TEST CASE TRANSMISSION ANALYSIS FOR THE PROPOSED BRENDA SOLAR ENERGY ZONE*

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* This document has been prepared as follow-on information for the *Draft Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States* (BLM and DOE 2010).

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The following is a list of acronyms, abbreviations, and units of measure used in this report. Some acronyms used only in tables may be defined only in those tables.

GENERAL ACRONYMS AND ABBREVIATIONS

AC	alternating current
AEP	American Electric Power
BLM	Bureau of Land Management
CUS	Capital Utility Specialist
DOE	U.S. Department of Energy
DLT	dedicated-line transmission
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
MILP	mixed-integer linear programming
NPV	net present value
PEIS	programmatic environmental impact statement
P-P-D	population-to-power density
ROW	right-of-way
RPS	Renewable Portfolio Standard
SEZ	solar energy zone
SLT	shared-line transmission
WECC	Western Electricity Coordinating Council

UNITS OF MEASURE

ft^2	square foot (feet)
km	kilometer(s)
km^2	square kilometer(s)
kV	kilovolt(s)
kW	kilowatt(s)
kWh	kilowatt-hour(s)
m^2	square meter(s)
mi	mile(s)
mi^2	square mile(s)
MVA	megavolt-ampere(s)
MW	megawatt(s)
MWh	megawatt-hour(s)

ENGLISH/METRIC AND METRIC/ENGLISH EQUIVALENTS

The following table lists the appropriate equivalents for English and metric units.

Multiply	By	To Obtain
English/Metric Equivalents		
acres	0.004047	square kilometers (km^2)
acre-feet (ac-ft)	1,234	cubic meters (m^3)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
cubic yards (yd^3)	0.7646	cubic meters (m^3)
degrees Fahrenheit (°F) –32	0.5555	degrees Celsius (°C)
feet (ft)	0.3048	meters (m)
gallons (gal)	3.785	liters (L)
gallons (gal)	0.003785	cubic meters (m^3)
inches (in.)	2.540	centimeters (cm)
miles (mi)	1.609	kilometers (km)
miles per hour (mph)	1.609	kilometers per hour (kph)
pounds (lb)	0.4536	kilograms (kg)
short tons (tons)	907.2	kilograms (kg)
short tons (tons)	0.9072	metric tons (t)
square feet (ft^2)	0.09290	square meters (m^2)
square yards (yd^2)	0.8361	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
yards (yd)	0.9144	meters (m)
Metric/English Equivalents		
centimeters (cm)	0.3937	inches (in.)
cubic meters (m^3)	0.00081	acre-feet (ac-ft)
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	1.308	cubic yards (yd^3)
cubic meters (m^3)	264.2	gallons (gal)
degrees Celsius (°C) +17.78	1.8	degrees Fahrenheit (°F)
hectares (ha)	2.471	acres
kilograms (kg)	2.205	pounds (lb)
kilograms (kg)	0.001102	short tons (tons)
kilometers (km)	0.6214	miles (mi)
kilometers per hour (kph)	0.6214	miles per hour (mph)
liters (L)	0.2642	gallons (gal)
meters (m)	3.281	feet (ft)
meters (m)	1.094	yards (yd)
metric tons (t)	1.102	short tons (tons)
square kilometers (km^2)	247.1	acres
square kilometers (km^2)	0.3861	square miles (mi^2)
square meters (m^2)	10.76	square feet (ft^2)
square meters (m^2)	1.196	square yards (yd^2)

1 INTRODUCTION

The purpose of this test case is to demonstrate the effectiveness and usefulness of the planned approach for conducting enhanced transmission assessments for proposed solar energy zones (SEZs) being carried forward in the *Final Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States* (Solar PEIS). This analysis is intended to provide additional information to the U.S. Department of the Interior Bureau of Land Management (BLM) and the U.S. Department of Energy (DOE) and stakeholders regarding the nature of transmission access issues associated with proposed SEZs and the extent of new transmission development that might be needed to support solar energy generation within the SEZs. The Brenda SEZ is located in La Paz County, Arizona, about 120 mi (193 km) west of Phoenix (Figure 1). As presented in the Draft Solar PEIS (BLM and DOE 2010), the total land area of the proposed SEZ is about 3,878 acres (16 km^2). The Brenda SEZ was selected for this test case because it represents a nontrivial combination of grid connection and delivery-to-load options that test the planned approach (e.g., proximity to existing transmission lines and alternative loads).

It is important to point out that the results presented in this test case are preliminary and subject to refinement and validation via:

1. Utilizing Western Electricity Coordinating Council (WECC) data sources and consulting with WECC, the California Independent System, and other pertinent utilities on the subjects of planned expansion facilities and spare transmission line capacities over the study horizon;

2. Re-affirming the method used for quantifying the magnitude of "solar-eligible" loads at identified load areas; and

3. Augmenting the transmission design assumptions using additional transmission design reference materials (e.g., from the Electric Power Research Institute [EPRI], North American Electric Reliability Corporation, and power engineering companies).

It is also important to note several assumptions for this test case, including that the assumed maximum output from the proposed Brenda SEZ is 770 MW,[1] and that a 10-mi (16-km) tie-line from the proposed SEZ to a connection point at the Salome Substation would need to be constructed. The primary candidates for Brenda SEZ load areas are the major surrounding cities. The dispersal pattern of the load areas partly determines the number of logical

[1] This test case assumed a value of 770 MW on the basis of the size of the Brenda SEZ proposed in the Draft PEIS. However, a revised assumption on the amount of potential solar development at the Brenda SEZ now projects about 609 MW of generation. The revised assumption will be used for the analysis to be presented in the Final Solar PEIS. While some of the results will change, the basic steps and general findings are expected to remain the same as reported here.

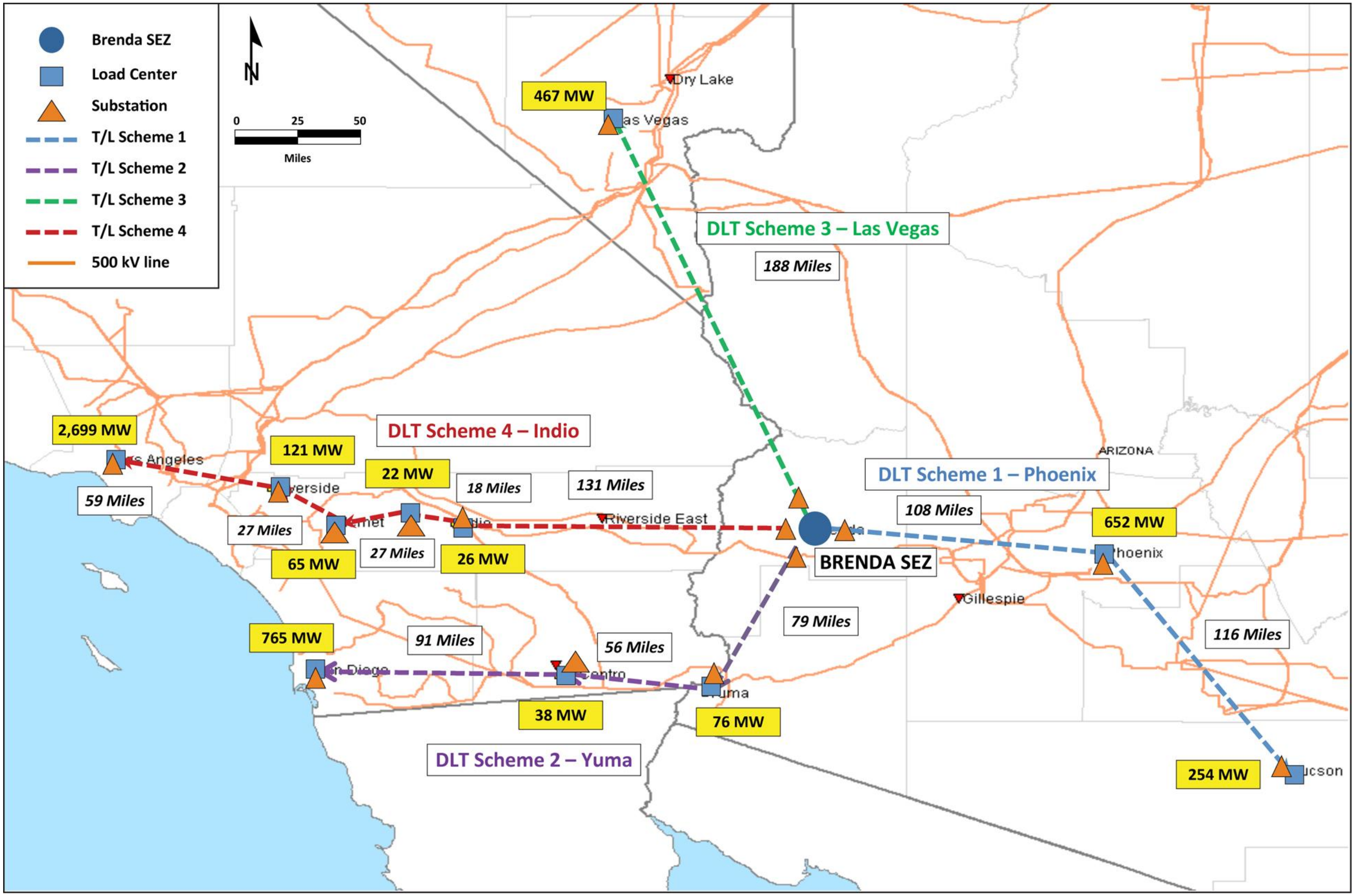

FIGURE 1 Possible Load Area Groupings for the Brenda SEZ and Possible DLT Transmission Schemes

transmission schemes for the Brenda SEZ. The most likely load area groupings for the SEZ are (1) Phoenix/Tucson; (2) Yuma, El Centro, San Diego; (3) Las Vegas; and (4) Indio Coachella, Palm Springs, Hernet–San Jacinto, Riverside, and Los Angeles. These groupings provide for linking loads along alternative routes from the Brenda SEZ so that the SEZ's output of 770 MW can be fully allocated.

To better quantify potential upper bound and mid-range impacts of bringing transmission to the SEZs, the transmission analysis as described below is proposed. The overall scope and approach for this additional analysis has been guided by review comments and programmatic oversight by the BLM, DOE, National Renewable Energy Laboratory, Western Area Power Administration, and the WECC, with a goal of developing reasonable estimates for transmission requirements and impacts, while recognizing that full-scale engineering analyses are beyond the scope of the Solar PEIS effort. The information generated by this analysis will include:

1. Identification and characterization of potential load areas to be served by the SEZ under consideration.

2. Characterization of transmission options for delivering power from the SEZ to the potential load areas under both an upper bound analysis and a mid-range analysis, and an estimation of the associated requirements in terms of transmission line length, number of substations, total land use requirement, voltage levels, wire sizes, and bundling configurations.

3. Identification of favorable and less-favorable transmission configurations in terms of potential impacts, including land use requirements and cost.

2 METHODOLOGY AND DATA SOURCES

To identify the potential load areas to be served by SEZs, a mathematical algorithm will be applied to identify which load areas would be the most favorable in terms of load requirements and distance from specific SEZs (see Section 2.1 for a detailed description of the methodology for load area identification). Because of the variable nature of solar generation, the identified load areas will need to represent significantly greater load than is expected to be delivered from a given SEZ (because no load area would depend entirely on solar generation to meet its peak loads).

The information on potential load centers for an SEZ will be used to conduct an upper bound assessment of transmission impacts for the SEZs, assuming that new transmission lines will be needed for all SEZ-generated electricity. This will be termed the "dedicated-line transmission" analysis, or DLT analysis, and will likely overestimate the costs and impacts by a significant margin. The estimated generation capacity of SEZs will be conservatively based on an assumed full build-out of each SEZ (i.e., 80% of acreage developed) to be delivered to one or more load areas. It is projected that one to four favorable load areas for each SEZ will be identified.

In addition to the upper bound analysis, an additional mid-range analysis will be conducted for some of the SEZs being carried forward to provide a semi-quantitative analysis of transmission needs using information about available capacity on existing lines and proposed new lines as the basis for impact estimates (this will be termed the “shared-line transmission” analysis, or SLT analysis). The SLT analysis will be conducted for all proposed SEZs in Arizona, California, and Nevada that are being carried forward in the Final Solar PEIS. These analyses will support responses to specific comments about opportunities to use existing and proposed new lines that were received on the Draft Solar PEIS.

Specifically, the upper bound DLT analysis will estimate the number and size of additional lines and substations required to move SEZ-generated electricity to load center(s) in order to estimate the acres of land that would be disturbed. The mid-range SLT analysis will estimate the number of line upgrades, new transmission lines, and substations needed, assuming tie-in to the existing grid where data indicate this would be likely. For both analyses, in order to calculate the number of miles of new transmission construction and acres disturbed, it will be assumed that new transmission construction will occur parallel to existing ROWs and/or within or along designated corridors.

2.1 METHODOLOGY FOR IDENTIFYING LIKELY LOAD AREAS

The methodology for identifying likely load areas is intended to provide a logical foundation and reproducible basis for associating SEZs with appropriate load areas. The goal is to develop SEZ/Load-Area assignments for each SEZ. This task represents the first step in an enhanced assessment of transmission requirements for SEZs. The SEZ/Load-Area assignments will provide the basis for examining the transmission needs and impacts for all SEZs, including those that can potentially take advantage of nearby transmission lines and/or substations with available capacity, those existing lines that could be upgraded to carry more capacity, and those that are likely to require new transmission capabilities.

2.1.1 Background

The approach is designed to provide realistic approximations but should not be interpreted as predictive or definitive, in part, because the transmission development process is complex and dynamic, and also because of limitations in scope. Many commercial entities (e.g., utilities, independent transmission developers), public entities, and governmental entities are involved in planning, financing, permitting, and constructing new transmission lines, and this analysis is not intended to capture those multi-entity dynamics. Likewise, this analysis does not represent a technically rigorous treatment of the load associations, and it does not employ new load flow analysis or optimization techniques that are used by industry to simulate grid flows and optimize cost/pricing issues.[2] Typically, many factors other than proximity to load are taken into consideration when utilities conduct transmission planning studies. Such rigorous analysis

[2] Note, however, that this study will use results from WECC alternating current (AC) load flow studies for estimating available capacity on transmission lines. See Section 2.2.

requires extensive modeling that is beyond the scope of the Solar PEIS. Instead, the logic outlined in this algorithm represents an effort to capture some of the important physical factors that determine logical load areas for prospective generation sources. By including considerations for the factors discussed below, the algorithm described is intended to produce realistic assessments of transmission requirements and associated impacts. This information may provide insight and data for supplying study requests to WECC for additional analysis by WECC's Transmission Expansion Planning Policy Committee Regional Transmission Expansion Planning 10-year planning process, and for WECC's Technical Studies Subcommittee reliability studies. In addition, this information may be used to augment the Western Renewable Energy Zone initiative.

2.1.2 Basic Considerations and Overview

The following objectives and factors are incorporated into the SEZ/Load-Area algorithm:

- Minimizing distances between each SEZ generation source and selected load(s);
- Identifying existing transmission lines where available capacity may exist;
- Taking advantage of existing ROWs or planned corridors, even where little or no excess capacity exists, and recognizing existing grid topology as it might lead to shorter transmission distances (to provide a realistic estimate of the routes that would likely be followed in constructing new transmission lines or upgrading existing lines);
- Identifying adequate loads to absorb planned SEZ generating capacities;
- Limiting solar-generated assignments for any given load area to a reasonable percentage of the total load for that area; and
- Allowing SEZs to serve out-of-state load areas.

These factors will be integrated into the algorithm for identifying load areas for each SEZ. Collectively, they are intended to mimic some of the basic considerations that drive transmission development, without requiring the rigor of detailed load flow analysis. These items are discussed in greater detail in the following descriptions.

Minimizing Distances between Generation Source and Designated Load(s). Distance minimization recognizes that transmission distance is one of the strongest factors affecting transmission costs and line losses. Minimizing distance represents a fundamental objective in most transmission planning efforts, although in some cases a power generator can afford to move power greater distances if the sale price in the more-distant market is higher than that in closer markets. However, in the methods used for SEZ transmission analyses, total incremental transmission distance will be treated as a basic parameter to be minimized, subject to the requirements for assembling a collection of loads that satisfy the other requirements.

Recognizing Existing Transmission Lines Where/If Available Capacity Exists. For locations where reliable data sources (e.g., Federal Energy Regulatory Commission [FERC] 2011; WECC 2010, 2011a,b) indicate that load carrying capacity might be available on existing transmission lines, the algorithm will treat that resource as top priority. While excess capacity may be relatively rare for many pathways around SEZs, in cases where it does exist and the capacity is in the direction of the load area where power is needed, it represents the least-cost and least-impact alternative for delivering power from SEZs to load areas. As such, it would be the first option chosen relative to other options for expanding or constructing new lines and/or rights-of-way (ROWs). It is important to recognize that proper location of a solar resource has the potential to actually reduce congestion by locating the resource between the point of congestion and load and effectively sending power in the opposite direction of existing flows.[3]

Taking Advantage of Existing ROWS or Planned Corridors Even Where Little or No Excess Capacity Exists. The identification of load areas for each SEZ will also recognize that existing lines provide favorable pathways even when excess capacity is limited. The incremental costs and impacts for expanding existing lines/ROWs are typically much lower than developing entirely new pathways. There are numerous alternatives for adding capacity along existing transmission pathways: adding new circuits/conductors to spare positions on existing structures; reconductoring the lines with high-temperature, low-sag conductors; making voltage upgrades; and/or widening the ROW to accommodate new circuits/structures. These options, along with the associated cost estimates, will be addressed in steps that follow after the initial sets of load areas are identified for each SEZ.

Recognizing Grid Topology as It Might Lead to Shorter Transmission Distances. “Incremental,” or new, transmission distances will be recognized in the analysis for interconnected load areas. For example, if two load areas are reachable at different points along a single transmission line, the selection logic will recognize that if both loads are to be connected, the more-distant load area only incurs an incremental transmission enhancement distance to link between the nearer load area and the more-distant load area. Recognizing interconnection dependencies can alter the selection of the most favorable load areas to be served by a given SEZ.

Identifying Loads: (a) Identifying Adequate Loads To Absorb Planned SEZ Generating Capacities. For each SEZ, an adequate collection of load areas will need to be selected to absorb the estimated solar-generating capacity at full build-out. In cases where surrounding load areas

3 As a simplified example, assume the prevailing power flow is 1,000 MW from point A to point B. By injecting power (e.g., 100 MW from a source such as an SEZ) at point C located between A and B, and contracting to serve an incremental 100 MW of load at point A, the net flow from A to C will be reduced to 900 MW (1,000 MW minus 100 MW), and 100 MW of load at A will be effectively served by the 100-MW SEZ injection. The total flow from C to B would remain 1,000 MW. Because of the physics of the transmission system, “physical” paths of power flows do not necessarily follow the contractual paths. In this case, the 100 MW of power injected from the SEZ will not necessarily follow a route from C to A (instead, it would displace power flowing from C to B), but the net result will be the same as if that power had followed that route.

represent small loads, this consideration will mean that multiple load areas will be identified for a given SEZ. Limits that operators of individual load areas would place on the use of renewable/solar power (see item (b) below) will also affect the number of load areas needed to accommodate generation from each SEZ (e.g., a simplifying assumption could be adopted that no more than 20% of a load area's demand (MW) requirements could be supplied from solar resources). In reality, the amount of solar power from an SEZ that individual load areas accept will vary based on economics, contracts with other sources, and state and federal regulations and policies mandating the use of solar power. *(b) Limiting Solar-Generated Load Assignments for any Given Load Area To Serve a Reasonable Percentage of the Total Load for That Area*. For a given load area, only a portion of total demand (MW) will be "eligible" to be served from an SEZ. This consideration recognizes that each load area would limit its exposure to variable generation as derived from solar sources. In the initial test case, the fraction applied to each load area was a simple 20% multiplier. As a refinement, the fraction could be set equal to the Renewable Portfolio Standard (RPS) requirement (i.e., the fraction of electricity required to be generated from renewable sources for the state where the load area is located). Peak load estimates for load areas are expected to be approximated from a simple scalar based on population.

Allowing SEZs To Serve Out-of-State Load Areas. The initial assumption in this analysis will treat SEZs as able to serve both in-state and out-of-state loads. If interests or questions are raised regarding sensitivities to this assumption, they can be addressed relatively easily with additional case studies.

2.1.3 Implementation

The SEZ/Load-Area assignment algorithm will be solved by using a simple mixed-integer linear programming (MILP) formulation. By defining the factors outlined above, the MILP will identify the most effective collection of load areas for each SEZ. The formulation will be flexible in terms of potential modifications or enhancements once initial test cases are prepared and reviewed. In general, the algorithm will be formulated as a distance minimization problem, subject to constraints to ensure that adequate loads are designated to consume the solar-derived generation from a given SEZ.

Objective function: Minimize the sum of incremental transmission distances to all designated load areas, subject to the following constraints:

- Sum of "eligible" demand (MW) from all selected load areas must be ≥ total SEZ generating capacity.
- SEZ-eligible demand (MW) for each load area = load area peak load × RPS fraction (or other multiplier for state of load area).
- Follow existing/planned ROWs/corridors to in-state and out-of-state load areas.

- Use existing available capacity as much as possible (i.e., lowest incremental distance/impact).

- For congested pathways, assume new capacity would need to be added.

- Use “incremental” distances to load areas located along ROWs/corridors that serve other load areas.

In some cases, particularly for the smaller SEZs, the SEZ/Load-Area assignments may be obvious upon initial inspection of the grid topography and magnitudes of capacity involved. In such cases, it may not be necessary to actually construct or solve the MILP.

The end product of this process will be a list of logical load areas for each SEZ. These lists will be used to assess the distances, upgrade requirements, and costs for:

- Transmission tie-lines to connect with the existing grid (and potential transmission capacity on existing lines), and

- New transmission capabilities (on, or parallel to, existing/planned ROWs).

2.2 TRANSMISSION ANALYSIS METHODOLOGIES

Subsequent to the identification of potential load areas as described in Section 2.1, the following additional assumptions, methods, and data sources are proposed for use in identifying upgraded and/or new transmission facilities that would be needed for individual SEZs, and for estimating the environmental impacts and costs of these upgraded or new facilities.

The total demand, in megawatts (MW) for each load area, will be roughly estimated by assuming a population-to-power density (P-P-D) of 400 people per MW (Portante et al. 2011). Since population is the most common parameter associated with a market area, the use of P-P-D is a convenient means of calculating the equivalent MW load given the population. The resulting MW load usually reflects the high side of the MW load estimate and, thus, supports analysis of upper bound impacts.

The DLT analysis will assume that all SEZ-generated power would require entirely new transmission lines. Where existing transmission lines are present, it is assumed that the new dedicated lines would be constructed parallel to the existing lines leading to the identified potential load areas and that they would require additional land for ROWs. The new transmission lines are assumed to traverse the identified potential load areas in sequence according to their linear distance from the center of the SEZ until the maximum allowable MW output for the SEZ is fully distributed. The purpose of the DLT analysis is to establish an approximate upper bound of potential impacts of transmission development associated with solar development in the SEZ in terms of land disturbance and cost.

The SLT analysis will examine existing transmission lines with potential spare capacity over a 10-year planning horizon, assuming that these lines could be used in transmitting electricity generated at the SEZ to various load areas. To accomplish this, the analysis will evaluate AC load flow data for the base year of 2011 through the tenth year of the assumed planning horizon. The difference between the line rating (in MW) and the base load flow (also in MW) is the allowable electrical capacity that could be used to transmit SEZ-generated power. If there is insufficient capacity on the existing line, the analysis will examine possible enhancements to existing transmission lines, as needed, to accommodate the full SEZ output. Added investment is also required for a tie-line or tie-lines that would run from the SEZ to the connecting point on the existing transmission line (note that larger SEZs may require more than one tie-line).

Within each methodology (i.e., DLT and SLT analyses), the goal is to identify transmission configurations that make efficient use of land and equipment investments, and provide other qualitative advantages (e.g., transmission system flexibility and long-term sustainability). Thus, the DLT analysis attempts to identify the best configuration for new dedicated lines, and the SLT analysis attempts to identify the most favorable option that recognizes the availability of existing transmission line capacity.

The planned data sources for the analyses include:

- Information about the proposed SEZs and potential generation levels as presented in the Draft Solar PEIS, associated spatial data (available at http://solareis.anl.gov/maps/index.cfm), and revisions to the proposed SEZs as described in the Supplement to the Draft Solar PEIS (BLM and DOE 2011).

- WECC systems map and load flow data from FERC for 2010, 2015, and 2020 under peak summer demand (FERC 2011).

- WECC path reports for calibration adjustments to line capacity estimates: for example, *10-Year Regional Transmission Plan, WECC Path Reports, September 2011* (WECC 2011b).

- Platts POWERMap data (Platts 2011): for load area identification and population estimates.

- The EPRI transmission Line Reference Book (EPRI 2005).

- Various technical publications from the Institute of Electrical and Electronics Engineers, EPRI, WECC, and other organizations (CUS 2010; AEP 2010).

Major assumptions to be employed in the analyses are as follows:

1. The study horizon will be assumed to be 10 years and cover the period 2011 to 2020. This assumption is constrained mainly by the available load flow data and facility expansion information from FERC. FERC can provide load flow

data only extending up to 2020. Load growth and transmission line loadings over this period of time will thus be included in the analysis.

2. Transmission lines that require new construction will be assumed to run parallel to existing transmission routes. The transmission line design that best suits the 770-MW SEZ is a 500-kV, single-circuit, bundle-of-two configuration. This configuration has a "loadability" of 900 MW for a line length of up to 300 mi (483 km) (see AEP 2010). The next best alternative to a 500-kV configuration is a 345-kV double-circuit line. This design, however, has a loadability of only 800 MW (AEP 2010). A power engineering consideration known as "reactive power flow" affects the selection of design options, and in this case, the 500-kV single-circuit bundle-of-two configuration provides adequate allowance for reactive power flows, but the 345-kV double-circuit may fall short of providing such necessary space.

3. A ROW requirement of 200 ft (61 m) for 500-kV transmission corridors and a land requirement of 950 ft^2 (88.3 m^2) per megavolt-ampere (MVA) for the electric substations are assumed (Western 2009; CUS 2010). These assumptions will be further reviewed and revised as needed prior to the Final Solar PEIS.

4. The Brenda SEZ will have a maximum output of 770 MW, which will remain constant over the planning horizon.

5. A present-worth method based on an opportunity cost of 3% will be employed. Projections for annual load growth will be assumed to be directly proportional to population growth. Cost of electric energy will be assumed to be constant at about $100/MWh. Only investment costs for the transmission lines will be considered in this study. Maintenance cost will be neglected for the time being to simplify the illustration of the analysis procedure. These assumptions will be further reviewed and revised as needed prior to the Final Solar PEIS.

6. As a simplifying approach to recognizing the variability characteristics of solar generation, load areas are assumed to have a maximum supply of 20% that is eligible to be served by solar power. Thus a load area with a total load of 100 MW is assumed to represent only 20 MW of potential load for new solar power generated in the SEZs. This consideration recognizes that each load area would limit its exposure to variable generation as derived from solar sources. As stated in Section 2.1.2, the amount of solar power from an SEZ that individual load areas will accept will vary based on the amount already supplied by other renewable sources and on state and federal regulations and policies mandating the use of solar power.

7. Transmission line expansion and reinforcements for 2011, 2015, and 2020 are based on the “Planned Facilities Map” provided by WECC via FERC Form 715 filings.

8. Peak baseline power flows will be derived from the proportional relationship between real power flows and the voltage angles. Power flow through a line can be estimated by taking the difference between the voltage angle for the sending and receiving terminals, and dividing by the line reactance (also requires applying appropriate unit-conversion factors). Note the qualifications discussed in Section 3.2.2.4.

9. The thermal ratings of the lines as contained in FERC Form 715 for WECC will be used to estimate spare capacity. Adjustments to recognize voltage stability issues (in addition to thermal line ratings) will be examined as noted in Section 3.2.2.4.

10. The current scope of analysis will treat each SEZ independently. Conducting coordinated transmission development studies that consider multiple SEZs contributing power to the same load center or centers is considered beyond the scope of the additional SEZ-specific transmission analysis planned for the Final Solar PEIS. However, discussion of the likelihood of potential impacts from multiple SEZs will be included in the Final Solar PEIS, based on the likely load centers identified for the SEZs.

3 TRANSMISSION ANALYSIS

3.1 IDENTIFICATION AND CHARACTERIZATION OF MARKET AREAS

The primary candidates for Brenda SEZ load areas are the major surrounding cities. The dispersal pattern of the load areas partly determines the number of logical transmission schemes for the proposed Brenda SEZ. Figure 1 shows the possible load area groupings for the Brenda SEZ with four possible associated DLT transmission schemes. The groupings provide for linking loads along alternative routes so that the SEZ’s output of 770 MW could be fully allocated.

Table 1 summarizes and groups the various load areas according to their associated DLT transmission scheme and provides details on how the MW load for each area was estimated.

3.2 TRANSMISSION OPTIONS AND ASSESSMENTS

The transmission analysis framework includes the DLT (“upper bound”) analysis and the SLT (“mid-range”) analysis. Transmission options and their analysis with DLT and SLT are discussed in the following sections.

TABLE 1 Candidate Load Area Characteristics for the Brenda SEZ

Load Group/DLT Transmission Scheme	City	Position Relative to SEZ	Population (2010)[a]	Estimated Total Demand (MW)[b]	Estimated Demand for Solar Market (MW)[c]
1	Phoenix	East	1,303,773	3,259	652
	Tucson	Southeast	508,393	1,271	254
2	Yuma	Southwest	149,264	373	75
	El Centro	Southwest	76,396	191	38
	San Diego	Southwest	1,530,100	3,825	765
3	Las Vegas	North	933,480	2,334	467
4	Indio Coachella	West	52,585	131	26
	Palm Springs	West	44,218	111	22
	Hernet–San Jacinto	West	130,587	326	65
	Riverside	West	242,690	607	121
	Los Angeles	West	5,398,872	13,497	2,699

[a] Population estimates taken from POWERMap (Platts 2011).

[b] The estimated total demand (MW) values equal 2010 population divided by 400 people/MW.

[c] The estimated demand (MW) for solar market in each city is 20% of the estimated total demand (MW).

3.2.1 Dedicated-Line Transmission Analysis

The DLT analysis approach assumes that the Brenda SEZ will require all new construction for transmission lines (i.e., dedicated lines) and substations. The new transmission lines(s) would directly convey the 770-MW output of the Brenda SEZ to the prospective load areas for each possible transmission scheme.[4] It also assumes that all existing transmission lines in the WECC region are saturated and have little or no available capacity to accommodate Brenda's 770-MW output throughout the entire 10-year study horizon.

4 In each case, this analysis assumes the dedicated lines will be rated 500 kV through the entire span. While this may represent an "overbuild" in some cases, it serves several purposes: (1) in most cases for Brenda (and presumably for other SEZs), the loadings are "end heavy" (highest loads located at the end of the dedicated line), so it makes sense to not downgrade voltage at the farthest reaches; (2) as contracts may come and go, using 500 kV throughout provides capabilities to carry SEZ power to more distant customers if needed; (3) the use of 500 kV throughout the line span is intended to accommodate longer-term planning horizon capabilities for the SEZs (i.e., possible expansion); (4) the assumption simplifies the analysis; and (5) the DLT analysis is intended to provide an upper bound.

Figure 1 displays the pathways that new dedicated lines might follow to distribute solar power generated at the Brenda SEZ to the four different identified load groups described in Table 1. These pathways parallel existing 500-, 230-kV, and lower voltage lines, although only the 500-kV lines are shown on the map. For example, for load group 1 (DLT Transmission Scheme 1), serving load centers to the east and southeast, a new line would be constructed to connect with Phoenix (652 MW) and Tucson (254 MW) so that the 770-MW output of Brenda could be fully utilized. This particular scheme has two segments. The first segment, from the SEZ to Phoenix, is 108 mi (174 km) long and the second segment, from Phoenix to Tucson, is about 116 mi (187 km) long.

For load group 2 (DLT Transmission Scheme 2), serving load centers to the southwest, Figure 1 shows that new lines would be constructed to connect with Yuma (75 MW), El Centro (38 MW), and San Diego (765 MW) so that the 770-MW output of Brenda could be fully utilized. This particular scheme has three segments. The first segment, from the SEZ to Yuma, is 79 mi (127 km) long, the second segment, from Yuma to El Centro, is about 56 mi (90 km) long, and the segment from El Centro to San Diego is 91 mi (146 km) long.

For load group 3 (DLT Transmission Scheme 3), serving load centers to the north, a new line would need to be constructed to connect with Las Vegas (467 MW). That line would be approximately 188 mi (303 km) long. However, the estimated 467-MW load for Las Vegas is not adequate to fully utilize the output from Brenda. Loads further north are either too small or too distant to construct additional connecting transmission segments.

For load group 4 (DLT Transmission Scheme 4), serving load centers to the west, Figure 1 shows that new lines would be constructed to connect with Indio Coachella (26 MW), Palm Springs (22 MW), Hernet–San Jacinto (65 MW), Riverside (121 MW), and Los Angeles (2,699 MW) so that the 770-MW output of Brenda could be fully utilized. This particular scheme has five segments. The first segment, from the SEZ to Indio Coachella, is 131 mi (211 km) long, the second segment, from Indio Coachella to Palm Springs, is about 18 mi (29 km) long, the third segment from Palm Springs to Hernet–San Jacinto is 27 mi (43 km) long, the forth segment, from Hernet–San Jacinto to Riverside, is 27 mi (43 km) long, and the final segment, from Riverside to Los Angeles, is 59 mi (95 km) long.

Table 2 summarizes the distances to the various load areas over which new transmission lines would need to be constructed by leg, as well as the assumed number of substations that would be required. One substation is assumed to be installed at each load area and an additional one at the SEZ. Thus, the total number of substations per scheme is simply equal to the number of load areas associated with the scheme plus one. Substations at the load areas will consist of one or more step-down transformers, while the originating substation at the SEZ would be composed of several step-up transformers.

Table 3 shows the net present value (NPV) of the various transmission configurations and takes into account the cost of constructing the lines and the projected revenue stream over the 10-year horizon. A positive NPV indicates that revenue more than offsets investments. The estimated land use requirement for the various transmission configurations is presented in Table 4.

TABLE 2 Potential Transmission Schemes, Estimated Solar Markets, and Distances to Load Areas for the Brenda SEZ

DLT Transmission Scheme	City	Estimated MW for Solar Market[a] (based on population size)	Total Solar Market (MW)	Sequential Distance (mi)[b]	Total Distance (mi)	Line Voltage (MW)	Number of Substations
1	Phoenix	652	906	108	224	500	3
	Tucson	254		116			
2	Yuma	75	878	79	226	500	4
	El Centro	38		56			
	San Diego	765		91			
3	Las Vegas	467	467	188	188	500	2
4	Indio Coachella	26	2,934	131	262	500	6
	Palm Springs	22		18			
	Hernet–San Jacinto	65		27			
	Riverside	121		27			
	Los Angeles	2,699		59			

[a] The estimated MW for solar market in each city is based on the 2010 population; 20% of the total estimated MW value is assumed as the maximum solar market.

[b] To convert mi to km, multiply by 1.609.

3.2.1.1 Findings for DLT Analysis

The results of this preliminary test case DLT analysis indicate that the most economically attractive configuration (i.e., the configuration with the highest positive NPV) would be DLT Transmission Scheme 1, which treats Phoenix and Tucson as the primary markets. The second most economic option is DLT Transmission Scheme 2, which would primarily serve the San Diego Area. DLT Transmission Scheme 3, which identifies Las Vegas as the primary market, falls short of fully accommodating the maximum potential of the Brenda SEZ and thus appears as the least attractive configuration in terms of NPV. However, the Las Vegas transmission scheme has the smallest impact in terms of amount of land disturbance. The least favorable transmission configuration in terms of the amount of land disturbed and NPV is DLT Transmission Scheme 4, which would deliver solar power from the Brenda SEZ to Los Angeles.

3.2.1.2 Discussion and Qualifications for DLT Analysis

Although the DLT analyses may be useful in determining higher cost/higher impact estimates for the Solar PEIS, these analyses do have shortcomings. The assumption that new lines would run parallel to existing transmission lines, while appropriate in this programmatic

TABLE 3 Comparison of Potential Transmission Lines with Respect to Net Present Value

DLT Transmission Scheme	City	Present Value Transmission Line Cost (million $)[a]	Annual Sales Revenue (million $)[b]	Present Worth Revenue (million $)[c]	Net Present Value Revenue (million $)
1	Phoenix, Tucson	784	134.9	1,152	368
2	Yuma, El Centro, San Diego	791	134.9	1,152	361
3	Las Vegas	658	81.8	699	41
4	Indio Coachella, Palm Springs, Hernet–San Jacinto, Riverside, Los Angeles	917	134.9	1,152	235

[a] Assumes construction cost spike is at the beginning of year 1; assumes a transmission cost of $3.5 million/mile (source AEP [2010]; includes uniform estimate for ROW costs); and a discount rate of 3%. Note: actual ROW costs are likely to differ significantly by state and area.

[b] Assumes a revenue spike occurs at the end of each year; assumes a discount rate of 3%.

[c] Assumes a discount rate of 3%.

analysis, is somewhat restrictive. It disregards the authority of the franchised local utilities to decide on the configuration of distribution systems within their service territories. Under deregulation, transmission and distribution of power is still regulated and wire-operators are given authority to manage the distribution system. It would be impractical to have more than one wire-company operating the transmission and distribution system in the same service area. Running several lines by different owners over a corridor does not make economic sense, and that is why the competitive transmission segments are limited to wholesale bulk generation and large users only.

In addition, the approach ignores the systems approach, whereby common reserves and spares are shared within a system to maximize the use of available resources. Also, because the transmission lines are assumed to be dedicated to SEZ operation, their utilization factor over the planning horizon would remain essentially constant at about 20% or less (based on the estimated average capacity factor of solar facilities and the number of load areas connected with the designated line [capacity factors would be even lower for the more “downstream” load areas]), which is low and would not likely justify the huge investments required. It also holds the SEZ owners captive to being the only probable investor on the transmission lines. Because of fundamental limitations for the DLT analysis as discussed above, the transmission configurations resulting from this approach should be considered hypothetical.

TABLE 4 Comparison of the Various Transmission Line Configurations with Respect to Land Use Requirements

DLT Transmission Scheme	City	Total Distance (mi)[a]	Number of Substations	Land Use (mi^2)[b] Transmission Line[c]	Substation[d]	Total
1	Phoenix, Tucson	224	3	8.4848	0.0289	8.51
2	Yuma, El Centro, San Diego	226	4	8.5606	0.0289	8.59
3	Las Vegas	188	2	7.1212	0.0175	7.14
4	Indio Coachella, Palm Springs, Hernet–San Jacinto, Riverside, Los Angeles	262	6	9.9242	0.0289	9.95

[a] To convert mi to km, multiply by 1.609.

[b] To convert mi^2 to km, multiply by 2.590.

[c] Assumes a ROW width of 200 ft (61 m) for a 500-kV line.

[d] Assumes a generic land use requirement for substations of about 950 ft^2/MVA (290 m^2/MVA). The size of each substation per scheme varies but has a sum total capacity limit of 770 MW × 1.1 (or about 847 MVA, assuming 1 MW = 1.1 MVA).

3.2.2 Shared-Line Transmission Analysis

The SLT analysis provides a more detailed analysis of transmission requirements by assessing the available capacity on existing lines between the SEZ and the load areas and the need for new dedicated lines. This approach:

1. Takes into account the configuration and performance of the existing transmission system and explores the possibility of using the existing spare capacity (if there is any) to facilitate the conveyance of power from the SEZ to the prospective load areas;

2. Assumes a 500-kV tie-line would be constructed to connect the SEZ with existing nearby transmission line. New substation(s) would be added if needed, or modifications would be made to existing substation(s) when feasible;

3. Maximizes the utilization of common resources (e.g., spinning reserves and ancillary power reserves) within the context of a wider grid;

4. Accounts for the effects of future expansion plans of relevant utilities in the WECC region; and

5. Takes advantage of connectivity between load areas and recognizes cumulative solar-eligible demand requirements.

The SLT analysis makes use of AC load flow data (FERC 2011) to establish normal flow patterns (i.e., magnitude and direction of power flows) on existing high-voltage lines surrounding the SEZ. It then calculates the spare capacity of the existing high-voltage lines under summer peak load conditions for 2011, 2015, and 2020. For the 10-year planning horizon, electrical growth for the load areas is recognized, including its effects on the loading levels of the transmission lines. (Note: For final analysis, additional FERC Form 715 cases will be incorporated, such as for summer average conditions.)

Using this approach for the Brenda SEZ, only two transmission configurations emerged as favorable; other configurations are possible but are clearly not optimal relative to the top two configurations. The first transmission scheme analyzed Phoenix and San Diego as the primary markets; the second analyzed Los Angeles as the primary market. Tables 5 and 6 show the estimated spare capacity on existing lines for 2011, 2015, and 2020 for both of these transmission schemes. For both transmission schemes and all three years, the estimated spare capacity exceeds the 770 MW that could be generated from the proposed Brenda SEZ; thus, the analysis indicates enough spare capacity through 2020 to accommodate the SEZ outputs.

TABLE 5 Estimated Spare Capacity on Existing Lines from the Proposed Brenda SEZ to Phoenix and San Diego (SLT Transmission Scheme 1)[a]

		Spare MW[b]		
Transmission Line Start/End Locations	Transmission Line Description	2011	2015	2020
Devers to Palo Verde	1 circuit 500 kV	4,693	4,488	4,582
Palo Verde to Rudd	1 circuit 500 kV	1,322	1,795	1,270
Hassayam to N. Gila	1 circuit 500 kV	887	1,144	1,425

[a] Calculation of spare MW using sending angle and receiving angle is described at the end of Section 2.2.

[b] Spare capacity calculated for summer peak conditions. For SEZ flows in the opposite direction of existing flows, “spare” capacity equals the thermal limit of the line plus the magnitude of existing flows. For SEZ flows in the same direction as existing flows, “spare” equals thermal limit minus the magnitude of existing flows.

TABLE 6 Estimated Spare Capacity on Existing Lines from the Proposed Brenda SEZ to the Los Angeles Area (SLT Transmission Scheme 2)[a]

Transmission Line Start/End Locations	Transmission Line Description	Spare MW		
		2011	2015	2020
Palo Verde to Devers	1 circuit 500 kV[b]	1,637	NA[c]	NA
Devers to ValleySC	1 circuit 500 kV	1,615	NA	NA
Palo Verde to Colorado River	1 circuit 500 kV	NA	1,158	958
Colorado River to Devers	2 circuit 500 kV	NA	5,738	5,636
Devers to ValleySC	2 circuit 500 kV	NA	4,001	3,482
ValleySC to Serrano	1 circuit 500 kV	2,434	1,979	2,532

[a] Calculation of spare MW using sending angle and receiving angle is described at the end of Section 2.2.

[b] Conflicting sources: double circuit per POWERmap (Platts 2011); single circuit per WECC diagram for year 2011.

[c] NA = not applicable.

All of the SLT analysis cases assume that a new 500-kV tie-line would be needed to connect the Brenda SEZ with the nearest existing 500-kV transmission line and would be connected at the existing Salome substation. Some augmentation of the Salome substation would be needed to add switching equipment and make room for the new incoming line. But no additional transformers would be anticipated provided that the SEZ site includes transformer equipment to deliver power at a voltage of 500 kV.

3.2.2.1 SLT Transmission Scheme 1[5]

SLT Transmission Scheme 1 identifies Phoenix and San Diego as its primary markets. The magnitude and direction of normal power flow through the 500-kV line from the Brenda SEZ to Phoenix is shown in Figure 2. It also shows the magnitude and direction of normal flows from the Palo Verde Nuclear Generating Station in Arizona to San Diego. As shown in Figure 2, the normal direction (Peak Summer 2011 case from FERC Form 715) is away from the Palo Verde station toward Los Angeles and toward San Diego. The amount of spare capacity in the direction from the Brenda SEZ to Phoenix is depicted in Figure 3. Spare capacity is derived by comparing the normal peak flow with published line capacity limits (based on FERC Form 715

[5] Transmission schemes (1–2) for SLT are different from transmission schemes (1–2) for DLT.

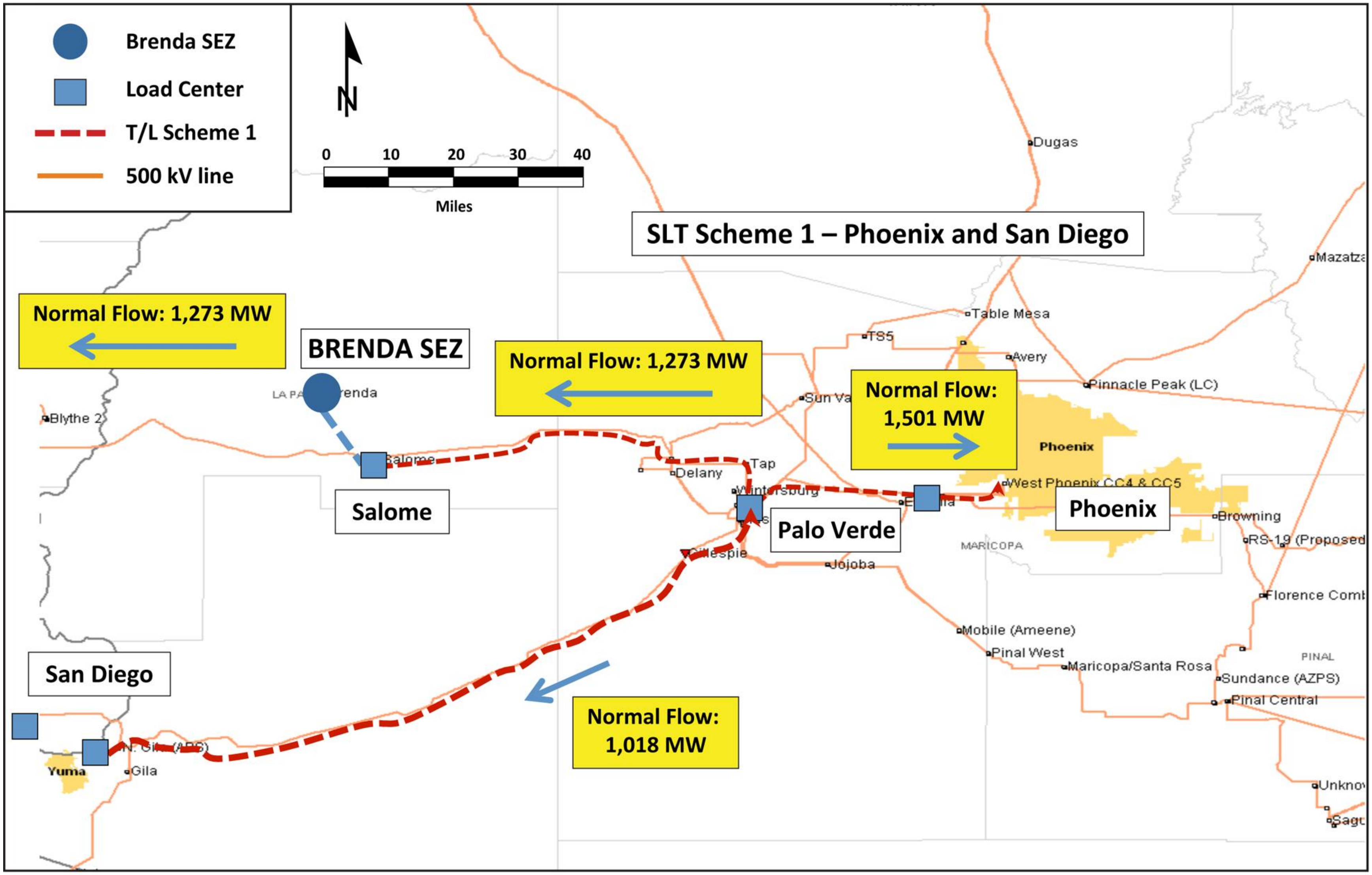

FIGURE 2 Magnitude and Direction of Normal Peak Power Flow through the 500-kV Lines Joining the Brenda SEZ, Phoenix, and San Diego (Source: Derived from 2011 FERC Form 715—Peak Summer Case)

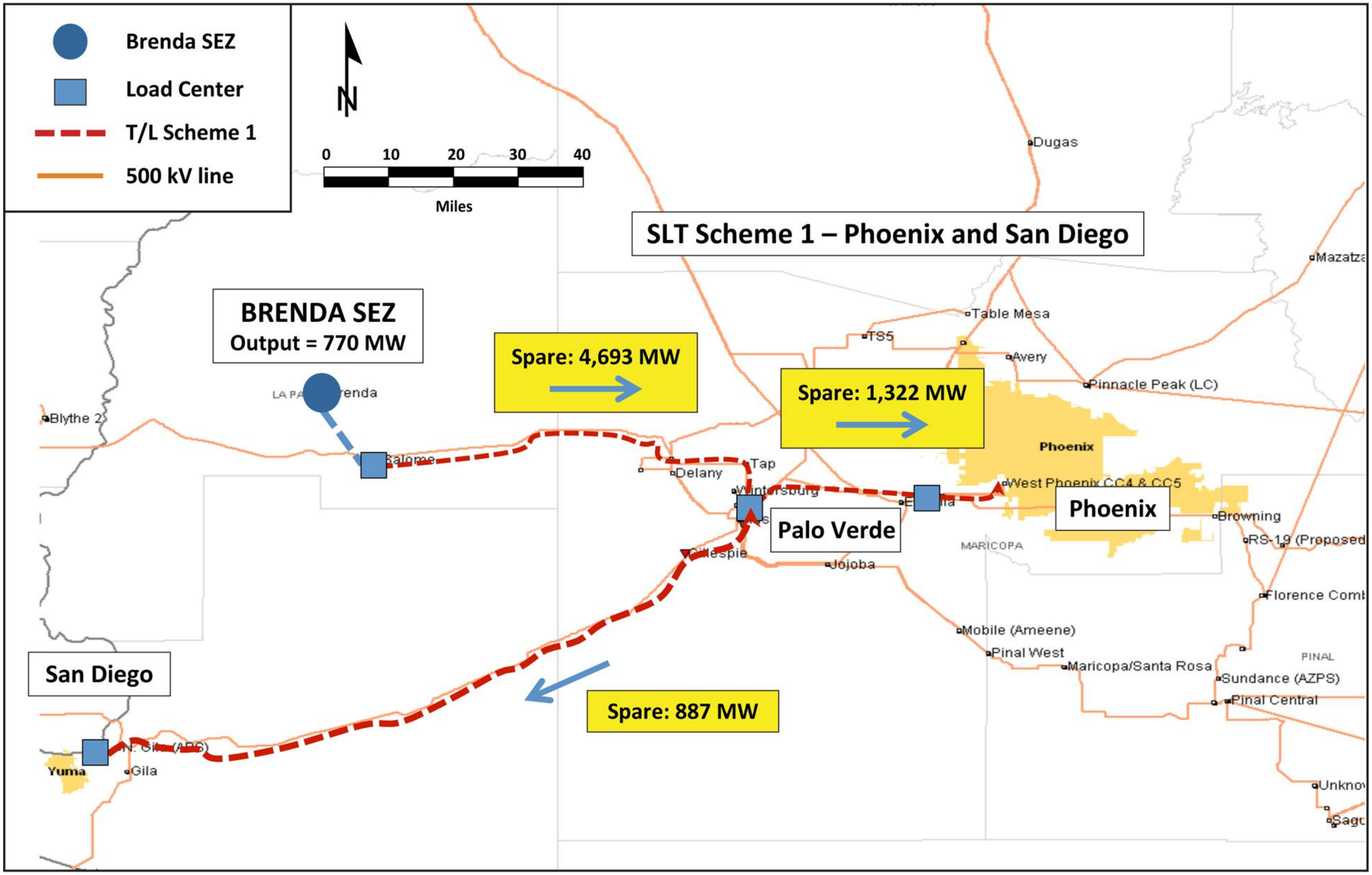

FIGURE 3 Amount of Apparent Spare Capacity for Transmitting Power from the Brenda SEZ to Phoenix and San Diego along the Existing 500-kV Transmission Lines

data). Note that the spare capacity is greater than the maximum output of the Brenda SEZ of 770 MW. (Follow-up qualifications are discussed in Section 3.2.2.3.)

SLT Transmission Scheme 1 could also extend deliveries to San Diego since there appears to be spare capacity along the Palo Verde-to-San Diego 500-kV line. This could increase the market size and diversity for power generated at the Brenda SEZ and could be examined for tradeoffs among potential benefits, costs, and impacts. However, this test case did not include an analysis of that extended option.

3.2.2.2 SLT Transmission Scheme 2

SLT Transmission Scheme 2 identifies Los Angeles as the primary market. The magnitude and direction of normal power flow through the 500-kV line from the Brenda SEZ to Los Angeles is shown in Figure 4. As shown in Figure 4, the normal direction (Peak Summer 2011 case from FERC Form 715) is toward Los Angeles (confirming well-known load flow patterns for this major load area). The amount of spare capacity in the direction from the Brenda SEZ to Los Angeles is depicted in Figure 5. As noted above for SLT Transmission Scheme 1, spare capacity is derived by comparing the derived normal peak flow with published line capacity limits (based on FERC Form 715 data). Note that the spare capacity is greater than the maximum output of the Brenda SEZ of 770 MW. (Follow-up qualifications are discussed in Section 3.2.2.3.)

3.2.2.3 Findings for SLT Analysis

An important finding from the SLT analysis is that there appears to be spare capacity available in the existing 500-kV network linking the proposed Brenda SEZ to major load areas and potential solar energy markets. The 10-year projection of the loading levels for existing and planned 500-kV transmission lines also predicts the availability of spare capacity to accommodate the SEZ output for the study years 2015 and 2020.

Both SLT Transmission Schemes 1 and 2 appear to present viable options for delivering solar-generated electricity from the Brenda SEZ to alternate sets of load areas, with practically the same cost (the cost to construct the tie-line from the Brenda SEZ substation to the Salome Substation and to augment the Salome station). However, SLT Transmission Scheme 2 (Los Angles market) may offer economic advantages by virtue of the larger size of the market (i.e., 2,699 MW versus 1,528 MW). Thus, SLT Transmission Scheme 2 might show a slightly better estimated revenue stream compared to SLT Transmission Scheme 1. Thus if a bilateral agreement could be made between operators in the Brenda SEZ and Los Angeles, this configuration could represent a more favorable arrangement. On the other hand, normal peak flows are heaviest in the direction of Los Angeles from the Brenda SEZ; thus from the perspective of competition for excess capacity, sending power in the direction of Phoenix might encounter less competition for available line capacity.

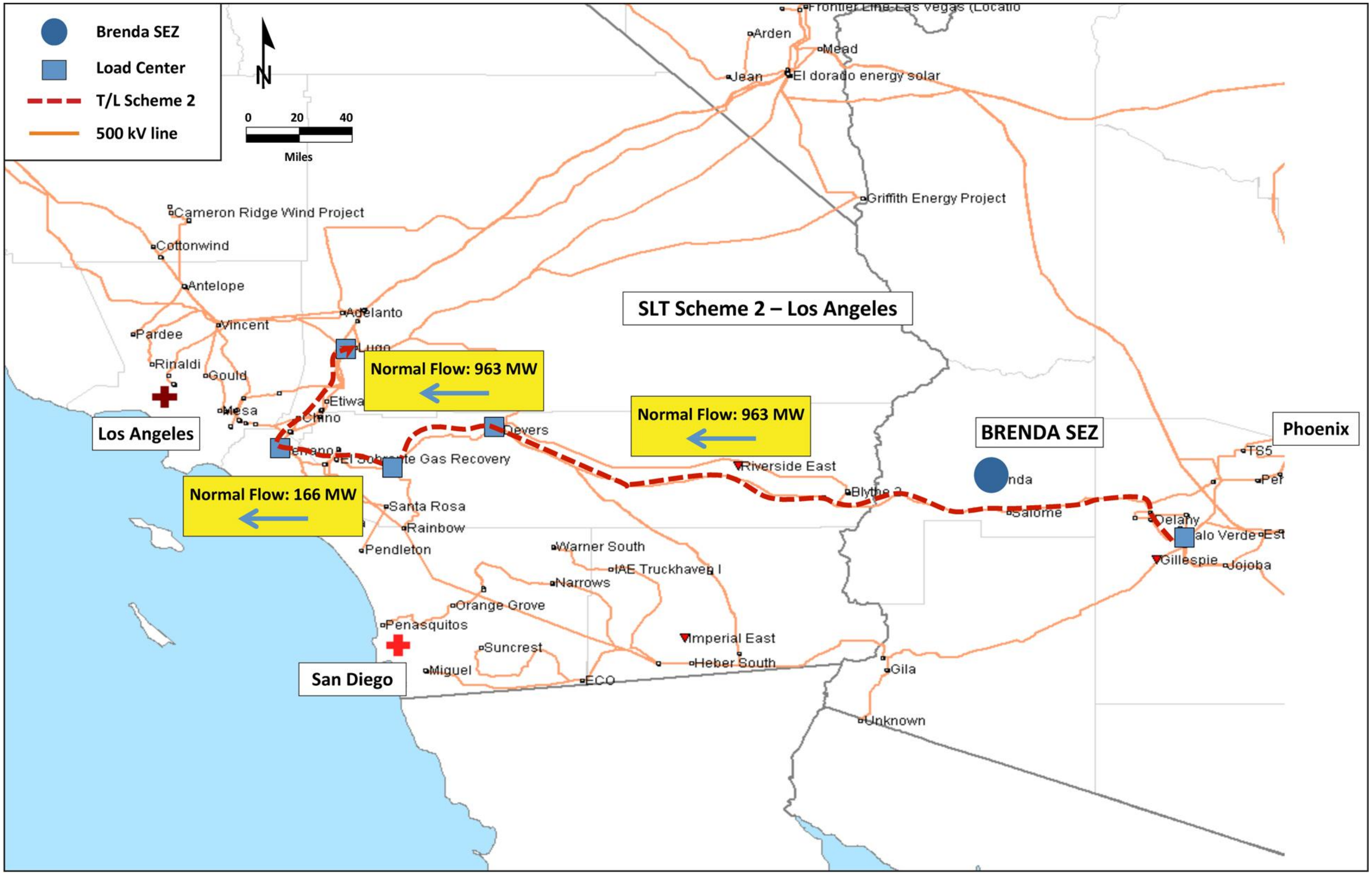

FIGURE 4 Magnitude and Direction of Normal Peak Power Flow along the 500-kV Line Joining the Palo Verde and Los Angeles Areas for 2011 (Source: Derived from 2011 FERC 715—Peak Summer Case)

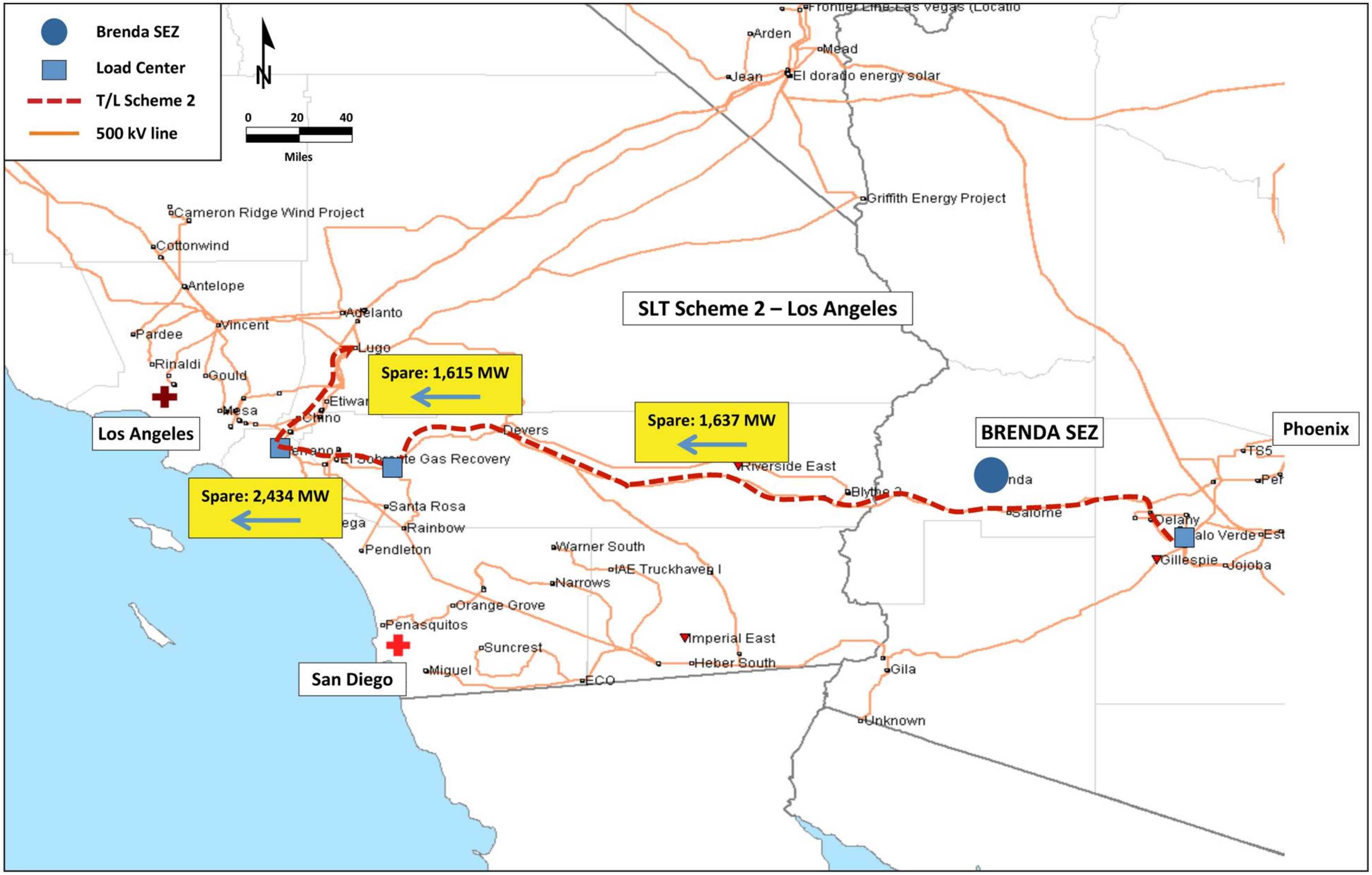

FIGURE 5 Amount of Apparent Spare Transmission Line Capacity along the 500-kV Line Joining the Palo Verde and Los Angeles Areas for 2011

It is worth noting that both SLT Transmission Schemes 1 and 2 could be merged and thus serve both Phoenix and Los Angeles because they share a common connection point—the Salome Substation. Power can flow in either direction once the connection is made from the Brenda SEZ substation to the Salome Substation. If a bilateral agreement could be made so that both Los Angeles and Phoenix become firm long-term clients, then this arrangement represents the most favorable option.

3.2.2.4 Discussion and Qualifications for SLT Analysis

One limitation of this analysis is that it does not investigate potential queues of customers who might be waiting to occupy excess transmission capacity.[6] Nonetheless, this finding of potential spare capacity indicates that the transmission investment cost for this SEZ could be minimal, limited to the cost of constructing the 10-mi (16-km) tie-line to existing transmission. This cost is estimated at about $35 million, assuming a cost of $3.5 million per mile. This finding needs to be confirmed through further peer review with transmission planning agencies, particularly the WECC.

In addition, the SLT approach makes use of thermal limits for establishing the line capacities, and conditions in the western states cause voltage stability to often be an overriding limitation. This issue will be examined in greater detail during final implementation, and adjustments will likely be made to the line limit treatments. On the other hand, an offsetting factor is that the study adopted peak load AC load flow cases (e.g., 2011, 2015, and 2020 FERC Form 715 Peak Summer Cases) for analysis. And, therefore, the results reflect higher than average line flows and lower than average estimated spare capacity for the lines. Because peak loads only occur for small fractions of time during a year, the average line flows would be significantly lower than peak, and the available line capacities would therefore be higher than estimated in this initial test case.

Numerous publications and data resources have been identified to further address these issues (as noted, for example, in Sections 1 and 2), and the assumptions will be examined, adjusted, and submitted for review during the course of the extended transmission analysis.

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6 Other technical considerations also affect the estimates of spare capacity but are generally beyond the scope of this study to explicitly address. Ultimately, comprehensive load flow simulations would be needed to confirm estimates, such as those made in this abbreviated analysis, and to explicitly address consideration of issues such as voltage stability, multiple-line pathway capabilities, and complex grid dynamics. For shorter-length transmission segments, as examined in the initial test case, the approach of using thermal limits minus base flows is expected to provide reasonable approximations that can serve as relative indicators compared with upper bound estimates from the DLT analysis. While the SLT analysis will not be able to address all of the complexities, for the Final Solar PEIS analyses, efforts will be made to incorporate adjustment factors for specific considerations (e.g., longer line segments, average versus peak conditions, and estimates for line limits) where possible.

4 SUMMARY AND CONCLUSIONS

This work has examined the various transmission options for the Brenda SEZ given the probable load areas around it. The major findings of the study may be summarized as follows:

1. In the context of the DLT analysis and a basic assumption that all transmission needs would be met with new construction (both lines and substations), the transmission configuration that treats Phoenix and Tucson as the primary load areas appears as the favored option based on NPV and land use requirements. The configuration would require a 500-kV single-circuit, bundle-of-two-conductor system traversing a total distance of 224 mi (360 km), and at least three major substations, including one at the SEZ.

   On the basis of the DLT analysis, the least favorable transmission configuration is the one that identifies Los Angeles as the primary load area. This configuration resulted in the highest land use requirements and second-lowest NPV. In one sense, this option could be used as an upper bound for environmental impacts associated with transmission development to support the Brenda SEZ, but it also represents an option that probably would not be selected because better alternatives exist.

2. In the context of the SLT analysis, the configuration identifying Los Angeles as the primary market appears somewhat more attractive than the one identifying Phoenix and San Diego (smaller market). The configuration requires very little investment (about $35 million), which includes only the construction of a 10-mi (16-km) tie-line from the SEZ plant to the connection point at Salome Substation. A combination of options, connecting the Brenda SEZ with both Los Angeles and Phoenix–Tucson load areas appears to offer even greater advantages, with little incremental cost. In this case, bilateral arrangements would appear to play an important role in feasibility of the option.

3. Overall, the configurations identified in the SLT analysis present very favorable options for transmission development in terms of cost, practicality of implementation (i.e., considering the authority of distribution and transmission line utilities to govern their monopolized service franchise areas), and overall synergistic effects.

4. Existing and projected loading levels of high-voltage transmission lines linking the SEZ to its possible load areas will be further investigated to confirm the finding that capacity exists to accommodate the estimated SEZ MW output.

5. Alternate load conditions (other than summer peak) will be investigated in order to make more definitive observations and conclusions about the magnitude and frequency of available line capacity as used in the SLT analysis.

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