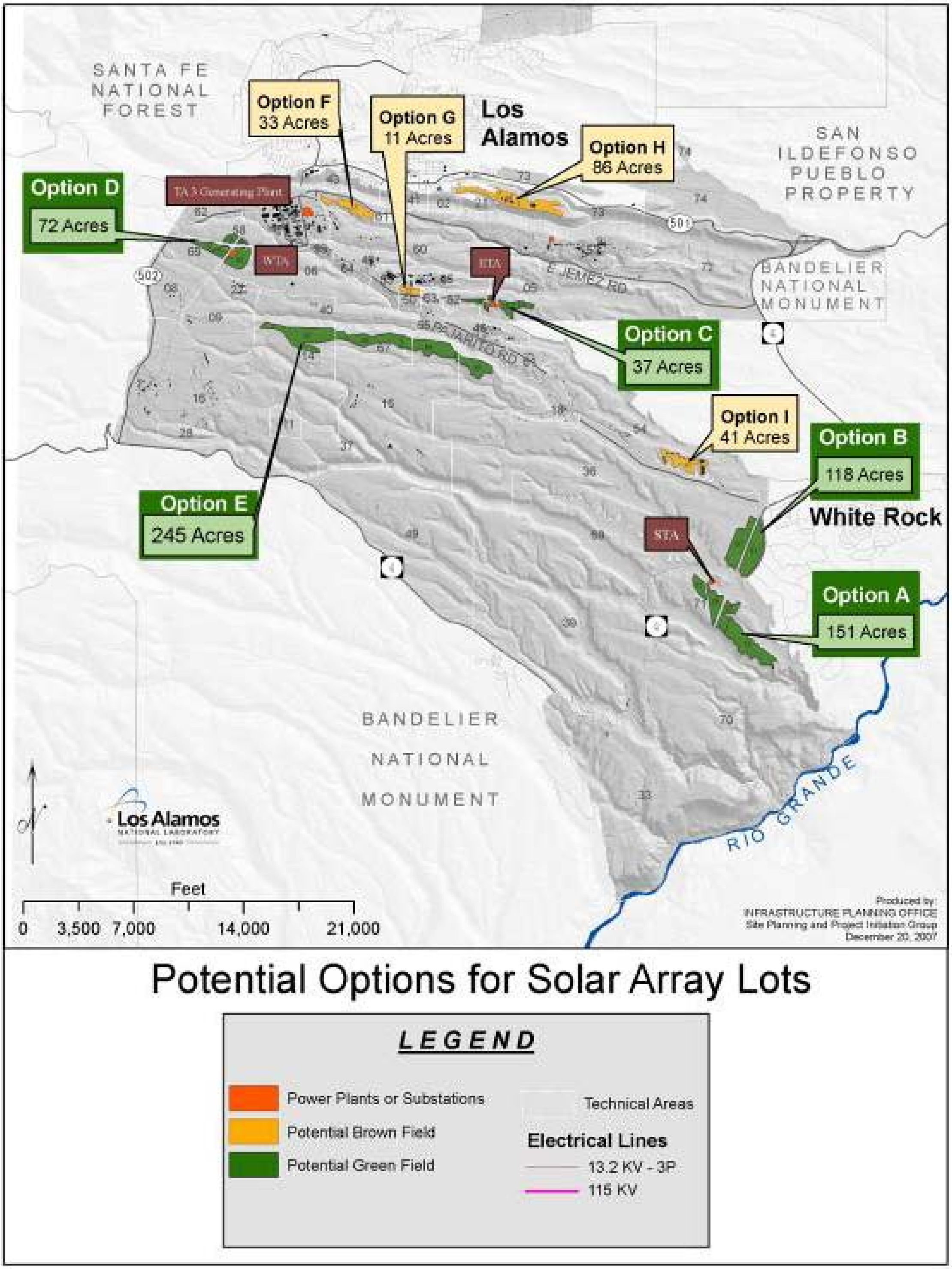

Figure 8 - LANL Potential Options for Ground Mount PV Systems

The four potential ground mount locations with up to date information from LANL is provided in Table 7.

Table 7 - Ground Mount Location Characteristics

Option	Site Area (acres)	Site Description	Distance to the Power Grid	Other Information	2015 Prioritization by LANL
A	169	Green field made up of 4 available sublots: 4 acres may be used as a sample site. 59 acres lie northwest of the power line. 29 acres lie southeast of the power line. 77 acres lie southeast of the 29 acre lot. These sublots sit on top of a mesa with sparse vegetation. They are located in a property protection area of the Laboratory in TA-71.	All sublots are within 100 feet of the 13.2 kV 3P power line with the exception of the 77 acre lot. Its northwest end is 825 feet from the power line, which extends through the 29 acre lot. All lots located near Substation STA.	Partial public view. Located near State Road 4.	High
B	114	Green field made up of 2 available sublots. A 56 acre lot to the northwest side of the power line and a 58 acre lot to the southwest of the power line. These lots are located just east of White Rock and are readily seen by the public. They are also located to the west of New Mexico State Road 4. Vegetation is pinion-juniper. Archeological sites are present on these sublots. These lots lie with the property protection area of the Laboratory in TA-36.	Both sublots are within 100 feet of a 13.2 kV 3P power line.	Public view. Located near State Road 4.	High

C	50	Green field made up of two sublots, one is 10 acres, the other is 40 acres. These lots are located within the security perimeter of the Laboratory. Vegetation is ponderosa pine, pinon, juniper, and scrub oak. Location surrounds Substation ETA. These sublots are located in TA-5 and TA-52.	Within 100 feet of a 13.2 kV 3P power line and Substation ETA.	May interfere with the proposed RLWCS project. No public view.	Medium
D	73	Green field made up of 4 sublots: a 13 acre lot; a 17 acre lot; an 11 acre lot; and a 32 acre lot. The 13 acre lot is across a small narrow canyon from the other sub lots. Located on the northwest end of the Laboratory and is currently in a property protected area. Vegetation is ponderosa pine which has been thinned for wildfire control. These sublots are located in TA-6, TA-58, and TA-69.	Surrounds substation Western Technical Area (WTA) and is within 100 feet of a 13.2 kV 3P power line.	Partial public view. Located near State Highway 501.	Medium

An aerial image of Option A is provided in Figure 9.

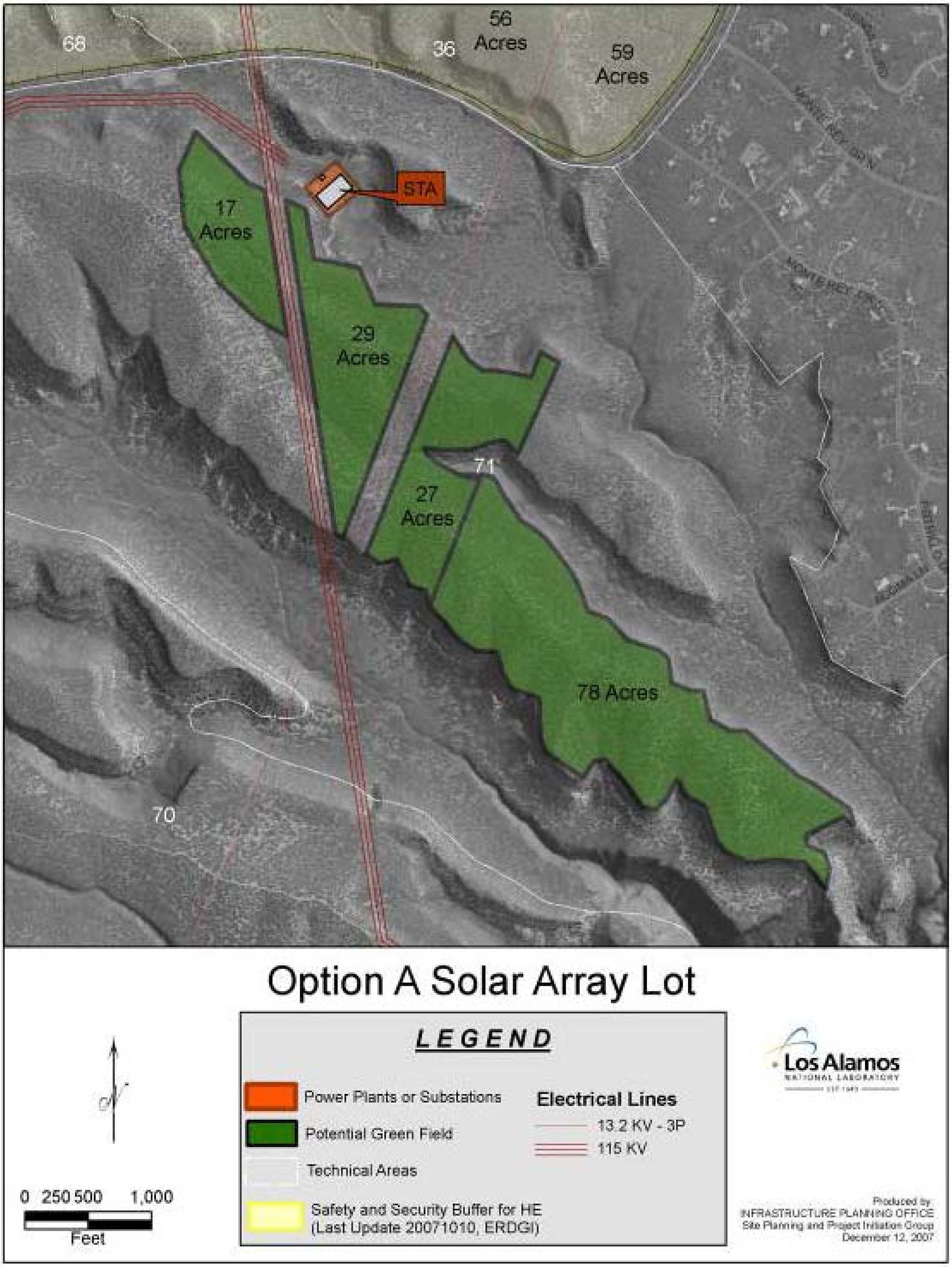

Figure 9 - Option A Solar PV

An aerial image of Option B is provided in Figure 10.

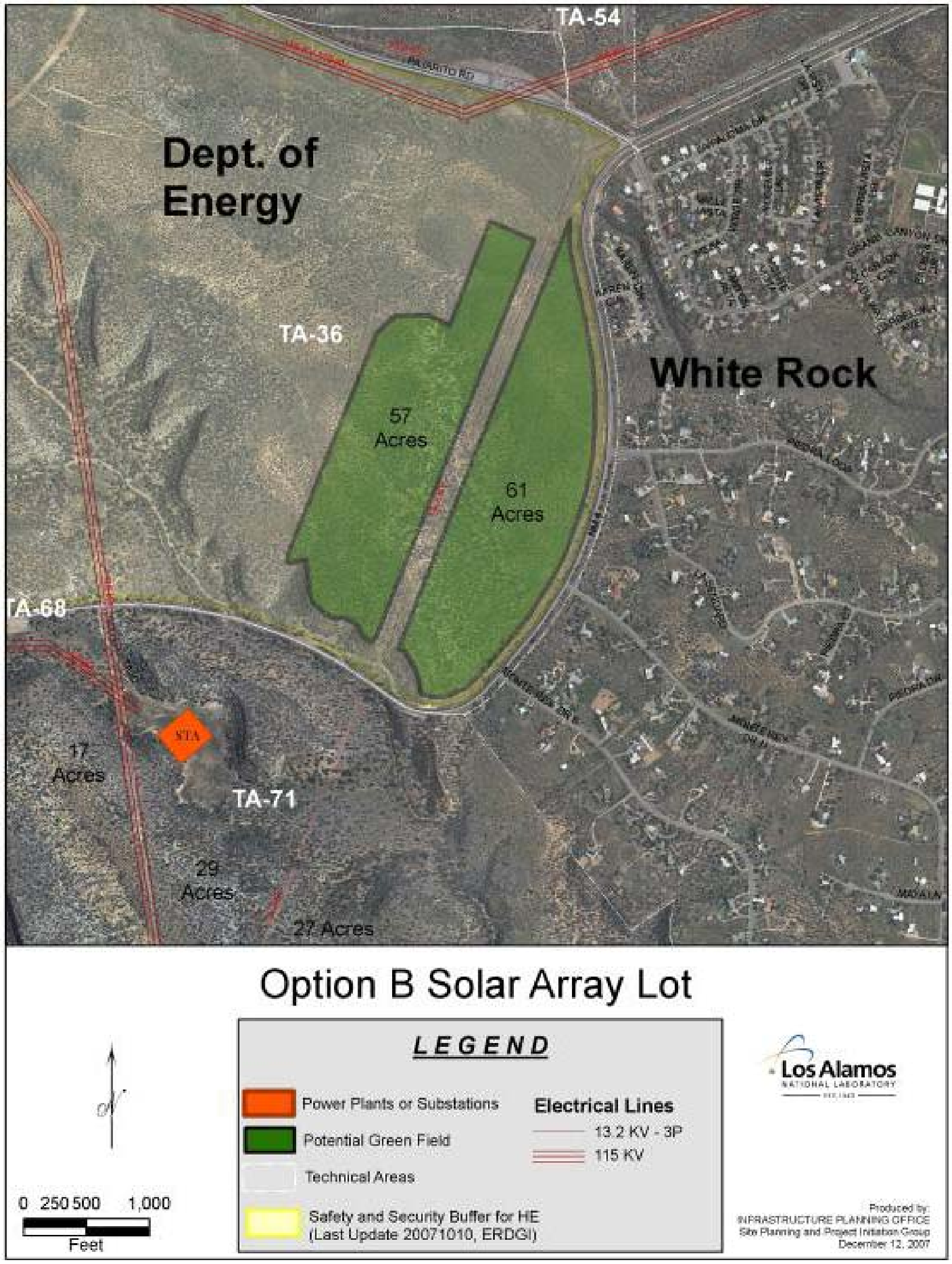

Figure 10 - Option B Solar PV

An aerial image of Option C is provided in Figure 11.

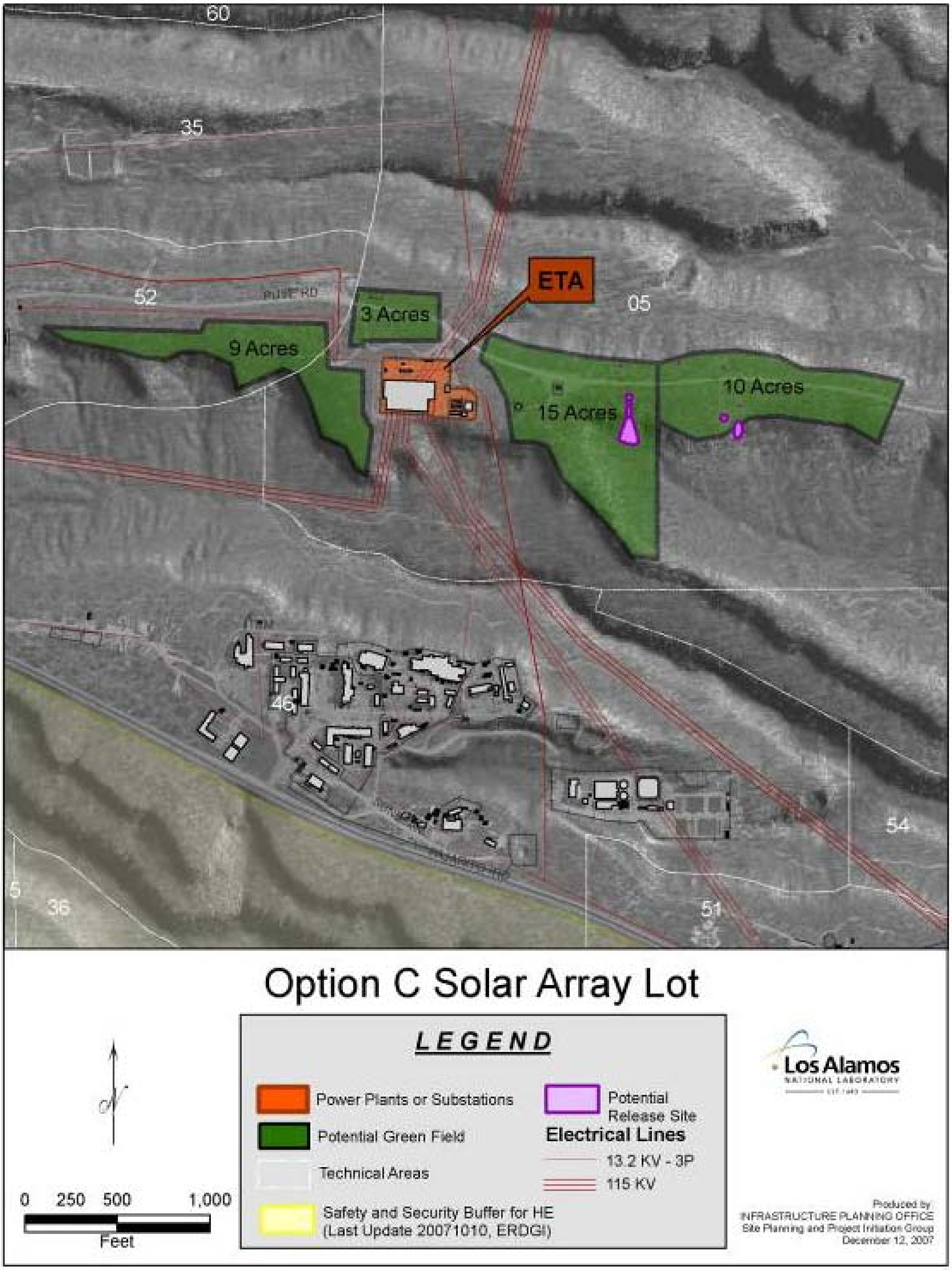

Figure 11 - Option C Solar PV

An aerial image of Option D is provided in Figure 12.

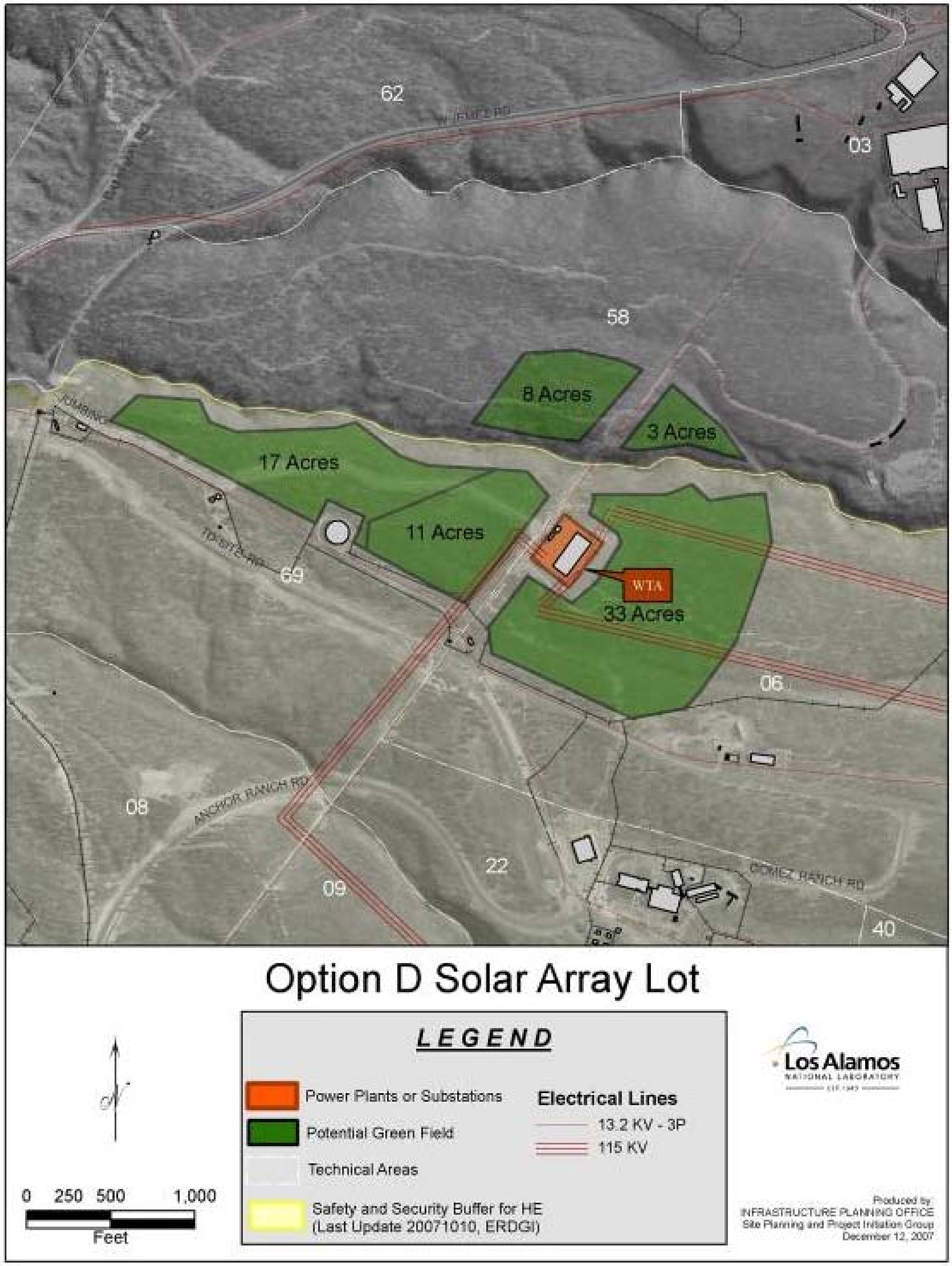

Figure 12 - Option D Solar PV

5.2 Ground Mounted PV Findings

An economic analysis was updated on April 8, 2015 for the four ground mount locations with up to date electricity costs, incentives, and photovoltaic installed costs. The new techno-economic parameters that were used in the analysis are provided in Table 8. The estimated 2018 utility rate, projected installed costs for 2018 and the projected 2018 federal tax credit were used in the analysis, assuming the system would be installed in 2018.

Table 8 - Fixed Tilt System Characteristics Per Site

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Installed Cost ($)	$2.00	$2.10
Analysis Period (yrs)	25	25
Inflation Rate (%)	0.10%	0.10%
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Table 13 – Power Purchase Agreement Economics

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- ***Year One Cost Savings:*** *$5,437,935*

- ***Percent of Energy Met by PV:*** *17.18% of (DOE+LANL county energy use)*

6 Wind Energy

LANL has no usable wind resource. Good wind resource is available on the ridge top of the National Forest land east of LANL, however many issues make the site difficult including access, difficult terrain and no electrical transmission (Figure 13).

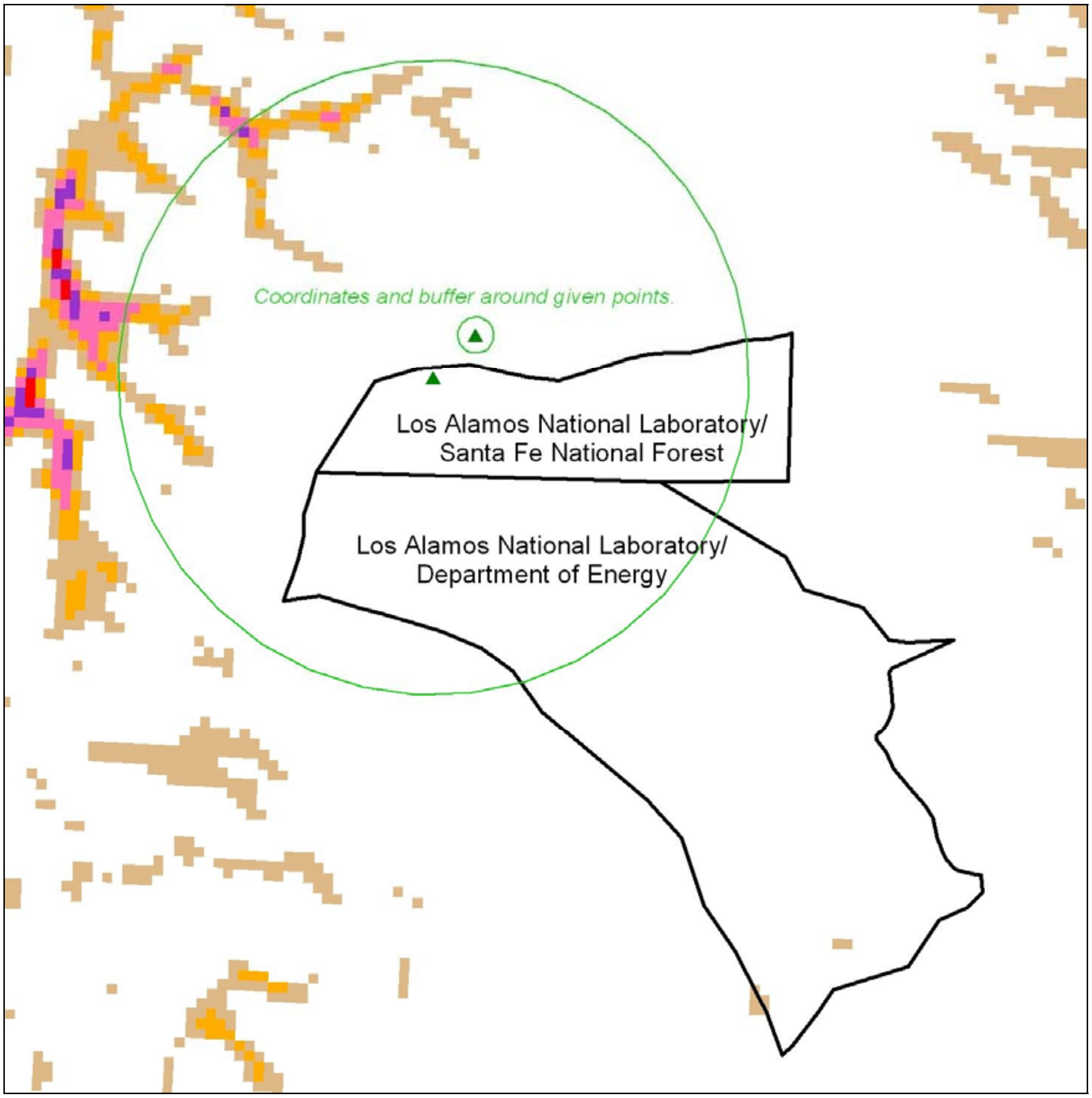

Figure 13 - Wind map of LANL and surrounding area