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Intended for:
Secretary Jim Noel, Cabinet Secretary EMNRD
NM Renewable Energy Transmission Authority
Board of Directors

October 18, 2010

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Date: October 6, 2010
Refer To: LA-UR-10-6319

NMRETA Board of Directors
c/o Jeremy Turner, Executive Director
NM Renewable Energy Transmission Authority
1516 Paseo de Peralta
Santa Fe, NM 87501

NMRETA Board of Directors:

Los Alamos National Laboratory (LANL) is pleased to issue for your consideration the attached report titled "New Mexico Renewable Development Feasibility Study". This report satisfies key deliverable requirements for contract FIA-10-025 which are intended to provide an evaluation of:

- Developable renewable energy capacity
- Total revenue needed to support this level of development
- Validation of transmission feasibility

Our report outlines findings related to two transmission Collector designs, Plan 1 and Plan 2. Key findings include: (1) Total developable renewable capacity by 2030 equals or exceeds 5,200 Megawatts; (2) To support this level of development, New Mexico's transmission Collector will cost up to $1,344.5 million, accrue tax revenues of $67 to $79 million and create up to 24,800 temporary and permanent jobs by 2030; and (3) Both Collector plans are technically feasible designs, based on AC power flow analysis.

Through this effort, an initial milestone in New Mexico's multi-year, statewide transmission upgrade program has been met. As discussed in Section 6 of our report, completion of three technical tasks will be key to the success of the upgrade program: a top-level screening of transmission alternatives (substantially accomplished by our report), a second more detailed grid analysis based on localized demand and generation forecasts and third, a final evaluation of grid operational issues prior to actual construction. New Mexico's upgrade program will certainly span multiple Administrations, given lead times required to design and install the necessary transmission corridors, high voltage transformers and substations etc. In addition, a decision must be made to implement an appropriate method for Collector cost recovery consistent with public policy requirements of various government entities.

Although each Collector plan meets the minimum threshold for feasibility, more analysis must be accomplished to insure New Mexico's grid can simultaneously serve future load growth, accelerate the development of renewables and maintain reliable electric service. In our role as an independent assessor of technical solutions, LANL offers its institutional support for ongoing refinement of New Mexico's statewide transmission Collector plan. We are prepared to meet with Transmission Task Force members to insure that the conclusions reported by this study provide value-added information for their important mission. We are also prepared to engage in a joint effort among state agency stakeholders and utility service providers as the Collector plan undergoes more detailed review. Finally, we are prepared to offer the unique planning tools and expertise which was applied to this study as a go-to resource for New Mexico's agencies, municipalities and utilities to evaluate future scenarios of common interest.

Please contact either of us, with questions or comments related to this study.

Regards,

G Loren Toole	Mary Ewers
Senior R&D Engineer	*Senior Economist*
Glt:ru	

cc: Dasari Venkateswara Rao, D-DO
Duncan McBranch, PAD-STE

1 Executive Summary

As a center for renewable energy development, New Mexico offers outstanding wind, geothermal and solar resources[1]. Today, fossil-fueled power (coal and gas) and nuclear power serves the State through transmission lines which interconnect to the Four Corners region. This situation presents challenges for renewable energy project developers that desire to export large amounts of renewable power given limited transmission capacity, flow bottlenecks and long interconnection paths. Upgrading New Mexico's existing grid offers substantial opportunities and serves as the key motivation for this report[2].

In collaboration with the New Mexico Renewable Energy Transmission Authority (RETA), Los Alamos National Laboratory (LANL) analyzed a variety of possible transmission upgrades over the next 20 years in order to export power generated by 5,200 Megawatts (MW) of renewable capacity. Two renewable energy development plans (or Collectors) were analyzed by applying LANL's independent technical judgement, tools and expertise[3]. Findings presented in this report ***do not indicate LANL's advocacy for any Collector technical features.***

Both plans identify opportunities to invest in grid upgrades and to create substantial economic development. They are intended to serve as examples of different design approaches: a looped transmission design identified by RETA (Collector Plan 1) which consists of upgrades to 345-kilovolt (kV) lines, shunts and transformers; design goals are discussed on page 18. A radial transmission design identified by LANL (Collector Plan 2) consists of upgrades to 115-, 230-, and 345-kV lines, shunts and transformers; design goals are discussed on page 14. Each plan is built-out over 5, 10 and 20 year time horizons through a phased series of transmission upgrades. Both plans are judged to be technically feasible designs which can potentially create immediate economic opportunities for New Mexico.

Economic findings focus on the direct, indirect and induced jobs created by the construction and operation of the 5, 10, and 20 year Collectors ***and*** the operation of 5,200 MW of new renewable energy projects. Renewable jobs are derived from production of renewable energy which also creates in-state and out-of-state energy sales. "Jobs" are defined in terms of "FTE- years" i.e. one "job" is one FTE for one year. In order to estimate the average number of annual jobs for the 20 year (2030) collector system, take the total FTE-years in 2030 and divide by 20. For Collector Plan 1, the average number of annual jobs created is 1,240; for Collector Plan 2, the average number of annual jobs created is 1,050.

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[1] See for example page 23, "Renewable Energy Generation Summary" contained in the report Western Renewable Energy Zones- Phase I Report, Western Governor's Association/US Dept. of Energy June 2008. The WREZ analysis indicates New Mexico's developable renewable capacity exceeds 27,000 MW.

[2] This report is intended to serve as an assessment of feasibility, mainly as an early-phase planning document. It is not intended to serve as the basis for detailed project design. Further analysis will be needed to define a statewide Collector configuration which meets requirements of all users. Section 6 outlines additional analysis tasks that must be completed to ensure the chosen renewable development plan is consistent with local planning forecasts and standards.

[3] Since the early 1990s, LANL has applied electric grid models and simulation software to problems of national and regional significance. This effort continues with a variety of other projects funded by the Department of Energy (DOE), other federal and state agencies and private companies.

Key conclusions, factors of importance, and sections referenced for further reading are outlined in Table 1. See Glossary listing for a definition of technical terms, acronyms and units of measurement.

Table 1. Key Study Conclusions

Feature	Collector Plan 1	Collector Plan 2	Details
Total renewable energy development potential (megawatts [MW])	Nameplate 5,200 MW; Injected 2,790 MW; Four Corners hub export 1,302 MW by 2030	Nameplate 5,200 MW; Injected 2,790 MW; Four Corners hub export 1,137 MW by 2030	Table 2, page 11; Table 8, page 26
Total line miles of transmission corridor developed over 10- and 20-year horizons	By 2015: 297 miles By 2020: 603 miles By 2030: 841 miles	By 2015: 382 miles By 2020: 633 miles By 2030: 849 miles	Tables 3/4, pages 19,20; Tables 5/6, pages 23,24
Total cost of installed transmission corridor upgrades over 20-year horizon.	$1,344,522,280; Annual bond cost is approximately $152,158,400	$1,032,679,080; Annual bond cost is approximately $116,867,300	Tables 4/6, pages 20,24; Table 9, page 30
Renewable energy sales at 20-year horizon (gigawatt-hours [GWh])	Exported: 5,800 GWh; In-state: 4,950 GWh; Cumulative export by 2030: 67,200 GWh	Exported: 4,500 GWh; In-state: 6,250 GWh; Cumulative export by 2030: 45,900 GWh	Appendix A; Table 10, page 31
Total jobs created (temporary and permanent); Gross State Product [GSP] gain for New Mexico's economy	Total jobs created: 24,800; Temporary: 9,900; Permanent:14,900; Cumulative GSP Gain by 2030: $3,311,292,900	Total jobs created: 21,000; Temporary: 8,400; Permanent:12,600; Cumulative GSP Gain by 2030: $2,803,147,500	Tables 9/10/11, pages 30,31; Table 15, page 34
Electricity assessment incurred by each Collector system (dollars per month), 100% recovery at 20-year horizon	Residential: $3.76 per month Commercial: $32.68 per month Industrial: $595.51 per month	Residential: $2.89 per month Commercial: $25.14 per month Industrial: $458.17 per month	Table13, page 33
Tax revenue accrued from each Collector system	By 2015: $22,397,900 By 2020: $46,331,700 By 2030: $78,566,700	By 2015: $20,600,400 By 2020: $35,873,100 By 2030: $66,994,900	Tables 9/10, pages 30,31

Collector Plan 1 will require an investment of $312 million more than Plan 2, and it will create approximately 3,800 additional jobs over 20 years (on average, 190 additional jobs per year). Additional benefits can realized by wheeling of bulk energy sales in-state or as export. Also related to energy sales, a fraction of costs related to the production of renewable energy are likely to be retained in New Mexico and therefore create benefits to the economy. Collector Plan 1 exports 67,200 Gigawatt-hours (GWh) of energy by 2030 at Four Corners hub, generating $804 million of wheeling and operations & maintenance (O&M) costs over 20 years. Collector Plan 2 exports 45,900 GWh, generating $786 million of costs by 2030. Tax revenue generated from each plan is approximately $4 million per year, or a total of $67 to $79 million by 2030. The value of energy sales to New Mexico's economy is not included in this analysis.

Gross State Product (GSP) gain divided by Collector construction cost represents an approximate gauge of state-level rate of return on investments. The rationale for this measure is that it measures relative impacts within all of New Mexico's economic sectors. Using this formulation, the annual compound rate of return for Collector Plan 1 is estimated to equal approximately 12.3% through 2030; the annual compound rate of return for Collector Plan 2 is estimated to equal approximately 13.6% through 2030.

A decision must be made to implement an appropriate method for Collector cost recovery consistent with public policy requirements of various government entities. This study analyzed one cost recovery method, however these findings ***do not indicate LANL's advocacy for a specific cost recovery method.***

Each Collector plan meets the minimum threshold for feasibility, however more analysis must be accomplished to insure New Mexico's grid can simultaneously serve future load growth, accelerate the development of renewables and maintain reliable electric service. This report and its findings represent "Phase 1" of three phases envisioned to develop refined Collector proposals. As "next steps", Phases 2 and 3 are described in Section 6. Phase 2 of this study process would additionally evaluate the best combined features from both plans if several large regional transmission initiatives (i.e. SunZia, Tres Amigas, Santa Fe Clean Line, High Plains Express and Southline) are added to interconnect other states, control areas or load centers.

Note: Box sidebars appear in various sections of this report to provide background for a non-technical reader. This information is intended to supplement content in the main body of the report by explaning planning concepts, offering cautions or different perspectives on study approaches that may need further consideration.

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Table of Contents

2 Introduction

Since the early 1990s, Los Alamos National Laboratory (LANL) has applied electric grid models and simulation software to problems of national significance. This effort continues with a variety of projects funded by the Department of Energy (DOE), other federal and state agencies and private companies. Critical to the success of these programs is the ability to integrate regional and state-scale models of the electric grid, to assess the propagation of impacts to the grid, and to present, interactively, the effect of potential mitigations required to stabilize an impacted grid. On the basis of these capabilities, this report is intended to meet the following study objectives:

- Develop an AC-power-flow model, using commercial tools accepted by the utility industry, to represent future conditions within New Mexico's electric grid.
- Conduct a screening analysis of options for accelerating potential renewable energy development through the addition of a statewide transmission Collector system on a 5, 10 and 20 year time horizon
- Evaluate total revenue needed, jobs created (temporary, permanent), plus indirect and direct impacts to the state's economy.
- Evaluate a potential cost allocation methodology.
- Issue a project report that will provide information for policy direction by state regulators, project developers, and legislators.

The study team included LANL staff (co-investigators G. Loren Toole and Mary Ewers; analysts Russell Bent, Marvin Salazar, Mark Hinrichs, Kunal Verma; government liaison Richard Ulibarri) and RETA staff (Jeremy Turner, Angela Gonzales). LANL served as technical project lead throughout the study, conducting analysis in an independent manner consistent with scientific standards of research employed at the Laboratory. RETA served as the primary source for renewable project data, provided administrative oversight of project milestones and critiques of interim study results.

The following supplemental sections are attached to this report:

- Glossary- technical terms, acronyms and units of measurement.
- Appendix A- Renewable Capacity Additions
- Appendix B- WECC Planning Cost Assumptions
- Appendix C- Collector Analysis Methods Used in this Study

See Glossary listing for a definition of technical terms, acronyms and units of measurement. Appendices A, B and C provide background information that is relevant to topics discussed in Sections 3, 4 and 5. Section 6 outlines additional analysis that must be completed to ensure New Mexico's renewable development plan is consistent with planning forecasts and standards.

3 Grid Analysis Assumptions and Methodology

3.1 Creating New Mexico's 2030 Grid Model

The Western Electricity Coordinating Council (WECC) regional AC power-flow model applied to this study contains more than 30,000 components (including 20,000 transmission lines; 6,500 transformers; 1,300 shunts). Since the model was originally created for the purpose of analyzing an alternate renewable energy development scenario[4], adjustments were required to ensure demand and supply conditions conform to WECC projections.

AC power-flow models are used to simulate conditions within the grid, including normal voltages and currents plus off-normal operation.

Specific model adjustments are outlined in Section 3.2. After adjustments were applied, the power-flow model was reduced to a four state area (including New Mexico, Arizona, Colorado and Utah).

An automated transmission expansion tool (***TRANS-EX***) was then applied to the reduced model. It is designed to reinforce the grid on a circuit-by-circuit basis, given line overloads and voltage excursions. Reducing grid "impedance" or resistance to flow is a key outcome which increases power transfer capability. The model building process iteratively reinforced circuits as needed with the automated tool. Two types of elements were added to increase grid transmission capacity:

- ***Line branches***: multi-conductor lines or dual circuits, transformers
- ***Line shunts***: capacitors, inductors

Line branch elements include additions of new (dual circuit) lines within existing corridors, up-rating existing conductors or conductor bundling and adding substation transformers, notably auto-wound units. The net effect of these additions was to provide higher capacity meshed flow paths for power flowing throughout the grid. Line shunt elements include additions of passive devices (capacitors or inductors) and active devices (SVCs, phase-shifters, power stabilizers, synchro-phasers).

A more detailed description of the study methodology applied in this study is provided in Appendix C.

[4] The regional wind integration scenario outlined in "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to the U.S. Electricity Supply," DOE/GO-102008-2567, May 2008.

3.2 Demand, Conventional Generation, Transmission Capacity

The following planning assumptions[5] were used to adapt LANL's AC power-flow model to serve as the basis for this study.

Significant uncertainty is associated with planning projections; the grid must be designed to accommodate a range of demand/supply scenarios.

All assumptions were applied uniformly to WECC's Reporting Areas . New Mexico's Reporting Area is designated as "AZ/NM/SNV" including Arizona, New Mexico and southern Nevada.

Section 3.2 outlines planning assumptions for conventional generation, demand and transmission capacity; Section 3.3 outlines planning assumptions for renewable (non-conventional) generation.

Demand

- All projections are specified for WECC Reporting Areas (NWPP, RMPA, AZ/NM/SNV, and CA/MX).
- WECC projected summer demand in 2030 is approximately 225,400 Megawatts [MW]. The assumed average-peak-growth-rate per year is 1.46% (2010 to 2030).
- WECC model's loads demand to be scaled, remove 9,900 MW from CA/MX; add 8,500 MW to NWPP; add 1,400 MW to AZ/NM/SNV.
- All load changes will be distributed in reporting areas in proportion to substation demand.
- Scaled 2030 load demand in New Mexico equals 5,700 MW.

Conventional Generation

- All projections to be based on WECC's projected location of conventional generation for 2017 FERC 715 High Summer filing, projected to 2030 nameplate capacities.
- Projected generating capacity in 2030 is approximately 261,300 MW; 16.7% generation reserve exists at summer peak in 2030.
- WECC model generation to be scaled, remove 23,000 MW AZ/NM/SNV; add 13,700 MW to CA/MX; add 5,000 MW to NWPP; add 4,200 MW to RMPA.
- All generation changes will be distributed in Reporting Areas in proportion to generator nameplate capacity.
- Scaled 2030 conventional generation in New Mexico equals 6,600 MW.

[5] Assumptions were mainly derived from WECC's Information Summary dated November, 2008; also see 2010 TEPPC Study Program (WECC), dated April 2010, for other information related to regional transmission projects.

Transmission Capacity

- All projections to be based on estimated planning costs for new transmission capacity for the Western Renewable Energy Zone (WREZ) study.[6]
- New corridor transmission line costs are estimated by voltage level on a per-mile basis including right-of-way costs: 115 kV, $750K/Mile; 230 kV, $1,389K/Mile; 345 kV, $2,038K/Mile.
- Existing transmission corridor (uprate) costs are estimated to equal approximately 66% of new corridor cost by voltage level on a per-mile basis.
- New corridors are assumed to be constructed as single-circuit, based on rated line capacities by voltage level[7]: 115 kV, 200 MW; 230 kV, 400 MW; 345 kV, 750 MW; 500 kV, 1,500 MW.
- Existing corridors (uprates) are assumed to be reconstructed as double-circuit, increasing rated line capacity by a factor of 2.
- Primary transformer costs are estimated on a per-MVA basis: $35,000/MVA for 230, 345, 500 kV upgrades.
- Primary shunt costs are estimated on a per-MVAr basis including both capacitive and inductive reactors: $33,000/MVAr for 230, 345, 500 kV upgrades.

[6] WREZ Transmission Characteristics Sub-Group Update, December 8, 2008, Memo from B. Pascoe. This study was sponsored by the Western Governor's Association, see http://www.westgov.org/wga/publicat/WREZ09.pdf.

[7] Actual line capacities will depend on corridor terminations and may differ from rated capacities.

3.3 Non-Conventional Generation

Data tabulated in Appendix A outline the respective winter/summer allocations of non-conventional generating (renewable) capacity assumed for this study.[8]

Figure 1 displays the location of nine renewable development zones assumed in this study.

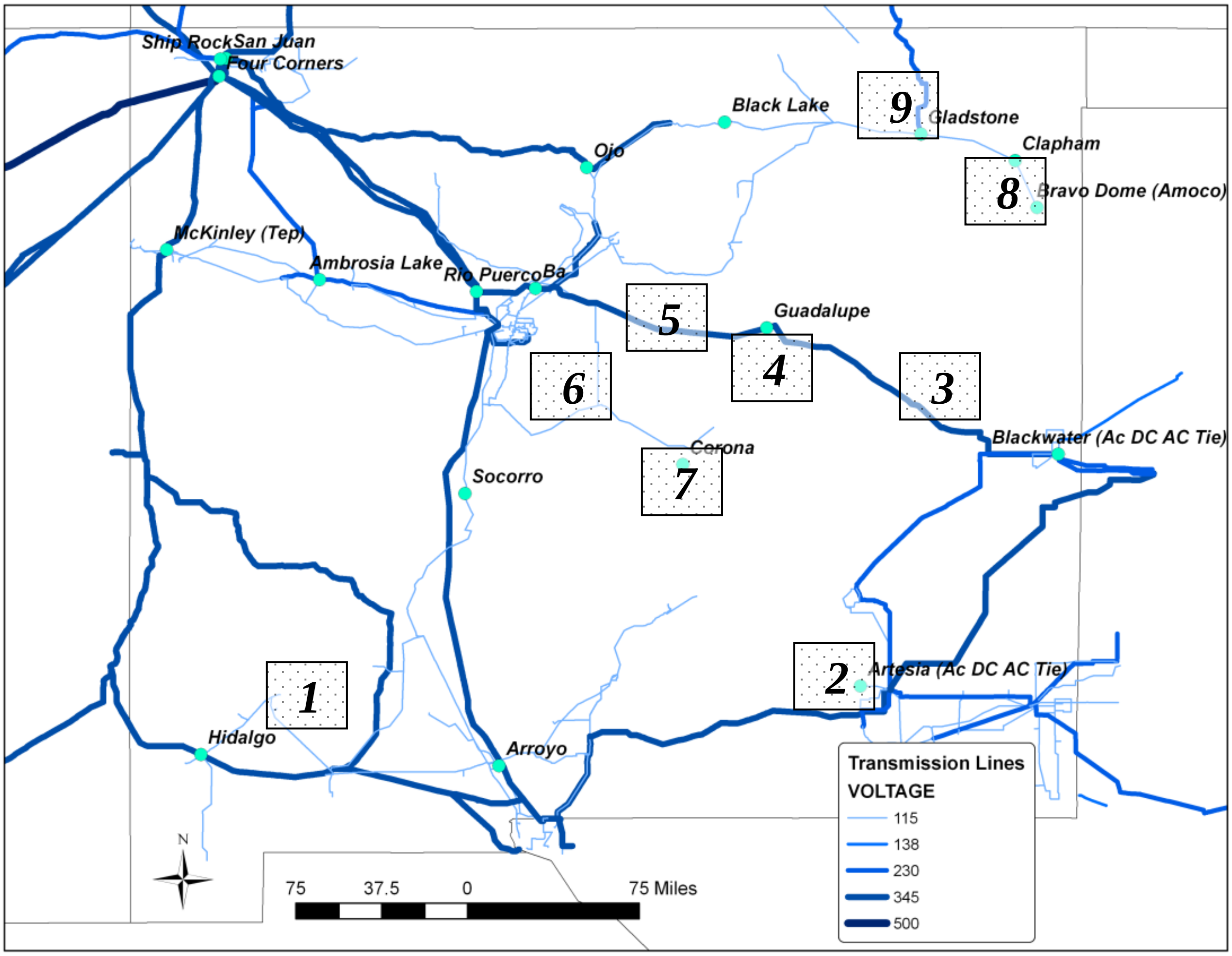

Figure 1. New Mexico's Renewable Development Zones

Key zones for renewable development include Luna (1), Artesia (2), Corona-Williard-Guadalupe-Santa Rosa (3–7), and Clapham-Springer (8–9).

Study assumptions related to timing of project development and generator nameplate capacities were provided by RETA, based on Large Generator Interconnection Procedure (LGIP) requests and other planning data. In evaluation of LGIPs for PNM's service area, RETA determined that approximately 91% requested interconnection of wind farms while only 9% requested

[8] Renewable capacity allocation factors are based on assumptions cited in footnote (4).

interconnection for solar. RETA also evaluated potential renewable energy zones within the state, the location of LGIP requests[9] and other information related to current efforts for 5-, 10- and 20-year project planning. This study, therefore, assumes a majority of future generation will be developed from wind resources. If a larger fraction of generation is developed as solar versus wind, a different pattern of variable power injection is likely, however, both are variable resources and not base load power. Additional studies will need to be completed as part of the regional effort with incumbent utilities to ensure continued grid operation and reliability. Phase 2 of this study process would additionally evaluate the best combined features from both plans if several large regional transmission initiatives are added to interconnect other states, control areas or load centers. This approach could potentially reduce the effect of highly-correlated output variability of renewable generators in New Mexico[10].

Table 2 summarizes renewable capacity additions modeled in this study for 5, 10, and 20-year horizons.

Table 2. Capacity Additions for Nine Development Zones

Zone	Collector	Tie-In	Capacity MW	Wind Region	Capacity Factor[11]	Injected MW	Resource
1	South and West	Luna	180	90	0.90	150	Solar
2	South and West	Artesia	130	93	0.90	110	Solar
3	Central	Lonesome	610	91	0.53	300	Wind
4	Central	Guadalupe	790	93	0.59	440	Wind
5	Central	Blackwater	880	91	0.53	430	Wind
6	Central	Williard	220	92	0.52	110	Wind
7	Central	Corona	1,290	91	0.53	640	Wind
8	North and East	Clapham	600	93	0.59	330	Wind
9	North and East	Springer	500	93	0.59	280	Wind
		Subtotal	**5,200**	**-**	**-**	**2,790**	**-**

Table 2 provides information on resource type, transmission tie-ins for each zone, renewable capacity, and injected power. Injected power was calculated by applying a generating capacity factor as an adjustment to "Capacity MW" (see Appendix A). This adjustment accounts for spatial diversity of resources, unit reliability, and seasonal variations. A total of 5,200 MW can potentially be developed with over 90% of capacity resourced from wind farms.

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[9] No changes are assumed for technology upgrades , either replacement or enhancement. This study assumes current wind and solar technologies will be utilized for New Mexico renewable development zones through 2030.

[10] Output variability can be attributed to two effects: weather-driven short-term changes in wind or solar resources and low spatial diversity among generators. The latter effect can be mitigated, in part, by interconnecting New Mexico's renewable generators to adjacent states which may exhibit different diversity patterns.

[11] These values are estimated for summer peak loading conditions, or a period of 548 hours; they cannot be compared to annual capacity factors which are averaged over much longer periods.

A composite value of injected renewable power (see Appendix A) was used for power-flow modeling. Table 2 indicates this value equals 2,790 MW during 2030 high summer demand conditions.

Each renewable zone will consist of mutliple generating sites that are connected via step-up transformers to New Mexico's transmission grid.

New Mexico's renewable energy production equals approximately 10,750 GWh by 2030, which corresponds to an annual renewable capacity factor of 44%.

3.4 Using Four Corners as New Mexico's Export Hub

In this study, the Four Corners hub is assumed to serve as New Mexico's primary means of exporting power.

Figure 2 displays the tie lines (P) connecting Four Corners hub to adjacent states.

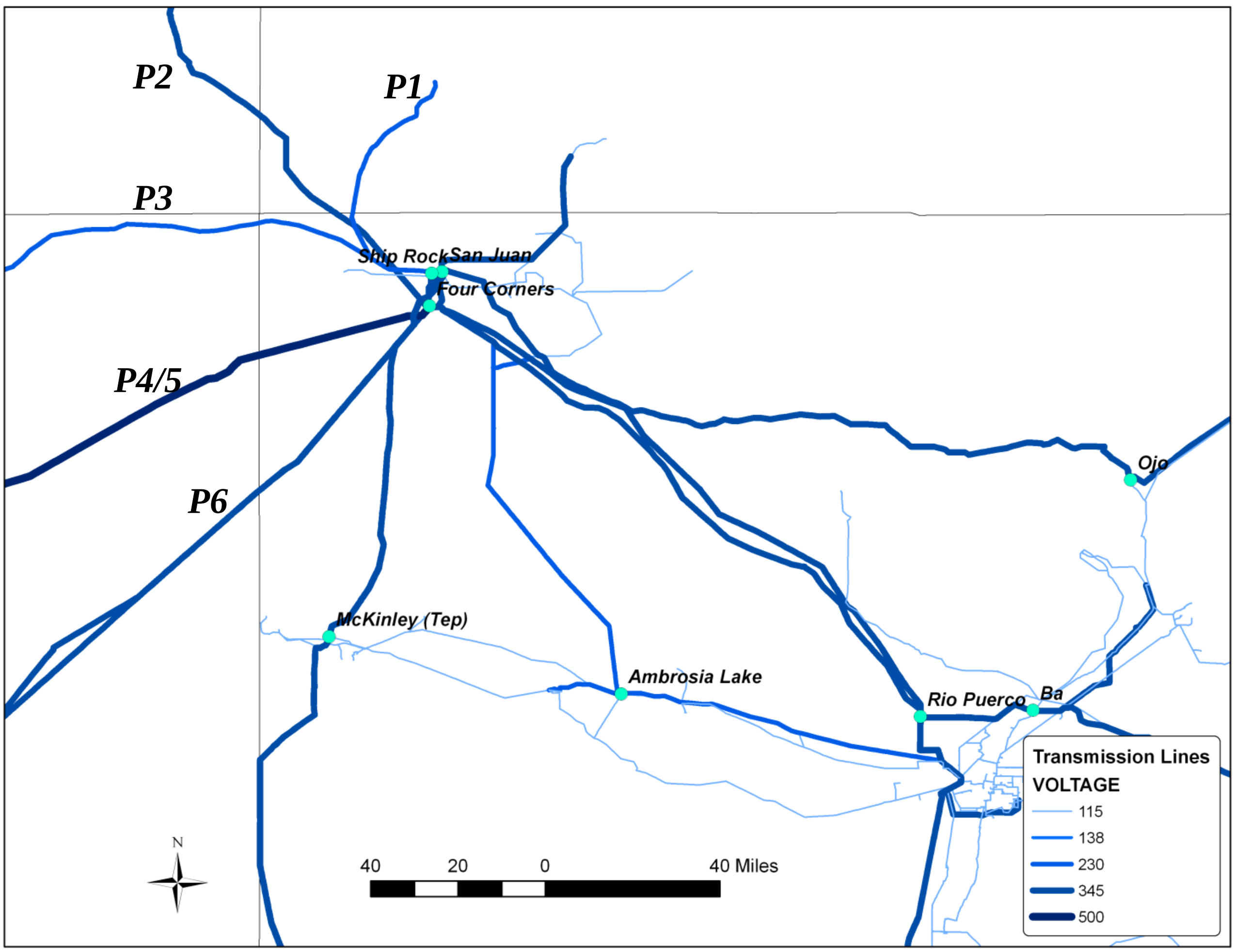

Figure 2. Four Corners Hub Key Features

Four Corners hub is comprised of two major interconnection nodes, San Juan and Four Corners substations, which tie fossil-fueled generating stations at San Juan (2,230 MW) and Four Corners (3,425 MW)[12] to lines serving both New Mexico and out-of-state load centers. Lines P1 through P6 in Figure 2 serve as exporting transmission paths connecting adjacent states; therefore, these lines are used in this study as the "monitor" set to provide a key measure for Collector performance. The set of grid components that comprise Four Corners hub consists of multiple transmission lines (tie lines), transformers, generators, and shunts.[13]

Tie lines can operate in a bi-directional manner, both importing and exporting power based onchanging demand and supply conditions.

Due to the complexity of flow directions and magnitudes at Four Corners hub, it is necessary to combine flows on multiple transmission lines to allow conditions to be assessed in a top-down manner.

By combining line flows, results obtained from three power-flow cases provide insight into current and future conditions at Four Corners hub. They are summarized graphically in Figure 3 (numbered 1, 2, 3):

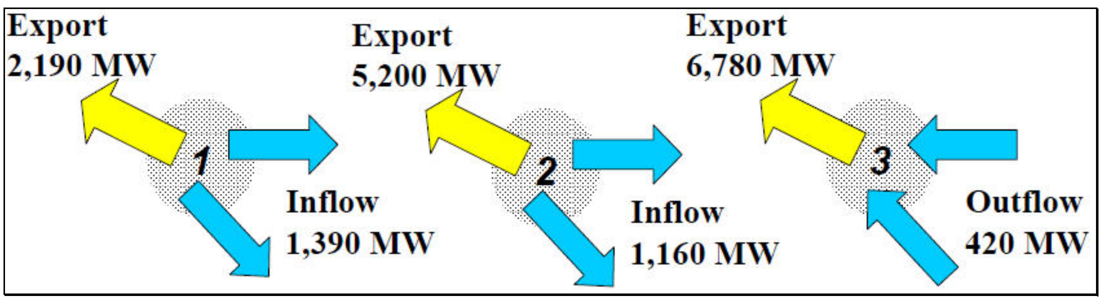

Figure 3. Four Corners Hub Flow Cases

Each case shown in Figure 3 is described as follows:

Case 1: Current (2010) summer peak flow. Four Corners hub provides 1,390 MW serving in-state demand. Four Corners hub also exports 2,190 MW.

Case 2: Future (2030) summer peak flow. Four Corners hub provides 1,430 MW serving in-state demand. Four Corners hub exports 5,180 MW. This case assumes no Four Corners hub plant retirements, includes no renewable energy, but includes the construction of RETA's 345-kV Collector system.

Case 3: Future (2030) summer peak flow. Four Corners hub provides no in-state demand, instead, 510 MW flows into Four Corners hub from in-state sources and 6,350 MW is exported. This case assumes no Four Corners hub plant retirements, includes 2,790-MW renewable-power injection, and the construction of RETA's 345-kV Collector system.

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[12] Plant capacities are based on 2030 nameplate ratings as outlined in WECC planning projections.

[13] In 2030, Four Corners hub is projected to include 16 transmission circuits (115, 230, 345 and 500 kV), five primary transformers (500/345, 345/230 and 230/115 kV) and 5,650 MW nameplate of fossil-fueled generation.

The largest observed flow change is associated with exports from Four Corners hub, which are projected to increase from 2,190 to 5,200 MW (Cases 1 and 2), or roughly doubling by 2030. This change results from WECC's uprating of fossil-fueled generation capacity, with no unit retirements. Values for projected export power in Cases 2 and 3 indicate that the operational status of Four Corners hub generation is likely to be relatively consistent whether renewable energy is included in New Mexico's generation mix or not. This occurs because a substantial reserve transmission capacity will be available at Four Corners hub combined with a future growing market in the southwest to sell fossil-fueled power mainly to Utah, Arizona, Nevada, and California.

Changes in flow patterns at Four Corners hub will, however, occur within New Mexico. Nearly 1,400 MW of power is currently delivered from Four Corners hub to in-state load centers. This condition[14] continues in Case 2, but is reversed in Case 3 when renewable generation is added. Case 3 indicates 420 MW of power enters Four Corners hub, which is then transmitted to out-of-state load centers. Case 3 also suggests power entering New Mexico, as shown in Case 2 has been displaced by renewables during high summer conditions.

[14] Regional north-south loop flow within WECC will potentially offset a fraction of power flow from within New Mexico flowing to Four Corners hub. This constraint requires additional power-flow analysis to assess actual export flows.

4 Power-Flow/Cost Analysis of Collector Plans

This section presents two renewable-energy development plans that support rapid renewable development while focusing on needed additions to New Mexico's transmission grid. In general, the grid must be expanded to serve three purposes: 1) Meet projected load growth, 2) Increase generation of renewable energy, and 3) Maintain reliable delivery of power. Either Collector plan will be required to simultaneously serve needs created by 1, 2, or 3. The basic features of each plan are:

- Collector Plan 1, proposed by RETA, consists of loop upgrades to 345-kV lines and transformers.
- Collector Plan 2, proposed by LANL, consists of radial upgrades to the 115-, 230-, and 345-kV lines and transformers.

"Radial" and "Loop" describe general transmission design features which connect lines, substations, and generators together as an integrated grid. They are important concerns for transmission planners because these features can affect operational reliability in a different manner. This study has not evaluated the reliability implications of implementing either Collector plan. See Section 6 for a discussion of additional analysis which may be needed.

There are common and dissimilar features between these plans. A common feature is inefficient transmission of power outflowing to Four Corners hub from within New Mexico. Existing grid features were designed historically to support inflowing patterns of power to serve load centers within the state. Therefore, it is necessary to reinforce the grid to support outflowing power. AC power-flow analysis indicates that outflow blockages from the central Collector area, in particular will occur unless capacity uprates are accomplished as part of both Collector plans.

Transmission lines are identified by "From-To" format which lists the terminating substation connected to each end of the line plus ID number.

To increase outflow six capacity uprates are needed including four transmission lines and two primary transformers; investments can be phased to provide required increases in outflow between 2015-2030.

The uprated lines and transformers include:

- B-A 10025 TO RIOPUERC 10390 line (29 miles, 345 kV)
- OJO 10232 TO OJO_EAST 10392 line (3 miles, 345 kV)[15]
- 14001 FOURCORN TO 14101 FOURCORN transformer (500/345 kV)
- RIOPUERC 10390 TO FOURCO&A 14107 line (102 miles, 345 kV)
- 79063 SHIPROCK TO 79064 SHIPROCK transformer (345/230 kV)
- RIOPUERC 10390 TO SAN_JU&A 10425 line (124 miles, 345 kV)

[15] Ojo East substation is currently not operational but is proposed for construction to increase New Mexico's load serving capability. See for example PNM's June, 2007 document titled "New Mexico Transmission Grid Investigation of Potential Access to New Generation Resources", IRP filing to NMPRC.

Additional transmission capacity provided by these uprates are required to ensure high capacity connections are available to carry power flowing on 230 and 345 kV lines between central New Mexico's Collector and export lines exiting Four Corners hub. Therefore, these components are included as additions in both Collector plans (Sections 4.1, 4.2). Line uprates include double-circuit construction in existing 345-kV corridors using larger conductors or bundling. Transformer uprates include the addition of a second transformer at the Four Corners and Shiprock substations, applying engineering practices to ensure high-reliability buswork design and acceptable fault currents.

4.1 Collector Plan 1

Collector Plan 1 is intended to incorporate these key features and to meet certain operating goals:

- Create a continuous 345-kV Collector transmission loop within New Mexico with high-reserve-capacity level for future renewable development.
- Create interconnections between existing 345-kV radial transmission lines to reinforce in-state power delivery reliability.
- Create high-capacity transmission paths to interconnect New Mexico's key renewable development zone (Williard-Guadalupe-Corona) to the 345-kV Collector.
- Upgrade existing line capacity from Rio Puerco and Ojo substations to support higher power inflow to Four Corners hub.

The map in Figure 4 identifies locations of major transmission additions associated with Collector Plan 1.

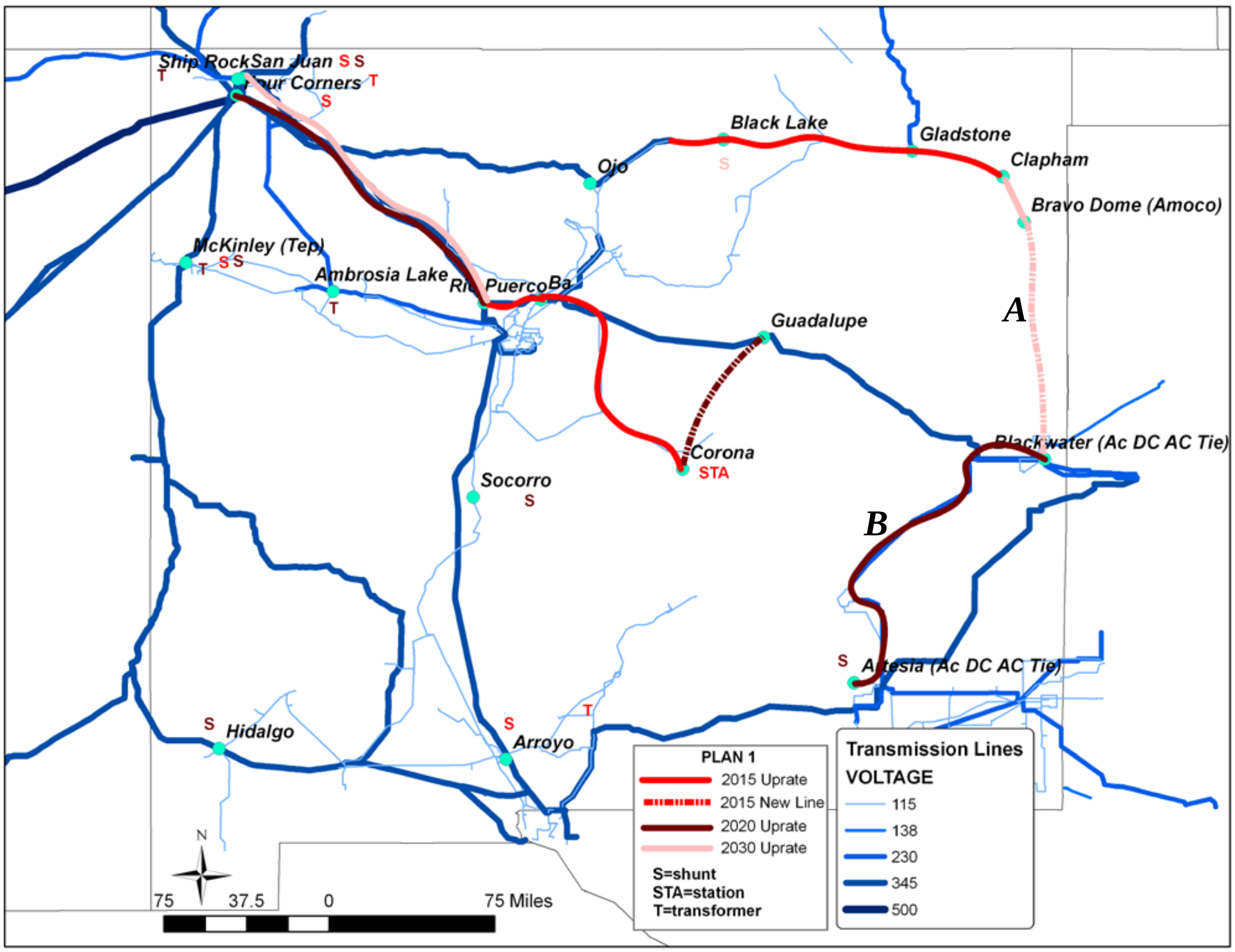

Figure 4. Transmission Additions: Collector Plan 1

Collector Plan 1 requires uprating capacity on 530 miles of existing 345-kV transmission corridors, an addition of 311 miles of 345-kV transmission corridors, the installation of three primary transformers at Four Corners and Shiprock[16], a new 345-kV substation at Corona, and the installation of nine transmission shunts for voltage stabilization. Tables 3 and 4 summarize additions associated with this plan. Each addition is characterized by function, type, miles to be constructed (if line addition), estimated costs, and in-service year.

Transformers, lines and shunts are added to increase flow, stabilize voltage and maintain reserve capacity; they are usually required in any expansion plan.

Additions include lines (L), transformers (T), shunts (S) and substations (STA). Function includes additions related to either the Collector or to Four Corners hub. Type includes uprates for existing lines or components or new additions.

Collector Plan 1 will increase export flow through Four Corners hub, depending on construction phase. The range of confidence is +/- 200 MW, assuming demand, non-conventional generation and conventional generation increase according to study planning assumptions. The estimated export values are:

- 2015: 600 MW
- 2020: 1,076 MW
- 2030: 1,302 MW

These values were estimated by AC power-flow analysis, using Four Corners exporting lines (P1-P6, see Figure 2) as the monitor set. A fraction of export flow also occurs at the Springer (AZ) and Walsenburg (CO) ties; flows of 360 to 390 MW are likely by 2030, which should be added to the totals reported above to estimate total renewable power exported from New Mexico.

By 2030, estimated annual energy generated by renewables utilizing Collector Plan 1 equals approximately 10,750 GWh which is comprised of 5,800 GWh export and 4,950 GWh in-state energy sales[17]. The in-state fraction would potentially compete with existing conventional generating resources as discussed in Section 4.3.

[16] Unit ratings and primary voltages are 840 MVA/500-345 kV, 300 MVA/345-230 kV, 224 MVA/230-115 kV, 570 MVA/345-115 kV, 300 MVA, 230-115 kV, 300 MVA/230-115 kV.

[17] Four Corners hub flow (MW) was reported by the AC power-flow model; annual energy was estimated by applying a capacity factor value of 44% (see Appendix A).

Table 3. Proposed Collector Plan 1 Additions: Phase 1

Addition	Function	Type	Miles	Estimated Cost	In-Service Year
(L) CLAPHAM 12020 TO GLADSTON 12100	Collector	Uprate	35	$47,077,800	2015
(L) GLADSTON 12100 TO BLACKLAK 12011	Collector	Uprate	72	$96,845,760	
(L) BLACKLAK 12011 TOTAOS 12082	Collector	Uprate	21	$28,246,680	
(L) CORONA 0988 TO B-A 10025	Collector	New	87	$117,021,960	
(STA) CORONA 03239	Collector	New	-	$57,000,000	
(L) B-A 10025 TO RIOPUERC 10390	Hub	Uprate	47	$63,218,760	
(L) OJO 10232 TO OJO_EAST 10392*	Hub	Uprate	34	$45,732,720	
(L) OJO_EAST 10392 TO OJO_EA&1 10437*	Hub	Uprate	1	$1,345,080	
(S) MCKINLEY (16102)	Hub	New	-	$13,200,000	
(S) ARROYO (11017)	Hub	New	-	$4,950,000	
(S)FOURCORN (14101)	Hub	New	-	$16,500,000	
(S) SAN_JU&B (10426)	Hub	New	-	$19,800,000	
(T) 14001 FOURCORN TO 14101 FOURCORN	Hub	New	-	$29,400,000	
		Subtotal	**297**	**$540,338,760**	-

****Note***: Ojo East uprates assume additional line capacity will be constructed to increase PNM's proposed capacity.

Table 4. Proposed Collector Plan 1 Additions: Phase 2, 3

Addition	Function	Type	Miles	Estimated Cost	In-Service Year
(L) BLACKWTR 13402 TO ARTESIA 13400	Collector	New	143	$192,346,440	2020
(L) GUADALUPE 10116 TO CORONA 0988	Collector	New	61	$82,049,880	
(S) SOCORROP (12073)	Collector	New	-	$3,300,000	
(S) ARTESIAR (13401)	Collector	New	-	$9,900,000	
(S) HIDALGO (11080)	Collector	New	-	$3,300,000	
(S) ARR___PS (11014)	Collector	New	-	$2,640,000	
(L) RIOPUERC 10390 TO FOURCO&A 14107	Hub	Uprate	102	$137,198,160	
(S) MCKINLEY (16102)	Hub	New	-	$13,200,000	
(S) SAN_JU&B (10426)	Hub	New	-	$19,800,000	
(T) 10010 AMBROSIA TO 10011 AMBROSIA	Hub	New	-	$7,840,000	
(T) 79063 SHIPROCK TO 79064 SHIPROCK	Hub	New	-	$10,500,000	
		Subtotal	**306**	**$482,074,480**	-
(L) ROSEBUD 12062 TO BLACKWTR 13402	Collector	New	107	$143,923,560	2030
(L) ROSEBUD 12062 TO CLAPHAM 12020	Collector	Uprate	22	$29,591,760	
(S) BLACKLAK (12011)	Collector	New	-	$1,980,000	
(L) RIOPUERC 10390 TO SAN_JU&A 10425	Hub	Uprate	109	$146,613,720	
		Subtotal	**238**	**$322,109,040**	-
		TOTAL	**841**	**$1,344,522,280**	-

4.2 Collector Plan 2

Collector Plan 2 is intended to incoporate these key features and to meet certain operating goals:

- Create an incremental series of upgrades to 345-, 230- and 115-kV circuits within New Mexico with low to moderate reserve-capacity levels for future renewable development.
- Allow existing 345-kV radial transmission lines to remain radial, with minimal impacts on in-state power delivery reliability.
- Distribute transmission capacity across all renewable development zones.
- Upgrade existing line capacity from Rio Puerco and Ojo substations to support higher power inflow to Four Corners hub.

The map in Figure 5 identifies locations of major transmission additions associated with Collector Plan 2.

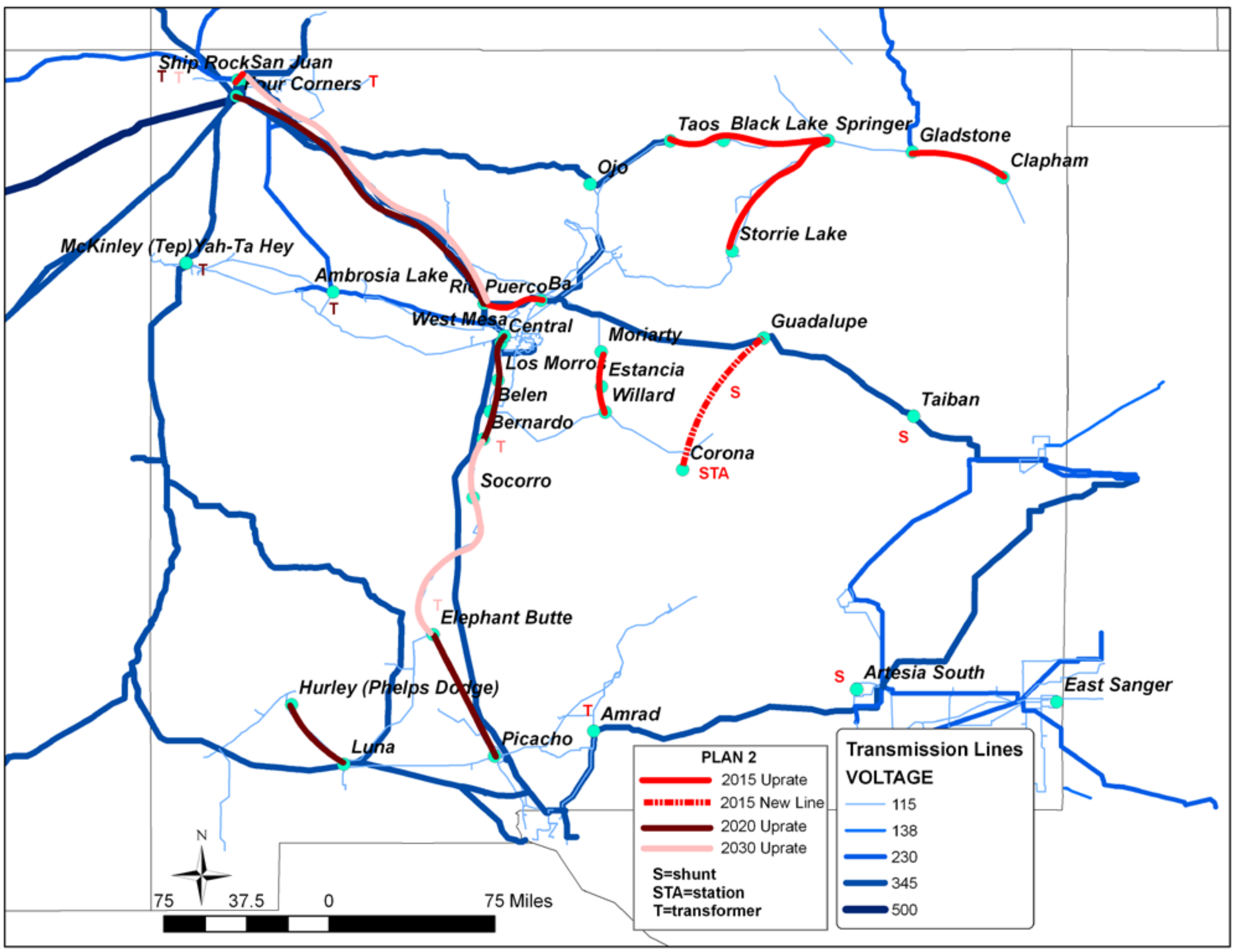

Figure 5. Transmission Additions: Collector Plan 2

Collector Plan 2 requires uprating capacity on 849 miles of existing 115-, 230-, and 345-kV transmission corridors, installation of seven primary transformers at Four Corners, Shiprock, Amrad, Bernardo, McKinley, and Ambrosia,[18] a new 345-kV substation at Corona, and installation of three transmission shunts for voltage stabilization. Tables 5 and 6 summarize Collector additions associated with Plan 2. Each addition is characterized by function, type, miles to be constructed (if line addition), estimated costs, and in-service year. Additions include lines, transformers, substations, and shunts. Function includes additions related to either the Collector or to Four Corners hub. Type includes uprates for existing lines or components or new additions.

Collector Plan 2 will increase export flow through Four Corners hub, depending on construction phase. The range of confidence is +/- 200 MW, assuming demand, non-conventional generation and conventional generation increase according to study planning assumptions. The estimated export values are:

- 2015: 290 MW
- 2020: 570 MW
- 2030: 1,137MW

These values were estimated by AC power-flow analysis, using Four Corners exporting lines (P1-P6, see Figure 2) as the monitor set. A fraction of export flow also occurs at the Springer (AZ) and Walsenburg (CO) ties; flows of 360 to 390 MW are likely by 2030, which should be added to the totals reported above to estimate total renewable power exported from New Mexico.

By 2030, estimated annual energy generated by renewables utilizing Collector Plan 2 equals approximately 10,750 GWh which is comprised of 4,500 GWh export and 6,250 GWh in-state energy sales. The in-state fraction would potentially compete with existing conventional generating resources as discussed in Section 4.3.

[18] Unit ratings and primary voltages are 840 MVA/500-345 kV, 300 MVA/345-230 kV, 224 MVA/230-115 kV, 570 MVA/345-115 kV, 300 MVA, 230-115 kV, 300 MVA/230-115 kV.

Table 5. Proposed Collector Plan 2 Additions: Phase 1

Addition	Function	Type	Miles	Estimated Cost	In-Service Year
(L) CLAPHAM 12020 TO GLADSTON 12100	Collector	Uprate	35	$17,325,000	2015
(L) BLACKLAK 12011 TO SPRINGER 12077	Collector	Uprate	37	$18,315,000	
(L) SPRINGER 12077 TO STORRIE 12079	Collector	Uprate	62	$30,690,000	
(L) BLACKLAK 12011 TO TAOS 12081	Collector	Uprate	21	$10,395,000	
(L) B-A 10025 TO EAST230 03235	Collector	Uprate	53	$71,289,240	
(L) MORIARITY 12047 TO ESTANCIA 12103	Collector	Uprate	18	$8,910,000	
(L) WILLIARD 12087 TO ESTANCIA 12103	Collector	Uprate	10	$4,950,000	
(STA) CORONA 03239	Collector	New	-	$57,000,000	
(L) GUADALUPE 10116 TO CORONA 0988	Collector	New	61	$82,049,880	
(S) GUDALUPE CORONA 03239	Collector	New	-	$13,200,000	
(S) TAIBANMS 10999	Collector	New	-	$9,900,000	
(S) ARTESIA 13400	Collector	New	-	$3,300,000	
(T) 11008 AMRAD TO 11010 AMRAD	Collector	New	-	$19,950,000	
(L) SAN_JUAN 10292 TO SHIPROCK 79064	Hub	Uprate	3	$4,035,240	
(L) B-A 10025 TO RIOPUERC 10390	Hub	Uprate	47	$63,218,760	
(L) OJO 10232 TO OJO_EAST 10392*	Hub	Uprate	34	$45,732,720	
(L) OJO_EAST 10392 TO OJO_EA&1 10437*	Hub	Uprate	1	$1,345,080	
(T) 14001 FOURCORN TO 14101 FOURCORN	Hub	New	-	$29,400,000	
		Subtotal	**382**	**$491,005,920**	

****Note:*** Ojo East uprates assume additional line capacity will be constructed to increase PNM's proposed capacity.

Table 6. Proposed Plan 2 Additions: Phase 2, 3

Addition	Function	Type	Miles	Estimated Cost	In-Service Year
(L) LOS_MORR 10416 TO BELEN_PG 12007	Collector	Uprate	13	$6,435,000	2020
(L) LOS_MORR 10416 TO WESTMS_3	Collector	Uprate	22	$10,890,000	
(L) BELEN_PG 12007 TO BERNARDC 12008	Collector	Uprate	13	$6,435,000	
(L) LUNA 10186 TO HURLEY_# 13008	Collector	Uprate	35	$17,325,000	
(L) HURLEY_# 13008 TO CENTRAL 13003	Collector	Uprate	6	$2,970,000	
(L) EL_BUTTE 12028 TO PICACHO 12059	Collector	Uprate	60	$29,700,000	
(L) RIOPUERC 10390 TO FOURCO&A 14107	Hub	Uprate	102	$137,198,160	
(T) 10382 YAHTEHAY TO 16102 MCKINLEY	Hub	New	-	$8,750,000	
(T) 10010 AMBROSIA TO 10011 AMBROSIA	Hub	New	-	$7,840,000	
(T) 79063 SHIPROCK TO 79064 SHIPROCK	Hub	New	-	$10,500,000	
		Subtotal	**251**	**$238,043,160**	-
(L) BERNARDO 12008 TO SOCORROP 12073	Collector	Uprate	27	$24,751,980	2030
(L) SOCORROP 12073 TO EL_BUTTE 12028	Collector	Uprate	65	$59,588,100	
(T) 12028 EL_BUTTE TO EL_BUTTE 03241	Collector	New	-	$21,000,000	
(T) 12008 BERNARDO TO 03242 BERNARDC	Collector	New	-	$21,000,000	
(T) 79063 SHIPROCK TO 79064 SHIPROCK 345	Hub	New	-	$10,500,000	
(L) RIOPUERC 10390 TO SAN_JU&A 10425	Hub	Uprate	124	$166,789,920	
		Subtotal	**216**	**$303,630,000**	-
		TOTAL	**849**	**$1,032,679,080**	-

4.3 Re-Dispatch of Conventional Generation

Because each transmission Collector incorporates a unique grid topology[19], the pattern of generator injections will be determined, in part, by available transmission capacity and degree of flow congestion. Other factors of importance include generator running costs, available generator capacity, and scheduled fossil-fueled generation from Four Corners hub. Both Collectors will, therefore, exhibit a specific re-dispatch of generator outputs.

Re-dispatching causes generator output across New Mexico's grid to be reallocated, based on costs, power flow, and other operational factors.

This study assumes renewable generator output will be injected and transported across New Mexico's grid as a "must-take" resource[20]. Re-dispatching is used to evaluate the extent to which displacement of conventional generation occurs.

New Mexico's grid model includes a total of 58 conventional generating units and nine renewable generating zones. Table 7 lists dispatched outputs for the largest conventional generating units, which exhibit re-dispatching.

Table 7. 2030 High Summer Dispatch for Conventional Generators

	Generator Output MW			
Generator	Rated	Plan 1	Plan 2	P1 –P2
(TX) CONNEWG1----(11208)	841	417	381	-36
(TX) CONNEWS1----(11209)	666	167	82	-84
LEF_G1------(10394)	235	106	235	129
NEWMANG1----(11112)	374	300	356	56
NEWMANG2----(11113)	340	206	67	-139
NEWMN4S1----(11117)	340	250	310	60
PEGS1-------(12058)	1117	1037	1080	44
RIOGD_G8----(11135)	729	640	726	86
ROSEBUD-----(12063)	243	243	0	-243
SJUAN_G1----(10318)	446	48	414	366
SJUAN_G4----(10321)	674	543	664	121
(AZ) SPR-GEN1----(16500)	2040	1116	113	-1003
(AZ) SPR-GEN2----(16501)	2040	863	506	-357

Units located outside New Mexico's borders are listed with the state prefix e.g. "(AZ)". "P1 – P2" tabulates the difference in dispatched generation between each plan. Collector Plan 2 will reduce

[19] "Topology" refers to the structure of links and nodes that comprise each Collector; for example, RETA's plan is built on 345 kV links (transmission lines) which offer higher capacity paths at that operating voltage.

[20] "Must take" assumes all renewable energy generated will be transported across New Mexico's grid for export or will serve local demand. It is not dispatched in the same manner as utility-owned units which can be ramped up and down.

output for this set of units by a net of 1,000 MW by 2030, while Plan 1 maintains higher conventional generator output. A large re-dispatch occurs at the Springer (AZ) generating hub, which is ramped down by higher tie flows with Collector Plan 2; San Juan generators are also ramped up by 480 MW with Plan 2's Collector.

In this study, dispatching adjusts for the "must-take" feature of renewables, which does not vary on the basis of economic factors. If renewables are allowed to compete for New Mexico's in-state power market, then conventional and non-conventional resources would be rebalanced within New Mexico. Preliminary analysis suggests that assigning running costs to renewable generation roughly equal to the Four Corners hub conventional units will reduce renewable output by approximately 50%. Also, exported power would be considerably reduced. These issues need further study to determine the net effect of re-dispatching given either Collector plan.

4.4 Comparison of Collector Technical Performance

This study indicates that both Collector plans are ***feasible*** representations of future grid conditions, based on results obtained by AC power-flow modeling.

In general delivered bus voltages are within acceptable range at 115 kV and above. Residual transmission overloads of less than 150 percent may also occur.

AC power-flow analysis provides a "snapshot" view of conditions which exist at a specific moment in the grid; multiple snapshots are usually needed.

A subset of observed off-normal conditions in either Collector model may be attributed, in part, to demand growth rather than the effect of adding renewable generation. These issues require further analysis to correctly assign requirements and costs to either cause.

A key metric for determining Collector performance is the observed level of net power export at Four Corners hub. Six transmission lines (labeled in Figure 3) comprise the "monitor" set; values for simulated AC line flows are summarized in Table 8, below.

Table 8. Projected 2030 Four Corners hub Export Line Flows

	Line Flow MW							
Case	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**OutFlow**	**Export**
No Collector or renewables	173	1,679	393	1,311	954	537	5,047	-
Plan 1 plus renewables	291	1,973	556	1,787	1,290	452	6,349	1,302
Plan 2 plus renewables	241	1,941	568	1,761	1,272	401	6,184	1,137
Voltage kV	345	345	230	500	500	345	-	-
Export to	CO	UT	AZ	AZ	AZ	AZ	-	-

"Export" equals the outflow difference between No Collector and either Collector Plan 1 or Plan 2. As demonstrated, the addition of a Collector with renewables results in larger export flows from Four Corners hub. Highest exported power will occur with Collector Plan 1, estimated to equal approximately 1,300 MW. Less power is exported with Collector Plan 2, estimated to equal approximately 1,140 MW.

Analysis of grid reliability includes line loading plus other factors such as contingency reserve, tie capacity and generator ramping rates.

Plan 1's looped transmission plan provides adequate reserve capacity (expressed as percentage of line loading) by 2030 to support reliable delivery of power. Average line loading is estimated to be 44.9%.[21]

Construction of several 345 kV line sections may be deferred if conductors are not economically loaded.[22] Removal of the following lightly loaded lines (labeled A and B in Figure 4) results in increased radial flows along the remaining sections of Collector Plan 1:

- ROSEBUD 12062 TO CLAPHAM 12020
- ROSEBUD 12062 TO BLACKWTR 13402

The net effect of not constructing these lines is negligible in terms of exported power. This analysis suggests that additional investment in these transmission lines may not be justified until higher levels of renewable development occur than projected for this study.

Plan 2's radial transmission plan provides adequate reserve transmission capacity by 2030 to support reliable delivery of power. Average line loading is estimated to be 45.9%. Due to the manner in which transmission components are upgraded, a number of 230- and 115-kV lines may require further reinforcement.[23] Notably, the Kayenta, AZ, tie to Four Corners hub is heavily loaded, requiring uprate. The following lines have been identified as potentially requiring additional power-flow analysis to determine the appropriate course of action:

- KAYENT&1(79094) To KAYENTA-(79043)
- SHIPROCK(79063) To KAYENT&1(79094)
- BELEN_PG(12007) To LOS_MORR(10416)
- WESTMS_3(12086) To LOS_MORR(10416)
- SPRINGER(12077) To STORRIE-(12079)
- BERNARDO(12008) To BELEN_PG(12007)
- ESTANCIA(12103) To MORIARTY(12047)
- SOCORROP(12073) To BERNARDO(12008)
- MANZANO-(10192) To EL_CERRO(10096)
- WESTMS_1(10370) To WESTMS_3(12086)
- PICACHO-(12059) To EL_BUTTE(12028)

[21] This value was estimated by averaging AC flows on 699 lines (115, 230, 345 and 500 kV), calculated as a percentage of line rating. It is potentially a significant quantity for transmission planners because higher line flows caused by grid failure (contingencies) may require emergency reserve capacity.

[22] "Economic line loading" has become a serious concern among utilities, as transmission construction costs increase and new corridor siting becomes more restricted. The actual value of loading required to provide economic operation must be determined for each voltage level and growth pattern.

[23] TSince it is unclear whether these upgrades are a necessary part of a Collector plan, they remain to be evaluated.

5 Economic Impact Analysis of Collector Plans

Positive economic impacts associated with developing either Collector and, therefore, enabling 5,200 MW of renewable energy projects to be developed are reported in this study as: 1) Capital (construction) investments in New Mexico; 2) Direct, indirect and induced jobs associated with the construction and operation of the Collector plus jobs created associated with the production of renewable energy and 3) Increased tax revenues[24].

Direct jobs are created by changes in the industries to which a final demand change was made. For example, jobs associated with Collector construction are "direct". ***Indirect jobs*** are created by changes in inter-industry purchases due to new demands of the directly affected industry. For example, jobs associated with operation or maintainenance of the new transmission system (crane operators) are "indirect". ***Induced jobs*** are created by the changes in household spending as income increases due to changes in production. For example, jobs associated with servicing households (landscapers, doctors) are "induced".

New jobs reported in this section for the 5, 10 and 20 year Collectors i.e. 2015, 2020 and 2030 are reported as aggregate number of jobs accumulated by each year. “Jobs” are defined in terms of “FTE- years” i.e. one “job” is one FTE for one year.

Key financial factors applied in this analysis are listed below.

Financial Factors

- All figures in 2010 dollars
- Project financial assessment extends from 2010 to 2029 (20 years)
- New Mexico gross receipts tax rate equals 6%
- Utility wheeling charge for renewable energy $2.75 to 5.50 per MWh[25]
- Generator operations and maintenance costs[26]:
  - Fixed: $1,500 per MW-Year
  - Variable: $10 per MWh
- Total Collector costs assigned to the following industries[27] (numbers shown in parenthesis represent the percentage of costs assumed to be retained in-state, based on regional purchase coefficients supplied by IMPLAN):

[24] Tax revenues do not include personal or corporate income taxes but include Gross Receipts taxes, licenses and related fees.

[25] Source: PNM; wheeling costs apply to transactions requiring utility transmission service to transport renewable energy to the Four Corners hub or to New Mexico’s load centers. Wheeling charges assumed for this study equal $2.75 to $5.50 per MWh, based on in-state or export sales. Source: PNM

[26] Source: NREL; see page 181, “20% Wind Energy by 2030: Increasing Wind Energy’s Contribution to the U.S. Electricity Supply,” DOE/GO-102008-2567, May 2008.

[27] Source: IMPLAN, LANLnumbers shown in parenthesis represent the percentage of costs assumed to be retained in-state, based on regional purchase coefficients supplied by IMPLAN.

- Construction: 30% (100%)
- Manufacturing: 30% (45%)
- Transportation and Warehousing: 20% (79%)
- Finance and Insurance: 10% (51%)
- Management: 10% (45%)

5.1 Application of IMPLAN Model

The Impact Analysis for Planning (IMPLAN) model is an input-output model widely used to estimate short-term regional economic impacts of policy and spending decisions. New Mexico's model divides the state into counties, but counties can be aggregated into larger regional entities all the way up to the state level.

Input-Output models are based on the assumption that inputs will produce economic outputs in a "linear" manner for typically responsive economies.

IMPLAN describes commodities flows from producers to intermediate and final consumers; it estimates changes in employment, employee compensation, value added, tax receipts, and other measures of economic activity.

In addition to tracking transactions between industries in response to changes in final demand, the model also calculates multipliers that estimate the downstream impacts that spending changes in one industry can have on other industries and the rest of the economy. Costs for both Collector Plan 1 and Plan 2 can therefore be distributed among a variety of industries. For this study, transmission Collector costs were assumed to impact the following industries: construction, manufacturing, transportation and warehousing, finance and insurance, and management[28]. IMPLAN computes the direct benefits from direct spending of dollars in each industry, as well as the indirect benefits that occur from the spending on intermediate goods supplied to produce the final goods.

In general IMPLAN's application to this study ***is based on a conservative approach***, notably input values have been chosen to allow economic outputs to be estimated at the lower, not upper, bound.

5.2 Other Types of Economic Impacts

In addition to jobs created and tax receipts, New Mexico will also benefit from the ***export of power*** either at Four Corners hub or at other inter-state tie lines. Benefits from the export of power will accrue to the generation owners but, for conservatism, are not considered a statewide benefit to New Mexico in this study. Generation profits can potentially either create new jobs or stabilize the consumer's future price of electricity, however the mechanism by which those outcomes may occur cannot be estimated with certainty.

[28] 60% of the costs were split between construction and manufacturing industries based on the assumption that one or more manufacturers would be established within New Mexico given the large volume of transmission and electrical equipment required. 20% of the total cost was allocated to transportation, 10% to finance and insurance, and the final 10% to management fees.

Wheeling costs and ***operation and maintenance (O&M) costs*** are treated as a stimulus to New Mexico's economy, thereby creating jobs and tax revenues. Wheeling costs (whether paid by out-of-state power purchasers or in-state purchasers) will provide income to New Mexico's transmission providers. Similarly O&M costs will be paid on a continuous basis by generation owners. A new service sector (or bundle of existing services) will potentially be created through the large-scale development of New Mexico's renewable energy zones. Services may be more or less specialized depending on the renewable technology employed. For example, turbine blade washing services will be needed routinely to insure that wind farm output is maintained at design levels. This type of service is assumed to generate income which is retained within New Mexico.

5.3 Results of Collector Analysis

Tables 9 and 10 detail project costs, revenue and benefits accrued by Collector Plan 1 and Plan 2 for the years 2015, 2020, and 2030. Costs are cumulative at each project phase. "Benefits to New Mexico" in the table summarizes jobs created and tax revenues that accrue to the state as a whole.

Table 9. Economic Impact Summary: Transmission Collector Construction

					Benefits to New Mexico	
Plan	Year	Line Miles	Construction Cost	Annual Bond Cost	New Jobs*	Tax Revenue
1	2015	297	$540,338,760	$61,149,700	6,200	$18,831,400
	2020	603	$1,022,413,240	$115,705,600	11,800	$35,632,200
	2030	841	$1,344,522,280	$152,158,400	15,500	$46,858,000
2	2015	382	$491,005,920	$55,566,700	5,700	$17,112,100
	2020	633	$729,049,080	$82,505,800	8,500	$25,408,200
	2030	849	$1,032,679,080	$116,867,300	12,000	$35,990,000

* Temporary and permanent jobs will be created in the approximate ratio of 40%-60%.

By 2015, as shown in Table 9, $540 million will be spent on Collector Plan 1, which is estimated to create 6,200 jobs throughout the state's economy. Jobs are assumed to accrue from direct, indirect and induced causes. Roughly 40% of all jobs created will be "short-term" employment positions that end when transmission and renewable projects are commissioned. The remaining 60% of jobs are considered "long-term" and remain active, creating an ongoing economic stimulus across many sectors. Bonds are assumed to be 20 year fixed rate bonds with an 8% interest rate. Future market conditions cannot be predicted with high confidence so a conservative estimate of today's market was used as the basis for these calculations.

Table 10 tabulates additional benefits that accrue to New Mexico from renewable energy production.[29] Table 10 lists estimated renewable energy available in 2015, 2020 and 2030 for export and in-state use.

Economic benefits can potentially be attributed to energy sales, serving either in-state or export markets; future pricing strategies for sales is uncertain.

[29] Income attributable to energy sales has not been included in this study. In-state buyback rates could be based on index prices at Four Corners hub, which vary by season; the recent weighted price is $54 per MWh. A variety of factors may affect export rates including emission credits, RECs, and fossil fuel price volatility which are difficult to quantify. Based on these factors, a price of $75-$85 per MWh could be assumed.

Table 10. Economic Impact Summary: Renewable Energy Production

Plan	Year	Export GWh	In-State GWh	Wheeling, O&M Costs	Benefits to New Mexico: New Jobs*	Benefits to New Mexico: Tax Revenue
1	2015	8,800	7,500	$101,820,300	1,200	$3,566,500
	2020	17,600	15,100	$203,640,600	2,400	$7,133,000
	2030	67,200	57,400	$804,062,500	9,300	$28,142,200
2	2015	6,030	10,300	$99,585,950	1,150	$3,488,300
	2020	12,050	20,600	$199,171,900	2,300	$6,976,600
	2030	45,990	78,600	$786,187,500	9,100	$27,516,600

*Temporary and permanent jobs will be created at the approximate ratio of 40%-60%.

"Export GWh" and "In-State GWh" equal the estimated sum of all exported energy delivered to the Four Corners hub, or distributed within New Mexico by that year.

The sale of exported power directly benefits generation owners and utilities for both Collector plans, however these revenues may or may not provide statewide benefits. Utilities within the State of New Mexico (and nationwide) must meet the Renewable Portfolio Standards (RPS) that require a fraction of all generation be produced by renewable energy. As such, RPS has created a distorted market for electricity in which the assumed buyback rate is typically much higher than the true market rate. As soon as utilities meet RPS requirements, they will no longer contract for renewable energy at higher rates and instead only offer lower market-based buyback rates. Significant uncertainty is associated with estimating likely revenue from energy sales over the 20-year study period, and the degree to which revenue is retained to create statewide benefits is also highly uncertain.

Total estimated jobs created plus a breakdown of job function in New Mexico's economy are listed in Table 11. Tabulated values are summed from results reported in Tables 10 and 11 which are cumulative at each project phase.

Table 11. Cumulative Jobs (FTE-years) Created: Direct, Indirect, Induced

Plan	Year	State Total	Direct	Indirect	Induced
1	2015	7,100	3,100	1,670	2,400
	2020	14,200	6,100	3,300	4,800
	2030	24,800	10,700	5,800	8,300
2	2015	4,300	1,850	1,000	1,400
	2020	8,500	3,700	2,000	2,800
	2030	21,000	9,000	4,900	8,000

In order to estimate the average number of annual jobs for the 20 year (2030) collector system, take the total FTE-years in 2030 and divide by 20. For Collector Plan 1, the average number of annual jobs created is 1,240; for Collector Plan 2, the average number of annual jobs created is 1,050.

5.4 Recovery of Collector Costs via Energy Assessment

There are at least three methods either proposed or currently in use for purposes of recovering transmission investment costs related to renewable development; they are[30]:

- MISO (Midwest Independent System Operator) proposes to establish a new category of transmission projects (Multi Value Projects, MVP); the cost of MVPs is spread evenly to load throughout the MISO footprint on an energy basis.
- SPP (Southwest Power Pool) has implemented a "highway/byway" cost allocation method. Transmission projects above 300 kV are considered highways, and the regional system is allocated all costs; for transmission between 100 kV and 300 kV, allocation is 1/3 regional system, 2/3 to the facility zone; for transmission less than 100 kV, the facility zone is allocated all costs.
- ERCOT (Electricity Reliability Council of Texas) enacted a "Wind plus Load Share" method based on required "Ancilliary Services". This include the cost to ERCOT of transmission reserves, regulation and reliability, the cost is hedgeable and can be exchanged for a variety of similar services.

The cost allocation method analyzed in this report is similar to MISO's method, that is, Collector plan costs would be allocated evenly on an energy basis to all electricity consumers in New Mexico.

An appropriate method for Collector cost recovery must be chosen, consistent with public policy requirements of various government entities.

Total electric energy (MWh) sales are projected to each out-year, i.e., 2015, 2020, and 2030, using a straight-line projection. Costs are then proportioned by energy sales to each customer class, as shown in Table 12.

Table 12. Projected Energy Sales by Customer Class

	Sale Megawatt-Hours MWh			
Year	State Total	Residential	Commercial	Industrial
2015	24,391,300	7,059,800	9,770,900	7,560,600
2020	26,224,600	7,590,500	10,505,300	8,128,800
2030	28,195,700	8,161,000	11,294,900	8,739,800

The bonded cost of each Collector plan is assumed to be recovered as a flat charge per MWh. Costs are distributed to each class, then re-estimated as a monthly per customer charge, based on projected number of customers in each class.[31] Results are tabulated in Tables 13-14.

[30] Summarized in memorandum titled "MISO, SPP and ERCOT Transmission Cost Allocation Proposals", Steptoe & Johnson LLP (David Fialkov), dated July 26, 2010.

[31] For this analysis, customer count is assumed to increase in the same proportion as MWh sales to the entire class.

Table 13. Annual and Monthly Cost Recovery by Customer Class: 100% Recovery

		Annual Cost Recovered			Monthly Per Customer Cost		
Plan	Year	Residential	Commercial	Industrial	Residential	Commercial	Industrial
1	2015	$17,699,200	$24,495,900	$18,954,500	$1.60	$13.93	$253.90
	2020	$15,790,700	$21,854,500	$16,910,700	$2.93	$25.49	$464.58
	2030	$10,550,900	$14,602,600	$11,299,300	$3.76	$32.68	$595.51
2	2015	$16,083,300	$22,259,400	$17,224,000	$1.46	$12.66	$230.71
	2020	$7,797,300	$10,791,500	$8,350,300	$2.11	$18.37	$334.75
	2030	$9,945,600	$13,764,900	$10,651,000	$2.89	$25.14	$458.17

Table 14. Annual and Monthly Cost Recovery by Customer Class: 50% Recovery

		Annual Cost Recovered			Monthly Per Customer Cost		
Plan	Year	Residential	Commercial	Industrial	Residential	Commercial	Industrial
1	2015	$8,849,600	$12,248,000	$9,477,300	$0.80	$6.97	$126.95
	2020	$7,895,400	$10,927,300	$8,455,300	$1.47	$12.75	$232.29
	2030	$5,275,500	$7,301,300	$5,649,600	$1.88	$16.34	$297.75
2	2015	$8,041,600	$11,129,700	$8,612,000	$0.73	$6.33	$115.36
	2020	$3,898,600	$5,395,800	$4,175,200	$1.06	$9.18	$167.37
	2030	$4,972,800	$6,882,400	$5,325,500	$1.45	$12.57	$229.08

“Annual Cost Recovered”lists the proportion of each Collector’s bond costs, allocated to a specific year and customer class; the costs are discrete, not cumulative which decrease as Collector investments decrease. ”Monthly Per Customer Cost” lists the estimated per customer charge; charges are cumulative and therefore increase over time.

Two cost recovery levels are shown: 100% (Table 13), 50% (Table 14); all costs scale in proportion to the level of recovery assumed. If recovery is less than 100%, costs would be shared in some proportion between customers, renewable developers and other Collector beneficiaries.

Table 13-14 indicates that costs recovered per customer between 2015 and 2030 are relatively similar for both Collector plans. However, some differences are projected to occur later in the study period. By 2030, assuming 100% recovery the Collector Plan 1 per-customer charge for industrial accounts is $595.51 versus the Plan 2 per-customer charge of $458.17, a difference of approximately 25%. Residential and commercial customer charges are also generally higher for Collector Plan 1. These differences are strictly attributable to the cumulative bonded costs of each Collector.

5.5 Comparison of Collector Economic Performance

Collector Plan 1 and 2 perform in a very similar economic fashion in terms of costs, jobs created, tax revenue generated, and income accrued from energy sales. This study analyzed one cost recovery method, however these findings ***do not indicate LANL’s advocacy of a specific cost recovery method.***

Economic findings focus on the direct, indirect and induced jobs created by the construction and operation of the 5, 10, and 20 year Collectors ***and*** the operation of 5,200 MW of new renewable energy projects. Renewable jobs are derived from production of renewable energy which also creates in-state and out-of-state energy sales. “Jobs” are defined in terms of “FTE- years” i.e. one “job” is one FTE for one year. For Collector Plan 1, the average number of annual jobs created is 1,240; for Collector Plan 2, the average number of annual jobs created is 1,050.

Collector Plan 1 will require an investment of $312 million more than Plan 2, and it will create approximately 3,800 additional jobs over 20 years (on average, 190 additional jobs per year). Additional benefits can realized by wheeling of bulk energy sales in-state or as export. Also related to energy sales, a fraction of costs related to the production of renewable energy are likely to be retained in New Mexico and therefore create benefits to the economy. Collector Plan 1 exports 67,200 Gigawatt-hours (GWh) of energy by 2030 at Four Corners hub, generating $804 million of wheeling and operations & maintenance (O&M) costs over 20 years. Collector Plan 2 exports 45,900 GWh, generating $786 million of costs by 2030. Tax revenue generated from each plan is approximately $4 million per year, or a total of $67 to $79 million by 2030. The value of energy sales to New Mexico's economy is not included in this analysis.

Gross State Product (GSP) gain divided by Collector construction cost represents an approximate gauge of state-level rate of return on investments, The rationale for this measure is that it measures relative impacts within all of New Mexico’s economic sectors. Table 15 summarizes the respective factors used for this calculation. GSP gains are cumulative for each project phase

Table 15. Estimated Collector Rate of Return

Plan	Year	Construction GSP Gain	Energy Sales GSP Gain	Sum GSP Gains	Rate of Return %
1	2020	$1,575,692,900	$313,840,900	$1,889,533,800	18.4
	2030	$2,072,111,400	$1,239,181,500	$3,311,292,900	12.3
2	2020	$1,123,574,500	$306,953,900	$1,430,528,400	19.6
	2030	$1,591,514,100	$1,211,633,400	$2,803,147,500	13.6

Using this formulation, the annual compound rate of return for Collector Plan 1 is estimated to equal approximately 12.3% through 2030; the annual compound rate of return for Collector Plan 2 is estimated to equal approximately 13.6% through 2030.

6 Recommendations: Further Refinement and Analysis of Collector Options

This study satisfies an initial milestone in New Mexico's multi-year, statewide transmission upgrade program. Although each Collector plan meets the minimum threshold for feasibility, more analysis must be accomplished to ensure New Mexico's grid can simultaneously serve future load growth, accelerate the development of renewables and maintain reliable electric service.

Completion of three analysis tasks will be key to the success of the upgrade program:

- Phase 1: A top-level screening of transmission alternatives (substantially accomplished by this report)
- Phase 2: A second more detailed grid analysis based on localized demand and generation forecasts
- Phase 3: A final evaluation of grid operational issues prior to actual construction

Each task outlined above will provide greater levels of detail and certainty regarding Collector plan features and the probability of outcomes which are discussed in this report.

Phase 2 will incorporate more detailed forecasts from each transmission providers[32] based on development of renewables within each utility's service territory and planned changes related to demand and conventional generation. This phase should include a statewide, 1/2 to 1 day planning workshop with participants from LANL, RETA, utilities and other organizations to discuss conclusions from this study and to identify collaborative next steps. The best combined features from both Collector plans can be evaluated during Phase 2 if several large regional transmission initiatives[33] are added to interconnect other states, control areas or load centers. Additional analysis of generator dispatching should be conducted at this step to ensure transmission capacity upgrades are properly balanced in terms of flows and production costs.

Phase 3 will ensure that the Collector plan will support robust transmission operation for delivery of power to New Mexico's consumers. It should include a contingency screening analysis of possible grid failure states (N-1) and operational analysis of generator firming requirements for large amounts of variable renewable generation. This task will require analysis of multiple power-flow cases which span an entire year's range of demand and generation levels. This requirement exceeds normal utility planning practices which typically focus only on demand conditions for three periods (peak summer, peak winter, and off-peak/shoulder). Given that the renewable development plan assumed in this report will create large swings in power injection[34] across multiple time periods, it will be necessary to analyze these issues in detail.

[32] New Mexico's major transmission providers are PNM, EPEC, Xcel Energy and Tri-State; each utility develops detailed long-term forecasts for their service territories related to demand and supply growth. This data must be reconciled with WECC long-term assumptions for consistency.

[33] Notably SunZia, Tres Amigas. Santa Fe Clean Line LLC, Southline, High Plains Express and similar high-capacity transmission projects proposed for development.

[34] Power injection swings of 3:1 or more for renewable generator output are possible; the degree to which New Mexico's renewables can provide energy and firm capacity must be determined.

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Glossary

AC	Alternating current, describes the common means of transporting energy within New Mexico’s electric grid.
Active device	Type of electrical component which can control electron flow (electricity controlling electricity).
Buswork	Components which comprise the superstructure of a substation; includes switches, breakers, transformers, insulators.
Capacitor	Shunt; a grid component used to adjust reactive power flow and maintain voltage stability.
Capacity factor	Measure of plant output variability, equals the quantity (average energy output/Peak energy output). Values are always between 0 and 1.
Contingency	An off-normal state of the grid caused by the single or simultaneous failures of transformers, lines and generators.
DC	Direct current, describes a means of transporting energy which is currently used only at New Mexico’s control area tie lines.
Fault	Failure attributable to some defect in an electrical circuit (loose connection or insulation failure or short circuit etc.).
FERC	Federal Energy Regulatory Commission, regulator of inter-state transmission service.
GSP	Gross State Product, a measure of the economic output of a state; it is the sum of all value added by the combined industries within the state.
Impedance	A physical characteristic of power components which measures a material's opposition to the flow of electric current.
Inductor	Shunt; a grid component used to adjust reactive power flow and maintain voltage stability.
Injected (MW)	Actual power flowing to the grid from a generator; usually estimated as a fraction of nameplate capacity.
Looped	A grid design approach using two feed (or source) points for a transmission line; potentially more reliable configuration.
LANL	Los Alamos National Laboratory, primary author of this report.
Linear	Modeling approach that exhibits the property: outputs are proportional to the inputs; does not account for feedback or dampening effects.
LGIP	Large Generator Interconnection Procedure, a formal process used to establish transmission interconnection requirements.

MW, GW	Megawatt or gigawatt (1,000 MW), a measure of instantaneous electric demand; a megawatt of capacity will produce electricity that equates to about the same amount of electricity consumed by 400 to 900 homes in a year.
MWh, GWh	Megawatt-hours or gigawatt-hours (1,000 MWh), a measure of energy consumed over a specific period of time.
MVA	Mega-Volt-Amperes, a power rating unit used to describe the maximum amount of power which can flow through a component.
MVAr	Mega-Volt-Amperes reactive, a power rating unit used to describe the effect of energy storage components.
Nameplate (MW)	Maximum (rated) power flowing to the grid from a generator; serves as the basis for estimating injected power flow.
NREL	National Renewable Energy Laboratory, Dept. of Energy research facility.
Passive device	Components incapable of controlling current; includes capacitors, inductors, transformers.
Radial	A grid design approach using one feed (or source) point for a transmission line; potentially less reliable configuration.
Rate of Return	Estimated Benefit-to-Cost ratio of the Collector project; a measure of economic impact within New Mexico.
Reporting Areas	Subdivision of the western region into smaller planning units for the purpose of forecasting.
RETA	(New Mexico) Renewable Energy Transmission Authority, sponsor of this study.
ROW	Right-of-Way for transmission corridors.
Shunt	A grid component connected between line and ground (common).
Transformer	A grid component used to interconnect different operating voltage levels.
WECC	Western Electricity Coordinating Council, primary planning organization for the 14-state western United States.
WR	Wind region, subdivision of area based on NREL’s wind resources maps.

APPENDIX A: Renewable Capacity Additions

This section describes key assumptions and methodology used to estimate New Mexico's future capacity additions and injected renewable power. The effect of regional wind diversity and seasonal variations are based on data provided by NREL.[35] Using this approach, the western United States is subdivided into 95 wind regions (WRs) according to specific characteristics of wind resources available. Figure A-1 indicates that six of 95 WRs were assigned to New Mexico.

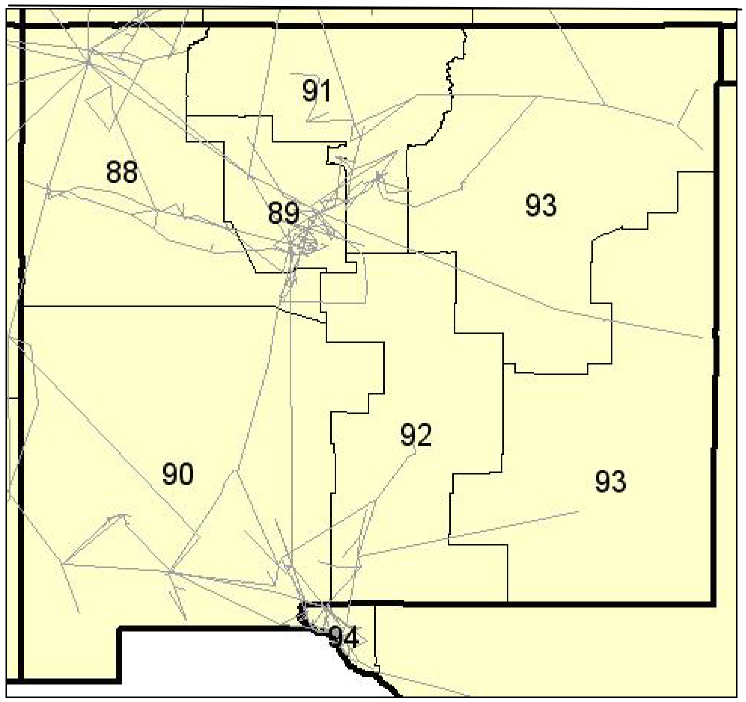

Figure A-1. NREL Wind Regions in New Mexico

Each WR displayed in Figure A-1 will exhibit unique characteristics in terms of percentage of time wind can serve as a generating resource, variability of wind and the extent to which wind is correlated between WRs. By subdividing a year into 16 time periods (548 hours x 16), sufficient resolution can be obtained to estimate expected generator output or injected power. Table A-1 lists NREL's definitions of each time period by season and estimated wind capacity factors for two periods.

[35] For more detail, see pages 170-172 in "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to the U.S. Electricity Supply," DOE/GO-102008-2567, May 2008.

Table A-1. NREL Wind Capacity Factors

	Wind Region					
ID Daily Period	**88**	**89**	**90**	**91**	**92**	**93**
H3 Summer 2 pm to 5 pm	0.202	0.213	0.254	0.230	0.140	0.217
H12 Winter 6 pm to 10 pm	0.566	0.579	0.542	0.530	0.522	0.591

For the purposes of this study, only H3 (summer) and H12 (winter) periods are used to estimate generator output. Table A-1 lists estimated "capacity factors" for each time slice and WR.

Capacity factor is defined as the fraction of each time slice that wind farms will operate. For example, in WR 88 during the H3 period, wind farms are estimated to operate only 20.2% of 548 hours or 110 hours. This pattern is further evident if all renewable output periods are plotted in chronological order, as shown in Figure A-2.

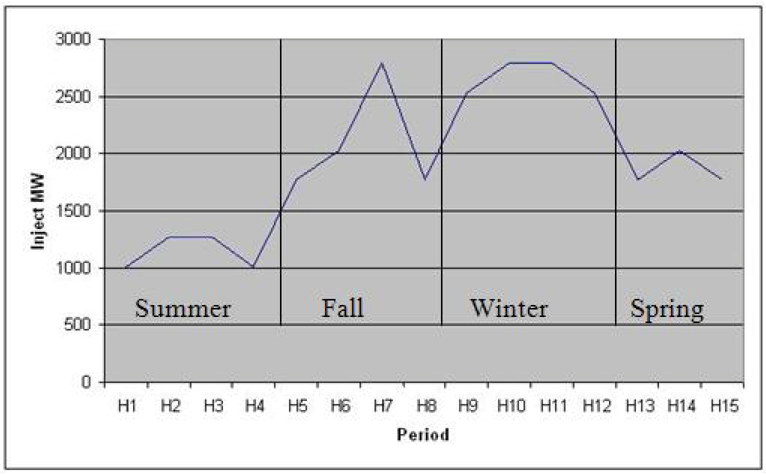

Figure A-2. New Mexico Renewable Output H1–H15

The composite annual capacity factor for renewable output plotted in Figure A-2 equals 44%. This suggests New Mexico's future renewable capacity is capable of generating 10,753,780 MWh (0.44 x 2,790 x 8,760) of energy annually by 2030. The range of output variation from period to period is likely to be large, however, with H1 (low) estimated to generate 553,480 MWh and H10 (high) estimated to generate 1,528,920 MWh.

Tables A-2 and A-3 tabulate statewide renewable capacity allocations for the H3 and H13 period, listed by development zone.

Table A-2. Summer (H3) Renewable Capacity Allocation

Zone	Collector	Tie-In	Capacity MW	Wind Region	Capacity Factor	Injected MW	Resource
1	South & West	Luna	180	90	0.90	150	Solar
2	South & West	Artesia	130	93	0.90	110	Solar
3	Central	Lonesome	610	91	0.23	130	Wind
4	Central	Guadalupe	790	93	0.22	160	Wind
5	Central	Blackwater	880	91	0.23	190	Wind
6	Central	Williard	220	92	0.14	30	Wind
7	Central	Corona	1,290	91	0.23	280	Wind
8	North & East	Clapham	600	93	0.22	120	Wind
9	North & East	Springer	500	93	0.22	100	Wind
		Subtotal	5,200	-	-	1,270	-

Table A-3. Winter (H12) Renewable Capacity Allocation

Zone	Collector	Tie-In	Capacity MW	Wind Region	Capacity Factor	Injected MW	Resource
1	South & West	Luna	180	90	0	0	Solar
2	South & West	Artesia	130	93	0	0	Solar
3	Central	Lonesome	610	91	0.53	300	Wind
4	Central	Guadalupe	790	93	0.59	440	Wind
5	Central	Blackwater	880	91	0.53	430	Wind
6	Central	Williard	220	92	0.52	110	Wind
7	Central	Corona	1,290	91	0.53	640	Wind
8	North & East	Clapham	600	93	0.59	330	Wind
9	North & East	Springer	500	93	0.59	280	Wind
		Subtotal	5,200	-	-	2,530	-

By summing capacity factors during all time periods across all six WRs, it can be shown that New Mexico's highest wind output is projected to occur during the H10-12 period. Wind farm output estimated for this period, therefore, serves as a benchmark planning value which can be inserted into the AC power-flow model. It equals summer output for zones 1-2 plus winter output for zones 3-9 or 2,790 MW.

The rationale for this approach is: transmission planning is based on insuring adequate delivery of power during periods of high demand. New Mexico creates its highest electric demands during summer mid-afternoon weekdays, which corresponds to the H3 period. There is a finite (but small) probability that H12's estimated output will occur during the H3 period, but transmission planners must provide sufficient capacity to serve worst-case power flows. Therefore, this study assumes windfarm output estimated for the H12 period occurs coincidently with high summer demand.

APPENDIX B: WECC Planning Costs

Tables B-1, B-2, and B-3 outline cost assumptions applied in this study related to uprating existing assets or new construction of transmission lines and substations.

Table B-1. Transmission Lines

Voltage- Circuit No.	$000/mile	Multiplier	Comments
765 kV AC Single Circuit	$2,250	1.25	Sub-group consensus
500 kV AC Single Circuit	$1,800	1.00	Frontier Line Analysis, 12/06 (FL)*
500 kV AC Double Circuit	$2,880	1.60	1.6x single circuit, FL, CPC
345 kV AC Single Circuit	$1,260	0.70	Sub-group consensus
345 kV AC Double Circuit	$2,016	1.12	1.6x single circuit
230 kV AC Single Circuit	$900	0.50	Sub-group consensus
230 kV AC Double Circuit	$1,440	0.80	1.6x single circuit
500 kV DC Bi-Pole	$1,440	0.80	0.8x 500 kV AC, FL, CPC

*FL and CPC used $2 million per mile with $300k for ROW (outside CA). Sub-group consensus is to use $2 million per mile, but our ROW costs (outside CA) are about $200k.Uprate of existing corridors is assumed to equal 66% of new corridor costs listed above.

Table B-2. Transmission Line Capacities

Voltage-Circuit No,	(MW)	Comments
765 kV AC Single Circuit	3,000	CPC
500 kV AC Single Circuit	1,500	Frontier Line Analysis, 12/06 (FL)
500 kV AC Double Circuit	3,000	2x single circuit
345 kV AC Single Circuit	750	Sub-group consensus
345 kV AC Double Circuit	1,500	2x single circuit
230 kV AC Single Circuit	400	Sub-group consensus
230 kV AC Double Circuit	800	2x single circuit
500 kV DC Bi-Pole	3,000	FL, CPC

Table B-3. Substations

Voltage-Capacity	Cost	Reference
500 kV - no tx	$50,000	IPC Planning Assumptions
500 kV - 1500 MVA tx	$100,000	IPC Planning Assumptions
345 kV - no tx	$40,000	IPC Planning Assumptions
345 kV - 1000 MVA tx	$75,000	IPC Planning Assumptions
230 kV - no tx	$35,000	IPC Planning Assumptions
230 kV - 500 MVA tx	$50,000	IPC Planning Assumptions
765 kV - no tx	$62,500	1.25x 500 kV, Sub-group consensus
765 kV - w/ tx	$125,000	1.25x 500 kV, Sub-group consensus
500 kV DC terminal, 3000 MW	$250,000	FL, CPC

APPENDIX C: Analysis Methods Used in this Study

This section generally describes analysis methods used in this study to expand New Mexico's transmission grid. Figure D-1 outlines the modeling steps that were applied to model a set of physical transmission paths in the power-flow model and reinforce the PSLF[36] transmission grid model as needed to ensure reliable power delivery. The WECC western regional model originally contained more than 30,000 components (including 20,000 lines, 6,500 transformers, and 1,300 shunts).

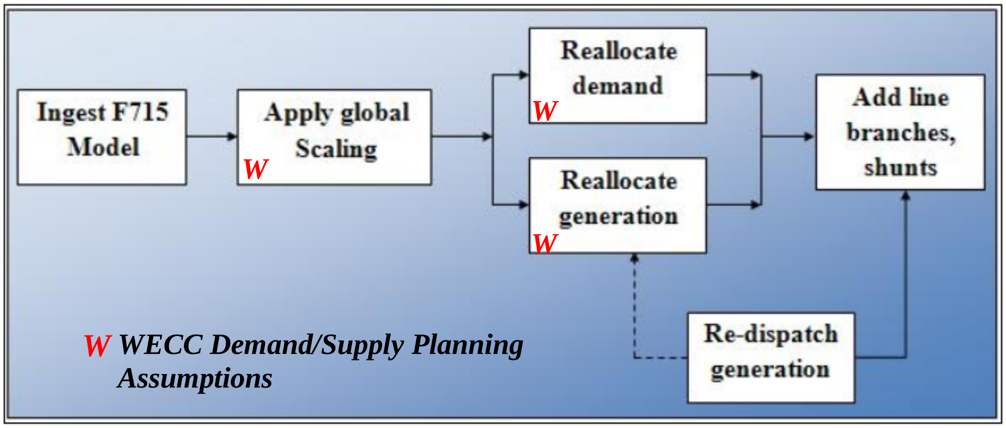

Figure D-1. Manual/Automated Modeling Steps

An automated transmission expansion tool (***TRANS-EX***) was applied to New Mexico's grid model. It is designed to reinforce the grid on a circuit-by-circuit basis, given line overloads and voltage excursions. The model building process applied by LANL iteratively reinforced circuits as needed with the automated tool. The baseline 2030 FERC 715 model was initially created by scaling all demand and generation elements globally.[37] Two types of elements were then added to increase grid transmission capacity:

- ***Line branches***: multi-conductor lines or dual circuits, transformers
- ***Line shunts***: capacitors, inductors

Line branch elements include additions of new (dual circuit) lines within existing corridors, up-rating existing conductors with larger wire and adding substation transformers. The net effect of these additions was to provide higher capacity meshed flow paths for power flowing throughout the grid. Line shunt elements include additions of capacitors or inductors. The net effect of these additions was to provide voltage reinforcement to support the magnitude of reactive power flows needed. The modeling process developed by LANL included increases in grid operating voltage for specific transmission lines, described in this report as "voltage step."

Transmission elements were added to ensure the model solved within normal operating range.

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[36] Positive Sequence Load Flow (PSLF) is a commercial utility analysis package offered by GE Energy, Schenectady NY.

[37] The 2030 FERC 715 model was created by scaling a utility-filed 2016 FERC 715 model to demand and generation levels forecasted by WECC for 2030. It serves as a baseline for comparison, allowing key features of the model to be simply expanded in place. At this step, no significant planning adjustments were made to accommodate large amounts of distributed renewable generation.

By completing the outlined model preparation steps, a solvable PSLF power-flow model was obtained. This analysis incorporates two levels of screening analysis with these features:

- ***Direct Current (DC) power-flow screening***[38] of the entire WECC 2030 electric system (more than 25,000 elements): this screening does not account for grid voltage problems that are addressed in the next screening level.
- ***Alternating Current (AC) power-flow validation***[39] of the most severe events reported by DC screening: the AC screening is intended to be a feasible representation of actual utility response, although not necessarily duplicative.

The first step of screening, loss of DC, is used to quickly scan the New Mexico grid to identify major weaknesses due to transmission line overloads. An overload will be caused by loss of a major element, such as a high-voltage substation, and a subsequent inability of the system to rebalance line flows within acceptable limits. Critical operating parameters, such as voltage, are not evaluated in this step. All analyses are performed for peak-day conditions.

The DC criterion used to determine the extent of a reportable problem is based on 100 percent current (thermal) rating of a conductor. This is more conservative than the limit used by many utilities, which is based on short-term emergency (STE) ratings, averaged over 15 minutes. Typically, the STE is higher than thermal rating.

DC power-flow screening is followed by AC power-flow validation, which is used to investigate severe events that result in a range of effects caused by reactive power disruptions. These analyses, termed the AC validation, are used to validate grid designs that result in a range of effects caused by reactive power. In these types of events, the contingency impact greatly exceeds a utility's N-1 planning criteria and may create large voltage impacts on the regional or control area grid. To restrict the contingency to relatively localized effects within its host control area, the screening analysis mitigates power imbalances locally, employing a method to adjust power imbalances from within the control area, maintaining a net export of power. For more severe outages, it may result in large power generation changes that must then be redistributed by dispatching.

The AC criterion used to determine the extent of reportable problems was a minimum of 0.93 per-unit[40] voltage with a decrease of 0.02 or greater from the base per-unit voltage for the unacceptable operating voltage limit; load shedding is performed to eliminate residual low voltages. For each electric contingency, effects on voltage, current, and other operating

[38] Direct current (DC) load flow screening is based on simplified dispatch and load shedding procedure initiated only by line thermal overloads. It utilizes a linearized approximation to power flow equations and is used to estimate power flows through transmission lines on an AC grid.

[39] Alternating current (AC) load flow screening incorporates control area balancing, identification of voltage problems, more sophisticated dispatching, and load shedding. It utilizes a full solution to power flow equations and is an exact representation of all effects in the system

[40] ***Per-unit*** is the expression of system quantities as fractions of a defined base unit quantity. Calculations are simplified because quantities expressed as per-unit are the same regardless of the voltage level.

parameters are reported for the system. Generating plants are dispatched[41] to try to reduce or eliminate any grid violations.

In the final step, economic dispatch weights were applied, by generating unit, to account for the must-run status of renewables and proportion of conventional to renewable capacity installed in each NREL wind region. (See Appendix A for wind region assignments.) Conventional generators were assigned weights based on three fuel types: GT/CT, MUST-RUN, and STEAM.[42] Renewables were weighted as MUST-RUN but adjusted to account for capacity factors provided by NREL. Re-dispatching was undertaken in an attempt to mitigate all remaining line overloads. This process was intended to serve as the final step in model preparation. Once the dispatch schedule is fixed, all generator injections were modified in the PSLF power-flow model. This step provided a coarse, incremental adjustment to overall supply balance.

[41] Dispatching is applied during a contingency to reduce line overloads or correct other violations. It requires adjustment of many generating plants to reduce or eliminate the violation and re-establish system balance.

[42] GT/CT: Gas turbine or combined cycle; MUST-RUN: renewable, hydro; STEAM: fossil-fueled (coal)