BEFORE THE NEW MEXICO PUBLIC REGULATION COMMISSION

IN THE MATTER OF PUBLIC SERVICE)
COMPANY OF NEW MEXICO'S)
CONSOLIDATED APPLICATION FOR)
APPROVALS FOR THE ABANDONMENT,)   19-_____-UT
FINANCING, AND RESOURCE REPLACEMENT)
FOR SAN JUAN GENERATING STATION)
PURSUANT TO THE ENERGY TRANSITION ACT)

DIRECT TESTIMONY

OF

NICK WINTERMANTEL

July 1, 2019

NMPRC CASE NO. 19-_____-UT
INDEX TO THE DIRECT TESTIMONY OF
NICK WINTERMANTEL

WITNESS FOR
PUBLIC SERVICE COMPANY OF NEW MEXICO

PNM Exhibit NW-1   Resume of Nick Wintermantel

PNM Exhibit NW-2   Astrapé RFP Evaluation Report

AFFIDAVIT

1   I.   INTRODUCTION AND PURPOSE

2 **Q.   PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.**

3 **A.**   My name is Nick Wintermantel, and my business address is 1935 Hoover Court,

4   Hoover, AL, 35226.

5

6 **Q.   WHAT IS THE PURPOSE OF YOUR TESTIMONY?**

7 **A.**   My testimony summarizes the evaluation process Astrapé Consulting ("Astrapé")

8   used to determine generation resource recommendations to replace San Juan

9   Generating Station ("SJGS") Units 1 and 4 and the results of that evaluation

10   process. I am including PNM Exhibit NW-2 with my testimony which is a full

11   report of the evaluation performed by Astrapé.

12

13 **Q.   PROVIDE A BRIEF OVERVIEW OF WHAT YOUR TESTIMONY**

14   **CONCLUDES.**

15 **A.**   My testimony concludes that the replacement resources that meet reliability

16   targets, and when combined provide reasonable risk and costs to customers, are:

17   seven aeroderivative gas units totaling 280 MW,[1] two combined solar battery

18   projects including a total of 60 MW of battery and 350 MW of solar, and two

19   stand-alone battery projects of 40 MW and 30 MW shown in PNM Table NW-1.

20   This combination of resources is the recommended plan submitted by Public

21   Service Company of New Mexico ("PNM" or "Company") and is discussed as

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[1] The 280 MW represents nameplate capacity. The net capability results in 269 MW for modeling
purposes.

1

1   Scenario 1. This set of resources takes advantage of the "best in class" offers, as

2   discussed in PNM Witness Nagel's testimony, across several technologies

3   including solar, battery, and natural gas resources while alleviating technology

4   risk for customers as discussed in PNM Witness Kemp's testimony. The selected

5   resources combine supplier-owned purchased power agreements ("PPAs") and

6   utility-owned Engineer Procure Construct ("EPC") projects. These replacement

7   resources, combined with the recent Renewable Portfolio Standard ("RPS") wind

8   resource of 140 MW[2] and the recent 50 MW PNM Solar Direct project, provide

9   great diversity to PNM's generation fleet.

10   **PNM Table NM-1 – Replacement Resources in Scenario 1**

Name	Resource Type	Nameplate Capacity	Ownership	Location
Jicarilla	Solar	50 MW	PPA	Rio Arriba
Arroyo	Solar	300 MW	PPA	McKinley
Jicarilla	Battery	20 MW	PPA	Rio Arriba
Arroyo	Battery	40 MW	PPA	McKinley
Sandia	Battery	40 MW	EPC	Bernalillo
Zamora	Battery	30 MW	EPC	Bernalillo
San Juan Gas	Natural Gas	280 MW	EPC	San Juan

11

12   Q.   BY WHOM ARE YOU EMPLOYED AND WHAT IS YOUR POSITION?

13   A.   I am a Principal Consultant and Partner at Astrapé, which is a consulting firm that

14   provides expertise in resource planning and resource adequacy to utilities across

15   the United States and internationally.

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[2] See New Mexico Public Regulation Commission Docket No. 19-00159-UT.

1   Q.   **PLEASE BRIEFLY SUMMARIZE YOUR EDUCATIONAL**

2   **BACKGROUND.**

3   A.   I graduated summa cum laude with a Bachelor of Science in Mechanical

4   Engineering from the University of Alabama in 2003 and a Master's degree in

5   Business Administration from the University of Alabama at Birmingham in 2007.

6   A copy of my resume is attached as PNM Exhibit NW-1.

7

8   Q.   **PLEASE DESCRIBE YOUR CONSULTING BACKGROUND AND**

9   **EXPERIENCE.**

10   A.   I have worked in the utility industry for over 19 years. I started my career at

11   Southern Company where I worked in various roles within Southern Power, the

12   competitive arm of the company, and on the retail side of the company within

13   Southern Company Services. In my various roles, I was responsible for

14   performing production cost simulations, financial modeling on wholesale power

15   contracts, general integrated resource planning, and asset management. In 2009, I

16   joined Astrapé as a Principal Consultant and have been responsible for resource

17   adequacy, resource planning, and renewable integration studies across the U.S.

18   and internationally.

19

20   Q.   **HAVE YOU PREVIOUSLY TESTIFIED IN UTILITY-RELATED**

21   **PROCEEDINGS?**

22   A.   I have testified in Georgia and provided written testimony in South Carolina and

23   North Carolina in utility-related proceedings. This is the first time I have

1   presented testimony before the New Mexico Public Regulation Commission

2   ("NMPRC" or "Commission").

3

4 Q.   **PLEASE   PROVIDE   AN   OVERVIEW   OF   YOUR   EXPERTISE**

5   **PERFORMING RESOURCE ADEQUACY AND PLANNING STUDIES.**

6 A.   Since being employed by Astrapé in 2009, I have managed target reserve margin

7   studies; capacity value studies of wind, solar, storage, and demand response

8   resources; resource selection decisions; and ancillary service studies for

9   integrating renewables. I performed these studies using Astrapé's proprietary

10   Strategic Energy Risk Valuation Model ("SERVM") used by utilities and system

11   operators across the U.S. and internationally. More recently, I performed studies

12   for companies seeking to increase their renewable penetrations, similar to PNM,

13   and have worked with our Astrapé team to develop a modeling framework within

14   SERVM to capture reliability, flexibility, and economics of varying resource

15   mixes.

16

17 Q.   **CAN YOU PLEASE EXPAND ON THE BUSINESS OF ASTRAPÉ?**

18 A.   Astrapé is the exclusive licensor of the SERVM model which is used by utilities,

19   system operators, and regulators to perform resource adequacy and planning

20   studies. Astrapé has managed SERVM licenses or performed studies for utilities

21   and regulatory organizations such as the Tennessee Valley Authority, Southern

22   Company, Duke Energy, Entergy, Pacific Gas & Electric, Louisville Gas &

23   Electric, and the California Public Utilities Commission. The SERVM model is

1   also used for resource adequacy by large independent operators such as the

2   Electric Reliability Council of Texas, the Southwest Power Pool, the Alberta

3   Electric System Operator, and the Midwest Independent System Operator.

4

5 **Q.**   **HAVE YOU PERFORMED CONSULTING SERVICES FOR PNM**

6   **BEFORE?**

7 **A.**   Yes. I have performed resource adequacy and resource planning studies for PNM

8   since 2013 using the SERVM model. A significant portion of Astrapé's work was

9   included in the Company's 2017 Integrated Resource Plan ("IRP"), which

10   included reliability and flexibility analysis for the PNM system. PNM now

11   licenses the SERVM model from Astrapé.

12

13 **II.   ASTRAPÉ'S ROLE AND THE SERVM MODELING FRAMEWORK**
14   **USED IN PNM'S RFP EVALUATION**

15 **Q.**   **BRIEFLY DESCRIBE ASTRAPÉ'S ROLE IN THE RFP EVALUATION.**

16 **A.**   After HDR Engineering, Inc. ("HDR") performed its screening evaluation to

17   develop its "best in class" RFP offers, as discussed in the testimonies of PNM

18   Witnesses Fallgren and Nagel, Astrapé was engaged to evaluate combinations of

19   these offers and recommend a set of low-cost replacement resources for PNM that

20   meet reliability targets.

21

1   Q.   **EXPLAIN WHY SYSTEM PRODUCTION COST AND RELIABILITY**

2   **MODELING IS REQUIRED TO EVALUATE DIFFERENT**

3   **REPLACEMENT RESOURCE COMBINATIONS.**

4   A.   The screening analysis performed by HDR analyzed each offer independently and

5   determined the low-cost offer by technology or "best in class," but did not provide

6   analysis of how the offers performed together or provide insight on how much

7   capacity to take of each technology. Production cost modeling is necessary in

8   order to understand how the range of different technologies perform within the

9   existing PNM generation fleet and with each other over the next 20-year period.

10   More importantly, the SERVM model assesses system reliability to help ensure

11   there is sufficient capacity and flexibility in each replacement resource

12   combination evaluated. For replacement resource combinations that meet

13   reliability requirements, the total system costs, including all production costs to

14   serve load and the fixed capital and O&M costs of the replacement resources (or

15   offers), are calculated to determine the net present value ("NPV") of expected

16   costs for each combination over the 20-year period. The costs of each

17   replacement resource combination can then be compared on a NPV basis.

18

19   Q.   **BRIEFLY DESCRIBE THE MODELING CHARACTERISTICS**

20   **REQUIRED TO PERFORM PRODUCTION COST AND RELIABILITY**

21   **MODELING ON PNM'S SYSTEM.**

22   A.   As the PNM system changes due to the retirement of base load resources and

23   higher renewable penetrations, future resource decisions must not only take into

1   account customer economics and reliability during peak demand, but also system

2   flexibility needs. This includes the capability of the system to meet unforeseen

3   net load ramps on an hourly and intra-hour basis. Typical planning studies utilize

4   load shapes and renewable profiles from a single weather year and only simulate

5   average unit performance characteristics. Since flexibility and reliability issues

6   are high impact, low-probability events, many scenarios of load, renewable

7   output, and conventional generator performance should be considered to

8   adequately capture their expected impact. In addition to considering many

9   scenarios to capture the reliability of the system, the production cost model should

10   also commit and dispatch resources chronologically, taking into account resource

11   characteristics such as startup times, ramp rates, minimum up times, and

12   minimum down times. By taking into account these resource characteristics, the

13   flexibility of the system can be assessed.

14

15   **Q.   BRIEFLY DESCRIBE THE SERVM MODEL.**

16   **A.**   As discussed in PNM Exhibit NW-2, the SERVM model is a chronological

17   production costing model and reliability model that takes into account the

18   uncertainty of weather, load forecast, generator outages, and intra-hour volatility

19   of intermittent resources. Thousands of yearly simulations are performed at 5-

20   minute time steps for each replacement resource combination, which allows the

21   model to calculate both reliability metrics and costs. SERVM respects all unit

22   characteristics including ramp rates, startup times, and minimum up and down

1   times. SERVM does not have perfect knowledge of net load[3] when it makes its

2   commitment and dispatch decisions. This is important since it mimics the

3   uncertainty faced by utility operators.

4

5   Q.   IN SIMPLE TERMS, PLEASE EXPLAIN THE RELIABILITY

6   ANALYZED AS PART OF THE EVALUATION.

7   A.   While reliability metrics and terms can come across as complex topics, it is

8   actually very simple. A Balancing Authority ("BA") such as the PNM BA must

9   plan to have enough capacity to serve its peak demand and have enough

10   flexibility or ramping capability in its generation fleet to meet its net load in real

11   time. As more intermittent resources are added to the system, the net load ramps

12   become larger requiring additional generation flexibility. To resolve generation

13   capacity shortages during peak demand periods, new generation capacity must be

14   installed or purchased. To resolve flexibility or system ramping problems,

15   additional online operating reserves are committed. Having additional reserves

16   available allows the system to mitigate the intra-hour and hourly ramps caused by

17   unforeseen solar, wind, and load ramps. Adding more flexible resources can also

18   be used to resolve flexibility problems.

19

---

[3] Net load is defined as gross load minus renewable resources and reflects the load the conventional fleet must serve on a minute to minute basis.

1   **Q.**   **HOW DOES SERVM MEASURE THE RELIABILITY OF THE PNM**

2   **SYSTEM FROM A CAPACITY AND FLEXIBILITY NEED**

3   **STANDPOINT?**

4   **A.**   SERVM calculates two reliability metrics for the PNM BA. Both of these metrics

5   use LOLE ("Loss of Load Expectation"), which is a count of the expected number

6   of days per year that load could not be met over the thousands of yearly

7   simulations performed. The first metric ("$LOLE_{CAP}$") measures capacity

8   shortfalls, while the second metric ("$LOLE_{FLEX}$") measures flexibility shortfalls.

9

10   **Q.**   **PLEASE FURTHER DESCRIBE $LOLE_{CAP}$.**

11   **A.**   The $LOLE_{CAP}$ metric represents the number of loss of load events due to capacity

12   shortages, calculated in events per year. Traditional LOLE calculations only

13   calculate $LOLE_{CAP}$. PNM Figure NW-2 shows an example of a capacity shortfall

14   which typically occurs across the peak of a day. In this example, all available

15   installed capacity was fully utilized but the load was greater than the generating

16   capacity causing a capacity shortfall. For these events, additional capacity must

17   be added to the system in order to reduce $LOLE_{CAP}$.

1
2

PNM Figure NW-2
LOLE$_{CAP}$ Example

3

4 **Q.** **PLEASE FURTHER EXPLAIN LOLE$_{FLEX}$.**

5 **A.** The LOLE$_{FLEX}$ metric is the number of loss of load events due to system

6 flexibility problems, calculated in events per year. In these events, there was

7 enough capacity installed but not enough flexibility to meet the net load ramps, or

8 startup times prevented a unit coming online fast enough to meet the

9 unanticipated ramps.

10

11 PNM Figure NW-3 shows an LOLE$_{FLEX}$ example occurring intra-hour. These

12 LOLE$_{FLEX}$ events are typically very short in duration and are caused by a rapid

13 drop in solar or wind resource output over a short time interval. Increasing online

10

1   spinning reserves or adding fast ramping capability resources can help resolve

2   these issues.

3   **PNM Figure NW-3**
4   **Intra-hour LOLE$_{FLEX}$**

5
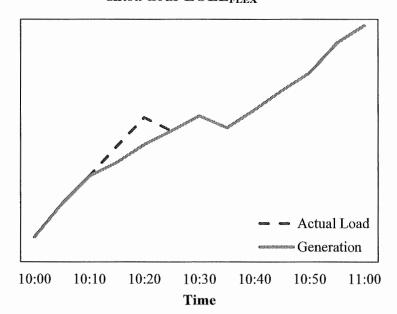
6   **Q.   HOW DID YOU ENSURE RELIABILITY METRICS WERE MET FOR**

7   **THE VARIOUS RESOURCE COMBINATIONS?**

8   **A.**   Each replacement resource combination modeled was developed to meet or be

9   below the LOLE$_{CAP}$ and LOLE$_{FLEX}$ criteria of 0.2 events per year.   If a

10   combination of replacement resources did not meet these criteria, either additional

11   capacity was added or additional online reserves were input into the model.   This

12   allows each replacement resource combination to be comparable rather than

13   allowing one combination to provide significantly lower reliability than another.

14

1 Q. **WHY WAS 0.2 EVENTS PER YEAR CHOSEN AS THE RELIABILITY**

2   **CRITERIA FOR LOLE$_{CAP}$ AND LOLE$_{FLEX}$?**

3 A. Based on the size of PNM's system, Astrapé recommended as part of the 2017

4   IRP that PNM target a 0.2 LOLE (two events in ten years) standard at a

5   minimum. The industry-standard reliability threshold is one firm load shed event

6   in ten years. This is known as the '0.1 LOLE' or '1-in-10 LOLE' standard. For

7   small systems with limited interconnections, this level of reliability is difficult and

8   costly to achieve. The simultaneous forced outage of two larger units during peak

9   conditions puts significant risk on smaller systems such as PNM's, compared to a

10   larger system with more than 50 generators.

11

12 Q. **DESCRIBE THE RELATIONSHIP BETWEEN RELIABILITY UNDER A**

13   **LOLE STANDARD AND RENEWABLE CURTAILMENT.**

14 A. LOLE events are times when generation cannot meet net load requirements;

15   renewable curtailment occurs when resources are greater than net load causing

16   over-generation periods. During these periods, the system cannot ramp down fast

17   enough to meet net load or all online generators are dispatched at minimum but

18   are still producing more than system net load needs. Renewable curtailment is

19   expected in systems with large renewable penetration and impacts the economics

20   of each replacement resource combination evaluated. In general, as renewable

21   penetration increases, renewable curtailment will increase. For modeling

22   purposes, there was no additional penalty included for renewable curtailment

23   other than the cost associated with generation that was not used to serve load.

1   Q.   **WHAT ARE THE IMPLICATIONS OF CAPTURING 5-MINUTE INTRA-**

2   **HOUR VOLATILITY OF LOAD, WIND, AND SOLAR IN THE MODEL?**

3   A.   By modeling the system on a 5-minute basis and capturing the volatility or

4   unexpected movement of load, wind, and solar, the dispatchable generation fleet

5   is forced to follow net load and absorb this volatility to maintain reliability. This

6   modeling framework quantifies the savings that flexible resources such as battery

7   or fast-start gas resources provide to the system, as compared to slower-starting

8   resources with poor ramping capability. This modeling also captures the

9   additional costs that inflexible resources such as solar and wind have on the

10   system since these resources cause the dispatchable fleet to ramp up and start up

11   more frequently in order to maintain reliability.

12

13   Q.   **OVER WHAT TIME HORIZON WERE THE REPLACEMENT**

14   **RESOURCE COMBINATIONS SIMULATED?**

15   A.   Consistent with PNM's 2017 IRP, the SERVM analysis was performed over a

16   period of 20 years. Due to the number of iterations required in reliability

17   modeling, study years 2023, 2028, and 2033 were simulated and production costs

18   were interpolated to produce 20-year production costs. Fixed costs, including

19   capital costs, O&M, transmission costs, and fixed gas transportation if applicable,

20   of the replacement portfolio were included over the 20 year period. The

21   expansion plan beyond the replacement resources was held constant across each

22   replacement resource combination analyzed.

23

1   Q.   **WHAT IS INCLUDED IN TOTAL SYSTEM NET PRESENT VALUE**

2   **COSTS WITHIN THE MODELING?**

3   A.   The results are the NPV over 20 years of the annualized production costs, net

4   purchase costs, and fixed costs of the replacement resources. Production costs

5   include all fuel burned, variable O&M costs, startup costs, and CO_2 costs for the

6   entire PNM Balancing Area. To calculate the NPV, Astrapé used PNM's most

7   recent weighted average cost of capital (7.2%) that was approved in the last rate

8   case.

9

10   **III.   SERVM MODELING INPUTS AND PARAMETERS**

11 Q.   **DID   THE   COMPANY   USE   OTHER   RESOURCE   PLANNING**

12   **MODELING SOFTWARE?**

13 A.   Yes. PNM also performed simulations with Encompass and PowerSimm.

14

15 Q.   **WERE THE MODELING INPUTS USED IN SERVM THE SAME INPUTS**

16   **USED IN THE ENCOMPASS MODELING PERFORMED BY THE**

17   **COMPANY?**

18 A.   Yes, as shown in detail in PNM Exhibit NW-2, the inputs were aligned to match

19   loads, resources, and fuel forecasts included in the Company's Encompass

20   modeling. As discussed previously, the SERVM model was simulated for the

21   2023, 2028, and 2033 study years. The Company provided an expansion plan

22   beyond the replacement resources which consisted of solar, wind, and battery

1 resources to meet future RPS and carbon targets. In order to ensure the reliability

2 of PNM's system in 2028 and 2033, the magnitude of solar, wind, and battery was

3 adjusted accordingly.

4

5 **Q.** **WHAT FUEL FORECAST AND CO2 FORECASTS WERE USED?**

6 **A.** See Table 9 in PNM Exhibit NW-2. The natural gas prices are based on a blend

7 of forward pricing and gas pricing forecasts provided by Pace Global ("Pace") for

8 PNM. Gas forwards from April 26, 2019 were utilized for the first 10 years;

9 thereafter, forward pricing was scaled to the Pace forecast curve to project pricing

10 for the next 10 years. CO_2 pricing was derived from Pace Global to reflect a 20-

11 year forecast of national costs per ton of CO_2 emitted.

12

13 **Q.** **WHAT LOAD FORECAST WAS USED IN THE MODELING?**

14 **A.** See Table 5 in PNM Exhibit NW-2. These load forecasts reflect an update from

15 the 2017 IRP and the Company's latest peak demand and energy forecasts.

16

17 **Q.** **WHAT NEIGHBORING REGIONS WERE MODELED WITHIN SERVM?**

18 **A.** Neighboring regions adjacent to the PNM BA were modeled. From a capacity

19 standpoint, it is important that the modeling recognizes market assistance during

20 extreme scenarios for PNM. For instance, when PNM's load is higher than

21 expected and several generators are on outage, PNM will make hourly purchases

22 if surrounding neighboring regions have excess capacity and transmission is

23 available. Also, during renewable curtailment hours, there is potential for PNM

1   to sell to these neighbors assuming they are not curtailing renewable resources as

2   well. From discussions with the Company and analysis of historical data,

3   purchases were limited to 150 MW of day ahead purchases and up to 150 MW of

4   non-firm purchases.

5

6   **IV.   SUMMARY OF OFFERS EVALUATED IN ASTRAPÉ'S MODELING**

7   **Q.   PLEASE PROVIDE A LIST OF THE RFP RESOURCES THAT HDR**

8   **PROVIDED TO YOU FOR MODELING PURPOSES.**

9   **A.**   The following Table NW-4 shows the resources that were considered for

10   modeling and provided by HDR. These offers are summarized in Tables 2 – 4

11   from PNM Exhibit NW-2. The offers were the "best in class" offers by

12   technology and were further split into Tier 1 and Tier 2 based on initial rankings

13   performed by HDR. The Tier 1 offers were used to create combinations of

14   replacement resources that would meet an $LOLE_{CAP}$ and $LOLE_{FLEX}$ of

15   approximately 0.2 events per year to ensure system reliability. Capacity was

16   added or removed to achieve the $LOLE_{CAP}$ target and operating reserve

17   assumptions were increased or decreased to achieve $LOLE_{FLEX}$ targets. Tier 2

18   offers, which were ranked further down in HDR's screening evaluation, were

19   used to stress test the least cost combinations resources found in the Tier 1

20   Modeling to understand if more optimal combinations existed. Note that the Tier

21   1 wind resource was already selected as the 2019 RPS resource by PNM due to

22   the early availability of this wind resource in 2020 and the changes in the RPS

1   standard requirements as part of the Energy Transition Act. Therefore this 140

2   MW is included in all replacement resource combinations.

3   **PNM Table NW-4. Summary of Tier 1 and Tier 2 Offers**

Technology	Tier 1/Tier 2	Capacity per Unit MW*
Solar	Tier 1	300
Solar	Tier 1	50
Solar	Tier 1	150
Solar	Tier 1	150
Solar	Tier 1	50
Wind	Tier 1	140**
Solar/Battery	Tier 1	300/150
Battery	Tier 1	200
Battery	Tier 1	100
Battery	Tier 1	40
Battery	Tier 1	40
Gas: 4-10 Aero-derivatives	Tier 1	38.44
Gas: Frame	Tier 1	196.1
Gas: 10-20 Recips	Tier 1	16.91
Gas: 1 Aero-derivative	Tier 1	38.44
Wind	Tier 2	400
Wind	Tier 2	200
Solar/Battery	Tier 2	50/20
Solar/Battery	Tier 2	150/40
Battery	Tier 2	40
Battery	Tier 2	100

4   ***Represents solar/battery MW for combined solar/battery technologies**
5   ****Selected as the 2019 RPS Resource and included in all replacement resource**
6   **combinations**
7

1   **V.**   **REPLACEMENT RESOURCE EVALUATION AND RESULTS**

2   **Q.**   **HOW DID ASTRAPÉ DEVELOP REPLACEMENT RESOURCE**

3   **COMBINATIONS WITH THE SHORTLISTED OFFERS FOR THE**

4   **MODELING?**

5   **A.**   As discussed in PNM Exhibit NW-2, resource combinations including only

6   renewable options (wind and solar offers) were explored first but were found to

7   not meet reliability requirements unless capacity resources were also added.

8

9   Next, using the Tier 1 offers as discussed above, replacement resource

10   combinations were designed to analyze varying amounts of solar (0 MW to 700

11   MW) with capacity resources including battery and gas technology to capture the

12   full range of possible combinations that could meet reliability. As discussed

13   previously, only the single wind offer selected as the 2019 RPS resource was

14   included in the Tier 1 modeling because the next best wind offers were

15   significantly more costly. These next best wind offers were analyzed as part of

16   the Tier 2 Modeling to understand if those offers were economic. The possible

17   combinations within the Tier 1 Modeling included "bookends" that ran from all

18   gas scenarios to all battery/renewable makeups. Table 23 in Exhibit NW-2 shows

19   all the combinations that were modeled as part of the Tier 1 Modeling. The

20   magnitude of the capacity resource included in each combination was the amount

21   needed to meet reliability thresholds. As noted earlier, "only renewables"

22   scenarios failed system reliability parameters. Each of the capacity resources (gas

1   and battery offers) were similarly analyzed with the varying solar offers (0 to 700

2   MW) to determine reliability and costs of each combination. Combinations of

3   battery options and combinations of gas options were also analyzed such as stand-

4   alone batteries with combined solar/battery and aero-derivatives with

5   reciprocating engines. A total of 81 different replacement resource combinations

6   were simulated as part of the Tier 1 Modeling. If reliability was not met, and

7   there were no more Tier 1 resources for that technology being simulated then Tier

8   2 resources were added. For example, in a few of the all battery/renewable

9   combinations, the Tier 2 battery options had to be added for reliability.

10

11   **Q.   WHY WAS IT NECESSARY TO ANALYZE COMBINATIONS OF**

12   **RESOURCES IN THIS MANNER?**

13   **A.**   This analysis of potential combinations showed which capacity resource

14   proposals optimally integrated the different amounts of renewable generation

15   amounts while maintaining system reliability. The analysis ultimately indicated a

16   range of how much capacity of each technology should be built. In the initial Tier

17   1 and Tier 2 Modeling, there was no constraint put on capacity for a given

18   technology or capacity size on a single project and therefore the most optimal

19   combination of replacement resources is represented from this modeling.

20

21   **Q.   WHAT WAS THE OPTIMAL UNCONSTRAINED REPLACEMENT**

22   **RESOURCE COMBINATION FROM THE TIER 1 MODELING MATRIX**

23   **THAT MET RELIABILITY METRICS?**

1   A.   The best performing replacement resource combination consisted of 350 MW of

2   solar, 150 MW of battery, and 269 MW of aeroderivative capacity shown in PNM

3   Table NW-5. The combination is represented by the least cost gas, solar, and

4   battery options. There was a substantial increase in energy price for the next

5   cheapest solar option which explains why only 350 MW of solar was selected.

6

7   **PNM Table NW-5. Tier 1 Modeling Optimal Cost Replacement Resources**

	Aeroderivatives	Recips	Frame	Battery	Solar
	MW	MW	MW	MW	MW
Tier 1 Optimal Replacement Resource Combination	269	-	-	150	350

8

9   Q.   **HOW DID THE ALL RENEWABLE AND STORAGE (NO GAS)**

10   **COMBINATIONS PERFORM WITHIN THE TIER 1 MODELING?**

11   A.   The results did not show that an all energy storage and battery combination was

12   the best performing option. While battery is included in the unconstrained best

13   performing option, the costs of battery bids to fill the entire capacity need was

14   more expensive than other low cost gas alternatives.

15

16   Q.   **DESCRIBE THE DIFFERENCES IN THE GAS OPTIONS AND WHY**

17   **THE AERODERIVATIVES RESOURCES WERE SELECTED OVER**

18   **OTHER OPTIONS.**

19   A.   The aeroderivatives and frame offers had similar fixed costs but the

20   aeroderivatives provide more flexibility, especially given their low minimum

1   capacity levels. The reciprocating engines provide more flexibility and slightly

2   cheaper energy costs, but those benefits do not overcome the fixed cost premium

3   on these offers. Across the entire Tier 1 combinations, the aeroderivatives

4   outperformed the frame and reciprocating engine offers.

5

6 Q.   **HOW WERE TIER 2 REPLACEMENT RESOURCE COMBINATIONS**

7   **DEVELOPED?**

8 A.   Tier 2 offers were included in the optimal replacement resource combination

9   found in the Tier 1 Modeling to understand if the economics improved.

10   Additional Tier 2 wind offers were added first which did not improve the

11   economics due to the higher costs of those incremental wind resources. Then,

12   additional hybrid battery/solar and stand-alone battery projects were added. The

13   batteries were allowed to replace both the aeroderivatives and 150 MW battery

14   project. Table 25 in Exhibit NW-2 shows all the combinations that were modeled

15   as part of the Tier 2 Modeling.

16

17 Q.   **WHAT WAS THE OPTIMAL UNCONSTRAINED REPLACEMENT**

18   **RESOURCE COMBINATION FROM THE TIER 2 MODELING MATRIX**

19   **THAT MET RELIABILITY METRICS?**

20 A.   The Tier 2 Modeling produced a combination that improved upon the Tier 1

21   Modeling which is shown in Table NW-6 below. This combination of resources

22   removed a single aeroderivative and added 20 MW of battery which better

23   optimized the capacity need and maintained flexibility on the system. This

1   combination included two combined solar plus battery projects. The first

2   included 300 MW of solar and 150 MW of battery and the second included 50

3   MW of solar and 20 MW of battery.

4

5   **PNM Table NW-6 Tier 2 Modeling Optimal Cost Replacement Resources**

	Aeroderivatives	Recips	Frame	Battery	Solar
	MW	MW	MW	MW	MW
Tier 1 Optimal Unconstrained 2023 Replacement Resources	269	-	-	150	350
Tier 2 Optimal Unconstrained 2023 Replacement Resources	231	-	-	170	350

6

7   **Q.**   **WERE ADDITIONAL OWNERSHIP BATTERY OFFERS CONSIDERED**

8   **AS PART OF THIS ANALYSIS?**

9   **A.**   Yes. While the original set of bids in the Tier 1 and Tier 2 Modeling included a

10   large number of PPA bids, the utility owned bids were limited due to a lack of

11   bidders having NM state contractor licenses. Because some original bidders were

12   automatically rejected for that reason, PNM solicited additional utility owned

13   battery proposals through a supplement to the original RFP in order to ensure a

14   range of ownership battery options would be evaluated.

15

16   **Q.**   **DESCRIBE THE ANALYSIS PERFORMED BY ASTRAPÉ TO**

17   **INCORPORATE THE STORAGE OWNERSHIP PROPOSALS**

18   **PROVIDED IN MAY OF 2019.**

1   A.   The unconstrained optimal combination of resources found in the Tier 2 modeling

2   was modeled with the low cost storage ownership proposals. This was done in

3   multiple combinations by removing gas resources and the battery resources

4   included in Tier 2 least cost combination of resources.

5

6   Q.   **HOW DID THE STORAGE OWNERSHIP OPTIONS PERFORM?**

7   A.   In comparison to the optimal unconstrained replacement resource combination,

8   the battery ownership options did not improve the economics. The large 300 MW

9   solar plus 150 MW battery PPA offer was less expensive than the battery

10   ownership options due to the low cost of these options as a result of qualifying for

11   the Investment Tax Credits.

12

13   Q.   **WHAT RISKS WERE IDENTIFIED IN THE UNCONSTRAINED**

14   **OPTIMAL SET OF REPLACEMENT RESOURCES?**

15   A.   As part of the Company's review, PNM asked Enovation Partners to review this

16   least cost set of replacement resources with a focus on energy storage since it

17   included a 150 MW battery. Enovation Partners as expressed in Witness Kemp's

18   testimony recommended that initial energy storage implementation by PNM

19   should not be beyond 2% - 5% of the system peak load and that individual

20   projects should be between 10 MW and no more than 40 MW. PNM accepted

21   this recommendation and asked Astrapé for further modeling with this constraint.

22

1   Q.   **AS A MODELER THAT LOOKS AT SYSTEM RELIABILITY AND**

2   **RISKS WHAT IS YOUR OPINION OF THAT APPROACH TO LIMITING**

3   **BATTERY SIZES AND OVERALL RESOURCES?**

4   A.   I support this approach. While the model is an excellent tool to compare

5   reliability and costs, there are attributes and factors that must be considered that

6   don't automatically translate in the model results and must be separately

7   incorporated. One of these is the risk associated with development and

8   deployment of new technology.

9

10 Q.   **HOW DID ASTRAPÉ INCORPORATE THIS CONSTRAINT?**

11 A.   The unconstrained optimal set of resources was modified to maintain smaller

12   energy storage options and limit the energy storage to 130 MW. The Tier 1 and

13   Tier 2 modeling approach demonstrated that the aeroderivative resources were the

14   best capacity resource other than battery capacity and that 350 MW of solar was

15   economic. Next, permutations with the least cost smaller battery offers (both PPA

16   and ownership options) were simulated similar to the Tier 2 Modeling approach.

17

18 Q.   **WHAT WERE THE RESULTS OF THIS CONSTRAINED MODELING?**

19 A.   The results of this analysis are shown in PNM Table NW-7which sorts the

20   replacement resource combinations that were simulated with these constraints.

21   The top 5 combinations are separated by an NPV of 2 million meaning they are

22   essentially equal from an economics basis. Given the other battery ownership

23   benefits discussed by PNM Witness Kemp and the fact that the differences in

1   economics are negligible, the Company proposes the third replacement resource

2   combination on the list. With battery ownership, PNM will have more flexibility

3   in the operation of those resources as more is learned about the operations through

4   the 20 year period. This proposed plan includes 269 MW of aeroderivatives, 350

5   MW of solar, and 130 MW of battery. The 130 MW of battery consists of a 40

6   MW PPA, 20 MW PPA, 40 MW ownership option, and 30 MW ownership

7   option. This combination is discussed by the Company as Scenario 1.

8

9   **PNM Table NW-7 Constrained Replacement Resource Combinations Sorted by**
10   **Least Cost**

Resource Replacement Combination	LM6000	PPA Battery	Ownership Battery	Solar	Total NPV	NPV Fixed Costs	NPV Production Costs
	MW	MW	MW	MW	M$	M$	M$
Constrained – 1	269	140	0	350	$4,677	$470	$4,207
Constrained – 2	307	100	0	350	$4,678	$461	$4,217
Constrained - 3 (Proposed Plan)	269	60	70	350	$4,678	$472	$4,206
Constrained – 4	345	40	0	350	$4,678	$430	$4,248
Constrained – 5	307	60	40	350	$4,679	$469	$4,210
Constrained – 6	269	140	0	370	$4,679	$482	$4,198
Constrained – 7	269	60	70	370	$4,679	$483	$4,196
Constrained – 8	269	100	40	350	$4,683	$476	$4,207
Constrained – 9	231	140	30	350	$4,693	$485	$4,208
Constrained – 10	345	60	0	350	$4,696	$456	$4,240
Constrained – 11	231	100	70	350	$4,698	$491	$4,207
Constrained – 12	269	140	0	500	$4,702	$449	$4,253
Constrained – 13	307	100	0	500	$4,708	$442	$4,266
Constrained – 14	345	0	40	350	$4,711	$457	$4,254
Constrained – 15	345	40	0	500	$4,718	$430	$4,288
Constrained – 16	345	60	0	350	$4,724	$474	$4,250
Constrained – 17	383	20	0	350	$4,726	$470	$4,256
Constrained – 18	345	60	0	500	$4,735	$456	$4,280
Constrained – 19	383	40	0	350	$4,758	$503	$4,255

11

1   **Q.**   **IS SERVM ABLE TO MODEL ALL OF THE UNIQUE BATTERY**

2   **VALUES?**

3   **A.**   SERVM is able to capture the capacity, energy, and ancillary service benefits of

4   battery but is not able to determine transmission and distribution locational

5   benefits. These must then be addressed beyond the model outputs. Not included

6   in my analysis, the Company determined that there was an additional transmission

7   benefit of the ownership options of approximately $11/kW-yr which would

8   further support the Company's decision to move forward with the combination of

9   replacement resources that included the ownership battery options. These

10   additional benefits were not included in PNM Table NW-7 above.

11

12   **Q.**   **WHAT ADDITIONAL RESOURCE COMBINATIONS DID PNM HAVE**

13   **YOU SIMULATE?**

14   **A.**   The Company requested Astrapé run 3 additional scenarios to compare against the

15   proposed plan. These were developed by PNM's resource planning department

16   and respect the 40 MW battery size project limit. These included the following:

17

18   Scenario 1 – This scenario is the proposed plan discussed above. It includes

19   seven aeroderivatives consisting of 269 MW, a combined solar/battery project

20   consisting of 300 MW of solar and 40 MW of battery, a combined solar/battery

21   project consisting of 50 MW of solar and 20 MW of battery, and two standalone

22   battery ownership projects consisting of 40 MW and 30 MW.

1   Scenario 2 - San Juan Location Preference Alternative Scenario – This scenario

2   included the least cost resources in the San Juan Location which included 7

3   aeroderivatives and 1 Frame machine.

4

5   Scenario 3 - No New Fossil Fuel Alternative Scenario – This scenario included

6   the least cost battery projects that were less than 40 MW and renewable resources.

7   It included 500 MW of solar and 11 battery projects summing to 410 MW. The

8   11 different battery projects included 7 PPA options and 4 ownership options.

9

10   Scenario 4 - All Renewable Replacement Scenario – This scenario includes all

11   renewable capacity. This scenario includes all wind and solar PPA projects

12   consisting of 1,200 MW of wind and 975 MW of solar.

13

14   Q.   **PLEASE SUMMARIZE THESE ADDITIONAL SCENARIOS AND THEIR**

15   **COSTS COMPARED TO THE RECOMMENDED COMBINATION.**

16   A.   These scenarios were treated in the same manner as all the other combinations

17   that were simulated as part of the Tier 1 and Tier 2 Modeling and battery

18   constrained approach. The results are shown in PNM Table NW-8 below. Of the

19   4 replacement resource scenarios put forth by the Company, the proposed plan is

20   the most economic. Scenario 2 has an NPV of $54 million more than Scenario 1

21   while Scenario 3 has an NPV of $156 million higher than Scenario 1. Scenario 4

22   is even more expensive due to all the renewable curtailment caused in that case

23   but still does not meet reliability criteria. Scenario 3 is unreliable as well and

1   would require additional capacity making the costs in the below table for that

2   scenario lower than what they would be if they were forced to be reliable.

3

4   **PNM Table NW-8 Additional Scenarios Provided by the Company**

Resource Replacement Combination	LM6000	Frame	PPA Battery	Owned Battery	Solar	Wind	Total NPV
	MW	MW	MW	MW	MW	MW	M$
Scenario 1 – Proposed Plan	269	0	60	70	350	140	$4,678
Scenario 2 – SJ preferred	269	196	0	0	0	140	$4,732
Scenario 3 – No Gas	0	0	260	150	500	140	$4,834
Scenario 4 – All renewable	0	0	0	0	975	1,199	$5,452

5

6   **VI.   ADDITIONAL CASE SUPPORT**

7   **Q.   OUTSIDE OF THE REPLACEMENT RESOURCE EVALUATION, ARE**

8   **YOU SUPPORTING ANY OTHER ANALYSIS AS PART OF THE**

9   **OVERALL CASE?**

10   **A.**   Yes, Astrapé provided fuel outputs from the SERVM runs in the evaluation to

11   PNM Witness Monroy for 2023. This 2023 data was provided for Scenarios 1 – 4

12   discussed above as well as the San Juan coal plant continues scenario.

13

14   **Q.   WITNESS MECHENBIER DESCRIBES ADDITIONAL ANALYSIS YOU**

15   **PERFORMED ON SCENARIO 1 IN RELATION TO THE 650 MW**

16   **EXPORT LIMIT. PLEASE EXPLAIN.**

17   **A.**   Within the SERVM simulations, Astrapé performed analysis on a few of the

18   8,760 hourly runs to see what percentage of hours the output of the 269 MW for

1   the gas turbine facility; 50 MW associated with Jicarilla Solar 1 (which includes a

2   20 MW battery energy storage facility but will be limited to 50 MW export

3   capability); 300 MW associated with Arroyo Solar (which includes a 40 MW

4   battery energy storage facility but will be limited to 300 MW export capability);

5   and 50 MW associated with Jicarilla Solar 2 for the PNM Solar Direct Project,

6   was above 649 MW. That analysis demonstrated that 0.03% of the hours (less

7   than 3 hours out of 8,760 hours) would have a simultaneous output above 649

8   MW. This is due to the intermittent nature of the 400 MW of solar and the fact

9   that the small aeroderivatives are usually serving some level of ancillary services

10   and not operating at full output. Based on these factors, any curtailment due to

11   transmission is estimated to be minimal.

12

13   **VII.   CONCLUSIONS**

14   **Q.   BASED ON THE MODELING, WHAT IS ASTRAPÉ'S CONCLUSION?**

15   **A.**   Based on the evaluation performed by Astrapé, the proposed plan of replacement

16   resources including 350 MW of solar, 130 MW of battery, and 269 MW of gas

17   meets reliability criteria and provides reasonable costs given the technology

18   constraints imposed. These replacement resources provide a diverse set of

19   resources and take advantage of the lowest cost renewable, battery, and gas offers

20   submitted into the RFP

21

1 **Q.** **DOES THIS CONCLUDE YOUR TESTIMONY?**

2 **A.** Yes, it does.

GCG#525661

Resume of Nick Wintermantel

PNM Exhibit NW-1

Is contained in the following 3 pages.

Nick Wintermantel | Principal, Astrapé Consulting, LLC

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Hoover, AL 35226
(205) 988-4404
nwintermantel@Astrapé.com

Mr. Wintermantel has 18 years of experience in utility planning and electric market modeling, Areas of utility planning experience includes utility integrated resource planning (IRP) for vertically-integrated utilities, market price forecasting, resource adequacy modeling, RFP evaluations, environmental compliance analysis, asset management, financial risk analysis, and contract structuring. Mr. Wintermantel also has expertise in production cost simulations and evaluation methodologies used for IRPs and reliability planning. As a consultant with Astrapé Consulting, Mr. Wintermantel has managed reliability and planning studies for large power systems across the U.S. and internationally. Prior to joining Astrapé Consulting, Mr. Wintermantel was employed by the Southern Company where he served in various resource planning, asset management, and generation development roles.

⟁ Experience

Principal Consultant at Astrapé Consulting (2009 – Present)
Managed detailed system resource adequacy studies for large scale utilities
Managed ancillary service and renewable integration studies
Managed capacity value studies
Managed resource selection studies
Performed financial and risk analysis for utilities, developers, and manufacturers
Demand side resource evaluation
Storage evaluation
Served on IE Teams to evaluate assumptions, models, and methodologies for competitive procurement solicitations
Project Management on large scale consulting engagements
Production cost model development
Model quality assurance
Sales and customer service

Sr. Engineer for Southern Company Services (2007-2009)
Integrated Resource Planning and environmental compliance
Developed future retail projects for operating companies while at the Southern Company
Asset management for Southern Company Services

Sr. Engineer for Southern Power Company (Subsidiary of Southern Company) (2003-2007)
Structured wholesale power contracts for Combined Cycle, Coal, Simple Cycle, and IGCC Projects
Model development to forecast market prices across the eastern interconnect
Evaluate financials of new generation projects
Bid development for Resource Solicitations

Cooperative Student Engineer for Southern Nuclear (2000-2003)
Probabilistic risk assessment of the Southern Company Nuclear Fleet

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➤ Industry Specialization

Resource Adequacy Planning	Resource Planning	Integrated Resource Planning
Competitive Procurement	Asset Evaluation	Financial Analysis
Environmental Compliance Analysis	Generation Development	Capacity Value Analysis
Renewable Integration	Ancillary Service Studies	

➤ Education

MBA, University of Alabama at Birmingham – Summa Cum Laude
B.S. Degree Mechanical Engineering - University of Alabama - Summa Cum Laude

Relevant Experience

➤ Resource Adequacy Planning and Production Cost Modeling

Tennessee Valley Authority: Performed Various Reliability Planning Studies including Optimal Reserve Margin Analysis, Capacity Benefit Margin Analysis, and Demand Side Resource Evaluations using the Strategic Energy and Risk Valuation Model (SERVM) which is Astrapé Consulting's proprietary reliability planning software. Recommended a new planning target reserve margin for the TVA system and assisted in structuring new demand side option programs in 2010. Performed Production Cost and Resource Adequacy Studies in 2009, 2011, 2013, 2015 and 2017. Performed renewable integration and ancillary service work from 2015-2017.

Southern Company Services: Assisted in resource adequacy and capacity value studies as well as model development from 2009 – 2018.

Louisville Gas & Electric and Kentucky Utilities: Performed reliability studies including reserve margin analysis for its Integrated Resource Planning process.

Duke Energy: Performed resource adequacy studies for Duke Energy Carolinas, LLC and Duke Energy Progress, LLC in 2012 and 2016. Performed capacity value and ancillary service studies in 2018.

California Energy Systems for the 21st Century Project: Performed 2016 Flexibility Metrics and Standards Project. Developed new flexibility metrics such as EUE_{flex} and $LOLE_{flex}$ which represent LOLE occurring due to system flexibility constraints and not capacity constraints.

Terna: Performed Resource Adequacy Study used to set demand curves in Italian Capacity Market Design.

Pacific Gas and Electric (PG&E): Performed flexibility requirement and ancillary service study from 2015–2017. Performed CES Study for Renewable Integration and Flexibility from 2015 – 2016.

PNM (Public Service Company of New Mexico): Managed resource adequacy studies and renewable integration studies and ancillary service studies from 2013 – 2017. Performed resource selection studies in 2017 and 2018. Evaluated storage.

GASOC: Managed resource adequacy studies from 2015 – 2018.

MISO: Managed resource adequacy study in 2015.

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SPP: Managed resource adequacy study in 2017.

Malaysia (TNB, Sabah, Sarawak)): Performed and managed resource adequacy studies from 2015-2018 for three different Malaysian entities.

ERCOT: Performed economic optimal reserve margin studies in cooperation with the Brattle Group in 2014 and 2018. The report examined total system costs, generator energy margins, reliability metrics, and economics under various market structures (energy only vs. capacity markets). Completed a Reserve Margin Study requested by the PUCT, examining an array of physical reliability metrics in 2014 (See Publications: Expected Unserved Energy and Reserve Margin Implications of Various Reliability Standards). Probabilistic Risk Assessment for the North American Electric Reliability Corporation (NERC) in 2014, 2016, and 2018.

FERC: Performed economics of resource adequacy work in 2012-2013 in cooperation with the Brattle Group. Work included analyzing resource adequacy from regulated utility and structured market perspective.

EPRI: Performed research projects studying reliability impact and flexibility requirements needed with increased penetration of intermittent resources in 2013. Created Risk-Based Planning system reliability metrics framework in 2014 that is still in use today.

3

Astrapé RFP Evaluation Report

PNM Exhibit NW-2

Is contained in the following 70 pages.

2019

PNM
RFP Evaluation
Report

Contents

1

Executive Summary

This RFP evaluation study was performed by Astrapé Consulting at the request of PNM. PNM plans to retire San Juan 1 and San Juan 4 in 2022 which leaves a significant capacity need on the system. Phase I and II of this study evaluated generic resources to provide guidance to PNM as they designed their RFP. Phase III of this study compares replacement resource combinations designed to fill the capacity need using actual RFP offers for solar, wind, gas, and energy storage at varying sites across the PNM footprint. This report covers the results of that analysis. The results of the simulations provide reliability metrics and total system costs for each replacement resource combinations. The results indicate a proposed plan given the available offers submitted to PNM based on meeting target reliability and providing lowest cost to customers.
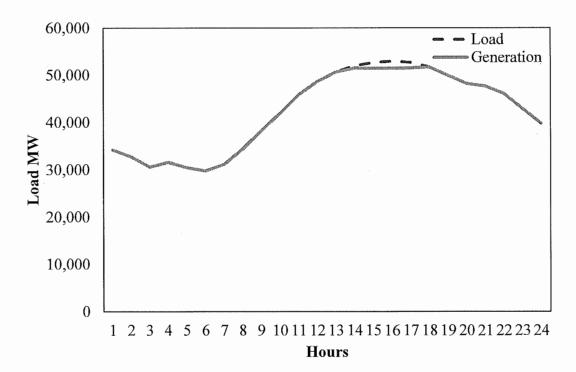
Modeling Background

As the PNM system changes including retirement of base load resources and additions of intermittent resources, future resource decisions must not only take into account customer economics and meeting peak demand but also system flexibility and the capability of the system to meet unforeseen net load ramps on an hourly and intra-hour basis. Typical planning studies utilize load shapes and renewable profiles from a single weather year and only simulate average unit performance characteristics. Since flexibility and reliability issues are high-impact, low-probability events, many scenarios of load, renewable output, and conventional generator performance should be considered to adequately capture their expected impact. Further, quantifying system flexibility issues and economics requires a model that chronologically dispatches units taking into account start up times, ramp rates, minimum up times, and minimum down times. System flexibility and costs are also driven by the impact of weather uncertainty on loads and renewable profiles, economic growth uncertainty, unit availability uncertainty, and transmission availability uncertainty. Each of these components are modeled stochastically in this study and commitment decisions are made without perfect knowledge to mimic the uncertainty faced by

operators. Utilizing the chronological production cost and reliability software SERVM[1], which was also used for the reliability study in the 2017 IRP, thousands of yearly simulations were performed at 5-minute time steps for each portfolio to perform the tasks outlined above. The SERVM simulation engine considers all unit characteristics and incorporates realistic load and renewable output variability and uncertainty to assess system flexibility needs and renewable integration costs. In addition to reporting PNM Balancing Area costs, SERVM reports many reliability and flexibility metrics including $LOLE_{CAP}$, $LOLE_{FLEX}$, and renewable curtailment. Below are the definitions of these metrics.

(1) $LOLE_{CAP}$: number of loss of load events due to capacity shortages, calculated in events per year. Traditional LOLE calculations only calculate $LOLE_{CAP}$. Figure ES1 shows an example of a capacity shortfall which typically occurs across the peak of a day. In this example, all available installed capacity was fully utilized.

Figure ES1. $LOLE_{CAP}$ Example

---

[1] As discussed in more detail in the body of the report, SERVM is used by utilities, regulators, and grid operators across the country to analyze resource adequacy and renewable integration.

(2) LOLE$_{FLEX}$: number of loss of load events due to system flexibility problems, calculated in events per year. In these events, there was enough capacity installed but not enough flexibility to meet the net load ramps, or startup times prevented a unit coming online fast enough to meet the unanticipated ramps.

Figures ES2 shows an example of LOLE$_{FLEX}$. The vast majority of LOLE$_{FLEX}$ events fall under the intra-hour problems seen in this figure. These events are typically very short in duration and are caused by a rapid drop in solar or wind resource output over a short time interval. Increasing online spinning reserves or adding fast ramping capability resources can typically resolve these issues.
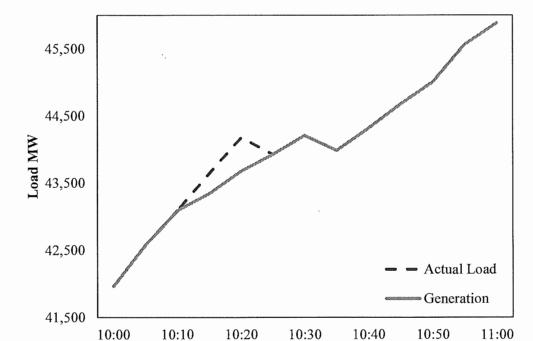
Figure ES2. Intra-hour LOLE$_{FLEX}$

(3) Renewable curtailment: Renewable curtailment occurs during over-generation periods when the system cannot ramp down fast enough to meet net load.

(4) Total System Net Present Value (NPV): A 20 year NPV of Production Costs + Fixed Costs of the incremental replacement resources. Production costs include all fuel burn, variable O&M, startup costs,

CO_2 costs and net purchase costs. Production costs and fixed costs were discounted at 7.2% reflected by the Company's weighted average cost of capital.

For this study, SERVM was simulated for the study years 2023, 2028, and 2033. Production Costs from SERVM were interpolated between simulated years and extrapolated out to 2042 representing a 20-year study. The study took into account weather, load forecast error, neighbor assistance, fuel forecasts, and intra-hour volatility of net load. Because the combinations of replacement resources are targeted at specific $LOLE_{CAP}$ and $LOLE_{FLEX}$ metrics, the results in effect incorporate the integration costs of higher renewable combinations because higher ancillary services are required for those portfolios. This avoids the need for additional integration cost adders that are traditionally developed through other modeling procedures.

Evaluation and Results

PNM and HDR performed an initial screening evaluation analysis to provide Astrapé with the most competitive offers ("best in class") by each technology. Table ES1 includes the Tier 1 and Tier 2 offers that were included in the modeling. Initially all renewable combinations were formed and simulated to understand if they could provide system reliability. Due to the intermittent nature of wind and solar, those all renewable combinations could not meet the reliability criteria which indicated that capacity resources would be required.

Table ES1. Summary of Tier 1 and Tier 2 Offers

Technology	Tier 1/Tier 2	Capacity per Unit MW*
Solar	Tier 1	300
Solar	Tier 1	50
Solar	Tier 1	150
Solar	Tier 1	150
Solar	Tier 1	50
Wind	Tier 1	140**
Solar/Battery	Tier 1	300/150
Battery	Tier 1	200
Battery	Tier 1	100
Battery	Tier 1	40
Battery	Tier 1	40
Gas: 4-10 Aero-derivatives	Tier 1	38.44
Gas: Frame	Tier 1	196.1
Gas: 10-20 Recips	Tier 1	16.91
Gas: 1 Aero-derivative	Tier 1	38.44
Wind	Tier 2	400
Wind	Tier 2	200
Solar/Battery	Tier 2	50/20
Solar/Battery	Tier 2	150/40
Battery	Tier 2	40
Battery	Tier 2	100

*Represents solar/battery MW for combined solar/battery technologies

**Selected as the 2019 RPS Resource and included in all replacement resource combinations

Next, the Tier 1 offers were used to create replacement resource combinations that would meet an $LOLE_{CAP}$ and $LOLE_{FLEX}$ of approximately 0.2 events per year[2]. These Tier 1 capacity combinations included a range of capacity resources from all battery/renewable combinations to all gas combinations. These combinations also varied solar as discussed Tier 1 Modeling section. Capacity was added or removed to achieve the $LOLE_{CAP}$ target and ancillary service assumptions were increased or decreased to achieve $LOLE_{FLEX}$ targets. Once the Tier 1 Modeling was complete, Tier 2 offers which were ranked further down in HDRs evaluation were used to stress test the least cost replacement resource combination from the Tier 1 Modeling to understand if more optimal combinations existed. As part of the Tier 1 and Tier 2 Modeling, there were no constraints put on technology or project size.

Based on the Tier 1 and Tier 2 Modeling, the least cost replacement resource combination that met reliability targets consisted of 6 aeroderivatives totaling 231 MW, and two combined solar/battery projects. The combined solar/battery projects includes a 300 MW solar/150 MW battery project and a 50 MW solar/20 MW battery project. The lowest cost all battery/renewable case was substantially more expensive than this least cost option. Filling the entire capacity need with battery is more expensive because it forces in higher cost battery options which are more expensive than competing gas alternatives. From a gas perspective, the aeroderivative options were more economic than either the frame or reciprocating engines in all cases. The aeroderivatives and frame offers had similar fixed costs but the aeroderivatives provide more flexibility, especially given their low minimum capacity levels. The reciprocating engines provide more flexibility and slightly cheaper energy costs, but those benefits do not overcome the fixed cost premium on these offers.

---

[2] While the industry standard is 0.1 events per year to represent 1 event in 10 years, Astrapé and PNM recommended and the 2017 IRP used 0.2 events per year.

In May 2019, the Company received additional standalone storage ownership options. The original set of bids in the Tier 1 and Tier 2 Modeling did not include many ownership options. The utility owned bids were limited due to a lack of bidders having NM state contractor licenses. Because some original bidders were automatically rejected for that reason, PNM solicited additional utility owned battery proposals through a supplement to the original RFP in order to ensure a range of ownership battery options would be evaluated. These least cost offers were added to the least cost combination from the Tier 1 and Tier 2 modelling and did not improve the economics of this unconstrained set of replacement resources.

Risk Evaluation

As part of the Company's review, PNM had Enovation Partners review this least cost set of replacement resources and especially its energy storage resources. That review and analysis provided PNM with the recommendation that initial energy storage implementation should not be beyond 2% - 5% of the system peak load and that individual projects should be between 10 MW and no more than 40 MW. Enovation Partners further discusses its reasoning for this recommendation in Mr. Kemp's testimony.

With this recommendation, PNM requested that Astrapé provide further modeling that replaced the 170 MW of battery options in the least cost combination from the Tier 1 and Tier 2 modeling with smaller available projects of up to 40 MW. The Tier 1 and Tier 2 unconstrained modeling determined that the 350 MW of solar and aeroderivatives would provide the most economic combination of replacement resources. Using PPA and ownership battery options that were 40 MW and less, many permutations were developed to determine the least cost combination that met reliability. Some of the larger low cost PPAs options were re-priced to provide 40 MW projects. Total battery capacity ranging from 20 MW to 170 MW was simulated with battery project sizes that were less than or equal to 40 MW. These results are shown in Table ES2. Seven combinations were within 3 million NPV of each other. The lowest cost combination consisted of all battery PPAs. Given other benefits of battery ownership and the fact that the delta in economics is negligible, PNM selected the combination that included seven aeroderivatives

consisting of 269 MW, a combined solar/battery project consisting of 300 MW of solar and 40 MW of battery, a combined solar/battery project consisting of 50 MW of solar and 20 MW of battery, and two standalone battery ownership projects consisting of 40 MW and 30 MW. This combination totals 269 MW[3] of gas, 350 MW of solar, and 130 MW of battery and is the Company's proposed plan and is also called Scenario 1.

Table ES2. Constrained Combinations Sorted by Least Cost

Resource Replacement Combination	LM6000	PPA Battery	Ownership Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs
	MW	MW	MW	MW	MW	M$	M$	M$
Constrained – 1	269	140	0	350	140	$4,677	$470	$4,207
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Constrained – 12	269	140	0	500	140	$4,702	$449	$4,253
Constrained – 13	307	100	0	500	140	$4,708	$442	$4,266
Constrained – 14	345	0	40	350	140	$4,711	$457	$4,254
Constrained – 15	345	40	0	500	140	$4,718	$430	$4,288
Constrained – 16	345	60	0	350	140	$4,724	$474	$4,250
Constrained – 17	383	20	0	350	140	$4,726	$470	$4,256
Constrained – 18	345	60	0	500	140	$4,735	$456	$4,280
Constrained – 19	383	40	0	350	140	$4,758	$503	$4,255

In addition to this modeling, the Company requested Astrapé run 3 additional scenarios to compare against the proposed plan. These were developed by PNM's resource planning department and respect the 40 MW battery size project limit. The scenarios include the following:

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[3] The 269 MW represents summer net capacity output versus the nameplate capacity of 280 MW.

- Scenario 1 – This scenario is the proposed least cost plan from the modeling discussed above. It includes seven aeroderivatives consisting of 269 MW, a combined solar/battery project consisting of 300 MW of solar and 40 MW of battery, a combined solar/battery project consisting of 150 MW of solar and 20 MW of battery, and two standalone battery ownership projects consisting of 40 MW and 30 MW.

- Scenario 2 - San Juan Location Preference Alternative Scenario – This scenario included the least cost resources in the San Juan Location which included 7 aero derivatives and 1 Frame machine.

- Scenario 3 - No New Fossil Fuel Alternative Scenario – This scenario included the least cost battery projects that were less than 40 MW and renewable resources. It included 500 MW of solar and 11 battery projects summing to 410 MW. The 11 different battery projects included 7 PPA options and 4 ownership options.

- Scenario 4 - All Renewable Replacement Scenario – This scenario includes all renewable capacity. This scenario includes all wind and solar PPA projects consisting of 1,200 MW of wind and 975 MW of solar.

Table ES3 shows the results of that modeling. Of the 4 replacement scenarios put forth by the Company, the proposed plan is the most economic. The next table shows the reliability of the replacement scenarios compared to the proposed plan. This shows that additional capacity resources would be required for both Scenario 3 and 4 demonstrating that the economics shown in Table ES3 are conservative. The costs would increase to ensure reliability for these two scenarios.

Table ES3. Additional Scenarios Provided by the Company

Resource Replacement Combination	LM6000	Frame	PPA Battery	Owned Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs
	MW	MW	MW	MW	MW	MW	M$	M$	M$
Scenario 1 – Proposed Plan	269	0	60	70	350	140	$4,678	$472	$4,206
Scenario 2 – SJ preferred	269	196	0	0	0	140	$4,732	$465	$4,267
Scenario 3 – No Gas	0	0	260	150	500	140	$4,834	$615	$4,219
Scenario 4 – All renewable	0	0	0	0	975	1,199	$5,452	$73	$5,380

Table ES4. Reliability Metrics of Additional Scenarios Provided by the Company

Resource Replacement Combination	LOLE Cap	LOLE Cap	LOLE Cap	LOLE Flex	LOLE Flex	LOLE Flex
	Events per Year					
Year	2023	2028	2033	2023	2028	2033
Scenario 1 – Proposed Plan	0.19	0.13	0.05	0.14	0.17	0.16
Scenario 2 – SJ preferred	0.21	0.07	0.03	0.16	0.17	0.16
Scenario 3 – No Gas	0.36	0.29	0.27	0.10	0.06	0.06
Scenario 4 – All renewable	5.63	2.52	1.01	3.35	0.73	0.17

Conclusion

Based on the evaluation performed by Astrapé, the proposed plan of replacement resources including 350 MW of solar, 130 MW of battery, and 269 MW of gas meets reliability criteria and provides reasonable costs given the technology constraints imposed. These replacement resources provide a diverse set of resources and take advantage of the lowest cost renewable, battery, and gas offers submitted into the RFP.

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I. List of Figures

II. List of Tables

III. Input Assumptions

A. Study Years and Resource Plans

The selected years for this study are 2023, 2028, and 2033. The 2023 study year is the first year after the retirement of San Juan 1 and 4. The 2028 and 2033 study years were chosen to represent the system every 5 years. PNM's resource mix has changed dramatically over the years to include significant renewable resources. New resource additions should not only consider economics but also reliability from a capacity and flexibility standpoint. In order to capture economics and reliability it is difficult to simulate every study year due to processing time. For this reason, Astrapé believes its approach of simulating these three years and interpolating system production costs between the years is appropriate.

Table 1 shows the underlying resource expansion plan used for the analysis, which was fixed across all the replacement resource combinations modeled. Given PNM's target to be carbon free by 2040 and RPS targets of 40% by 2025 and 50% by 2030, this expansion plan ensures those goals are met.

Table 1. Expansion Plan for 2023, 2028, and 2033

Year	Resource
2023	140 MW RPS Wind Resource
Incremental Additions by 2028	300 MW of Battery 100 MW of Solar 200 MW of Wind
Incremental Additions By 2033	300 MW of Battery 225 MW of Solar 250 MW of Wind

B. Modeled Offers

PNM and HDR performed an extensive evaluation of all offers submitted into the RFP and screened the offer list down to the "best in class" offers by technology. See the HDR report for the detailed screening evaluation. These bids included renewable, energy storage, combined renewable/storage, and natural gas technology options. Table 2 shows the offers that were included in the production cost and reliability

modeling by technology and tier. The Tier 1 offers were the most competitive of each technology and were used to develop a comprehensive list of replacement resource combinations while the Tier 2 offers in the list were added into the best combination developed in the Tier 1 Modeling to determine if the economics could be improved.

The solar and wind resources are sorted by levelized PPA price. The solar and wind resources were modeled with hourly shapes and calibrated to the capacity factor provided by the bidder. Given the pricing of the wind resources, only one was selected as a Tier 1 resource. This resource has already been selected as an RPS resource[4] so it was included in all the resource replacement combinations. From a solar perspective, all solar resources were included, and the replacement resource combinations varied from 0 MW of solar to 700 MW of solar.

Table 2. Solar and Wind Offers

Technology	Tier 1/Tier 2	Capacity MW
Solar	Tier 1	300
Solar	Tier 1	50
Solar	Tier 1	150
Solar	Tier 1	150
Solar	Tier 1	50
Wind*	Tier 1	140
Wind	Tier 2	400
Wind	Tier 2	200

*Selected as an RPS Resource

Both standalone battery and hybrid renewable/battery projects were submitted. Given the Federal Production Tax Credit and Investment Tax Credit incentives that are given with the hybrid projects, the overall costs of these projects have cost advantages compared to the standalone battery. Both the hybrid projects and standalone battery projects were included in the Tier 1 Modeling. For the hybrid projects, SERVM forces the battery to be charged by the renewable energy source for the first five years in order to

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[4] See New Mexico Public Regulation Commission Docket No. 19-00159-UT.

monetize the Federal Tax Incentives. After 5 years, the battery is allowed to be charged by the grid and perform similar to a standalone battery.

Table 3. Hybrid and Stand Alone Battery Offers

Technology	Tier 1/ Tier 2	Solar Capacity MW	Battery Capacity MW	Combined Capacity Max Output MW	Battery Duration Hours
Solar/ Battery	Tier 1	300	150	300	4
Solar/ Battery	Tier 2	50	20	50	4
Solar/ Battery	Tier 2	150	40	190	4

Technology	Tier 1/ Tier 2	Battery Capacity MW	Battery Duration Hours
Battery	Tier 1	200	4
Battery	Tier 1	100	4
Battery	Tier 1	40	4
Battery	Tier 1	40	4
Battery	Tier 2	100	4
Battery	Tier 2	40	4

The gas units included aeroderivatives, reciprocating engines, and frame technology. From a fixed cost standpoint, the aeroderivative and frames are lower cost than the reciprocating engines. The reciprocating engines provide slightly more flexibility and lower variable costs but at a high capital cost premium. The minimum output level of the frame makes it less flexible compared to the smaller aeroderivative and reciprocating engines. All gas offers in the Tier 1 selections are located at San Juan except for the single LM6000 offering at La Luz.
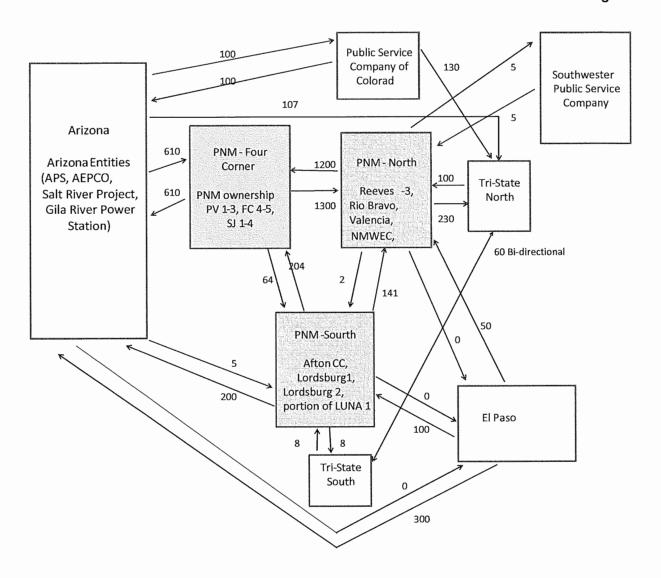
Table 4. Natural Gas Offers

	Technology	Tier 1/ Tier 2	Summer Capacity per Unit MW	Min Capacity per Unit MW	Ramping Capability per Unit MW/Min
4- 10 LM6000	Aero-derivative	Tier 1	38.4	11.3	12
SGT6-5000F	Frame	Tier 1	196.1	113	13.4
10-20x18V50SG	Recips	Tier 1	16.91	2.0	18.2
1 LM6000	Aero-derivative	Tier 1	38.4	11.269	10

C. Study Topology

Figure 1 shows the study topology used in the analysis. To adequately understand system resource adequacy, it is important to capture the load diversity and generator outage diversity that a system has with its neighbors. For this study, the PNM system was divided into three regions: (1) PNM-North, (2) PNM-South, and (3) PNM-Four Corners. The surrounding regions captured in the modeling included all of the Arizona load serving entities, Public Service Company of Colorado, Tri-State Generation and Transmission Association, Southwestern Public Service Company, and El Paso Electric Company. For commitment and dispatch purposes, the PNM regions and Tri State Generation and Transmission Association regions were committed as one region to reflect the current balancing area makeup. In this commitment and dispatch of the PNM and Tri State regions, the transmission constraints were respected. All output results of the modeling reflect the PNM Balancing Area, which includes the Tri State regions. All transmission input information was provided by PNM Transmission. After discussions with Wholesale Marketing and analysis of recent historical purchases during peak conditions, the external assistance into the PNM balancing areas was capped at 300 MW. It was assumed that 150 MW could be purchased from the day ahead market and the hourly non-firm market purchases were limited to 150 MW.

Figure 1. Study Topology

D. Load Modeling

Table 5 displays the PNM annual peak forecast for 2023, 2028, and 2033 under normal weather conditions.   This represents PNM's latest load forecast developed in May of 2019.

Table 5. 2023, 2028, and 2033

Year	Coincident System Peak* (MW)
2023	2,072
2028	2,159
2033	2,229

*EE and PV-DG removed from the forecast. Value includes Data Center Projections

To model the effects of weather uncertainty, 36 historical weather years were developed to reflect the impact of weather on load. Based on the last five years of historical weather and load, a neural network program was used to develop relationships between weather observations and load. Different relationships were built for each month. These relationships were then applied to the last 36 years of weather to develop 36 load shapes for 2023, 2028, and 2033. Equal probabilities were given to each of the 36 load shapes in the simulation. Figure 2 ranks all weather years by summer peak load and shows variance from normal weather. In the most severe weather conditions, the peak can be as much as 7.8% higher than under normal weather conditions.

Separate relationships were built for the North and South regions to ensure proper weather diversity was captured.
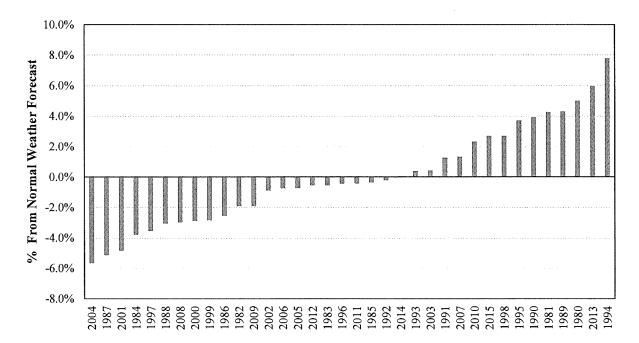
Figure 2. 2023 Peak Load Rankings for All Weather Years

Loads for each external region were developed in a similar manner as the PNM loads. A relationship between hourly weather and publicly available hourly load[5] was developed based on recent history, and then this relationship was applied to 36 years of weather data to develop 36 load shapes.

E. *Economic Load Forecast Error*

Economic load forecast error multipliers were developed to isolate the economic uncertainty that PNM has in its 4 and 5 year load forecasts. Table 6 shows the economic load forecast multipliers and associated probabilities used in the study. The table shows that 5% of the time, it is expected that load will be under-forecasted by 5% four years out. The load forecast multipliers were applied to all regions. Within the simulations, when PNM under-forecasted load, the external regions also under-forecasted load. The SERVM model utilized each of the 36 weather years and applied each of these seven load forecast error points to create 252 different load scenarios. Each weather year was given equal probability of occurrence.

Table 6. Load Forecast Error

Load Forecast Error Multipliers	Probability (%)
0.95	5%
0.97	10%
0.99	15%
1.00	40%
1.01	15%
1.03	10%
1.05	5%

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[5] FERC 714 Forms were accessed to pull hourly historical load for all neighboring regions.

F. *Existing Thermal Resources*

The existing thermal resources included in the study are shown in Table 7. All input data was based on the most recent PROMOD simulations and interactions with PNM planning. San Juan 1 and 4 are assumed to be retired in all the replacement combination simulations.

Table 7. Summary of Resources

Unit Name	Fuel Type	Capacity (MW)	Location
AFTON	Natural Gas	230	PNM-South
FOUR CORNERS 4	Coal	100	PNM-Four Corners
FOUR CORNERS 5	Coal	100	PNM-Four Corners
PALO VERDE 1	Uranium	134	PNM-Four Corners
PALO VERDE 2	Uranium	134	PNM-Four Corners
PALO VERDE 3	Uranium	134	PNM-Four Corners
REEVES 1	Natural Gas	44	PNM-North
REEVES 2	Natural Gas	44	PNM-North
REEVES 3	Natural Gas	66	PNM-North
RIO BRAVO 1	Natural Gas	132	PNM-North
VALENCIA	Natural Gas	150	PNM-North
LORDSBURG 1	Natural Gas	40	PNM-South
LORDSBURG 2	Natural Gas	40	PNM-South
LUNA 1	Natural Gas	189	PNM-South
LA LUZ	Natural Gas	40	PNM-North

To accurately reflect the flexibility of the PNM system, each resource was modeled with detailed heat rate curves, min-up and min-down times, startup times, and ramp rates. All constraints were respected by SERVM in the simulations and are shown in Table 8. All units except for Palo Verde 1-3 were allowed to serve regulating and spinning reserves. Only Lordsburg 1, Lordsburg 2, and La Luz were able to serve non-spinning reserves.

Table 8. Resource Characteristics

Unit Name	Capacity (MW)	Minimum Capacity (MW)	10 Min Ramping Capability (MW)	Min-up Time (Hours)	Min-down Time (Hours)	Startup Time (Hours)	Serve Regulation	Serve Quick Start (Non-Spin)
AFTON	230	165	80.9	4	4	3	Y	N
FOUR CORNERS 4	100	65	5.55	20	20	24	Y	N
FOUR CORNERS 5	100	65	5.55	20	20	24	Y	N
PALO VERDE 1	134	134	0	48	100	48	N	N
PALO VERDE 2	134	134	0	48	100	48	N	N
PALO VERDE 3	134	134	0	48	100	48	N	N
REEVES 1	44	10	20.9	3	3	2	Y	N
REEVES 2	44	10	19	3	3	2	Y	N
REEVES 3	66	15	26.4	3	3	2	Y	N
RIO BRAVO 1	132	80	52.8	2	2	0	Y	N
VALENCIA	158	85	13.1	4	3	0	Y	N
LORDSBURG 1	40	10	40	0	0	0	Y	Y
LORDSBURG 2	40	10	40	0	0	0	Y	Y
LA LUZ	40	10	40	0	0	0	Y	Y
LUNA 1	189	100	190	8	8	3	Y	N

G. *Fuel Forecasts and CO$_2$ Forecasts*

The 2023, 2028, and 2033 fuel and CO$_2$ forecasts are shown in Table 9. The natural gas prices are based on a blend of forwards pricing and gas pricing forecast provided by Pace Global ("Pace") for PNM. Gas forwards from April 26, 2019 were utilized for the first 10 years, thereafter, forwards pricing was scaled to the Pace forecast curve to project pricing for the next 10 years. CO2 pricing was derived from Pace Global to reflect a 20 year forecast of national costs per ton of CO$_2$ emitted. A High Gas and CO$_2$ sensitivity was also simulated which is shown in Table 10.

Table 9. Fuel Costs and CO$_2$ Costs

Fuel Type	Units	2023	2028	2033
Nuclear	$/MMBtu	0.87	0.89	0.91
Four_Corners_Coal	$/MMBtu	3.12	3.50	3.75
Lordsburg_Afton_Gas	$/MMBtu	2.55	3.21	3.32
Reeves_Delta_Gas	$/MMBtu	3.39	4.03	4.13
Valencia_Gas	$/MMBtu	2.83	3.47	3.57
Four Corners Gas	$/MMBtu	2.83	3.46	3.56
CO$_2$	$/ton	-	2.21	3.42

Table 10. High Gas Sensitivity

Fuel Type	Units	2023	2028	2033
Nuclear	$/MMBtu	0.87	0.89	0.91
Four_Corners_Coal	$/MMBtu	3.12	3.50	3.75
Lordsburg_Afton_Gas	$/MMBtu	4.10	4.67	5.38
Reeves_Delta_Gas	$/MMBtu	4.76	5.28	6.04
Valencia_Gas	$/MMBtu	4.20	4.72	5.47
Four Corners Gas	$/MMBtu	4.18	4.71	5.46
CO$_2$	$/ton	-	7.30	12.03

H. Unit Outage Data

Unlike typical production cost models, SERVM is not provided an Equivalent Forced Outage Rate (EFOR) for each unit as an input. Instead, historical NERC Generating Availability Data System (GADS) data events are entered for each unit, and SERVM randomly draws from these events to simulate the unit outages. Historical events are entered using the following variables:

Full Outage Modeling
Time-to-Repair Hours
Time-to-Fail Hours

Partial Outage Modeling
Partial Outage Time-to-Repair Hours
Partial Outage Derate Percentage
Partial Outage Time-to-Fail Hours

Maintenance Outages
Maintenance Outage Rate - % of time in a month that the unit will be on maintenance outage. SERVM uses this percentage and schedules the maintenance outages during off peak periods

Planned Outages
Specific time periods are entered for planned outages. Typically, these are performed during shoulder months.

As an example, assume that from 2013 through 2017, Four Corners 4 had 15 full outage events and 30 partial outage events reported in the GADS data. The Time-to-Repair and Time-to-Fail between each event is calculated from the GADS data. These multiple Time-to-Repair and Time-to-Fail inputs are the distributions used by SERVM. Since there typically is an improvement in EFOR across the summer, the data is broken up into seasons such that there is a set of Time-to-Repair and Time-to-Fail inputs for summer, off peak, and winter based on history. Further, assume Four Corners 4 is online in hour 1 of the simulation. SERVM will randomly draw a Time-to-Fail value from the distribution provided for both full outages and partial outages. The unit will run for that amount of time before failing. A partial outage will be triggered first if the selected Time-to-Fail value is lower than the selected full outage Time-to-Fail value. Next, the model will draw a Time-to-Repair value from the distribution and be on outage for that number of hours. When the repair is complete it will draw a new Time-to-Fail value. The process repeats

until the end of the iteration when it will begin again for the subsequent iteration. The full outage counters and partial outage counters run in parallel. This more detailed modeling is important to capture the tails of the distribution that a simple convolution method would not capture.

The most important aspect of unit performance modeling in reliability studies is the cumulative MW offline distribution. Most service reliability problems are due to significant coincident outages. Figure 3 shows the distribution of outages for the PNM Balancing area based on historical modeled outages. The figure demonstrates that in any given hour, the system can have between 0 and 1,000 MW of its generators offline due to forced outages. The figure shows that in approximately 10% of all hours throughout the year, the balancing area has greater than 400 MW in a non-planned outage condition. This is typically comprised of several units that are on forced outage at the same time.
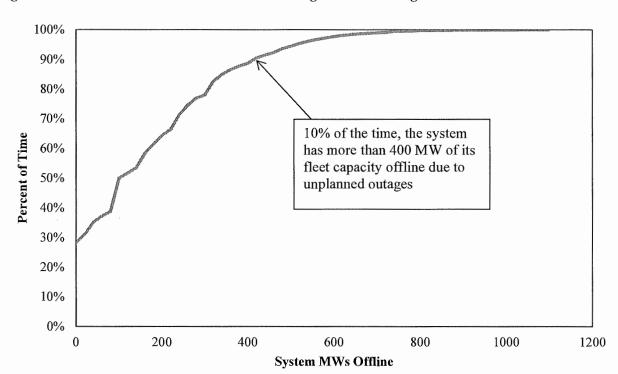
Figure 3. Conventional Resources on Forced Outage as a Percentage of Time

10% of the time, the system has more than 400 MW of its fleet capacity offline due to unplanned outages

Table 11 shows modeled EFOR rates for each individual unit.

Table 11. Forced Outage Rate Data

Unit Name	Fuel Type	EFOR (%)
AFTON	Natural Gas	4.00
FOUR CORNERS 4	Coal	20.00
FOUR CORNERS 5	Coal	20.00
PALO VERDE 1	Uranium	2.00
PALO VERDE 2	Uranium	2.00
PALO VERDE 3	Uranium	2.00
REEVES 1	Natural Gas	3.00
REEVES 2	Natural Gas	2.27
REEVES 3	Natural Gas	3.00
RIO BRAVO 1	Natural Gas	3.00
VALENCIA	Natural Gas	3.00
LORDSBURG 1	Natural Gas	3.00
LORDSBURG 2	Natural Gas	3.00
LA LUZ	Natural Gas	3.00
LUNA 1	Natural Gas	4.00

Planned maintenance rates are shown in Table 12.

Table 12. Planned Maintenance Rates

Unit Name	Days	Rate (%)
AFTON	35	10
FOUR CORNERS 4	12	3
FOUR CORNERS 5	8	2
PALO VERDE 1	0	0
PALO VERDE 2	35	10
PALO VERDE 3	35	10
REEVES 1	12	3
REEVES 2	12	3
REEVES 3	12	3
RIO BRAVO 1	12	3
VALENCIA	12	3
LORDSBURG 1	4	1
LORDSBURG 2	4	1
LA LUZ	4	1
LUNA 1	8	2

I. Renewable Resource Modeling

Table 13 shows the solar resources that were captured in the study up to 2023. Future generic expansion solar resources are shown in previous Table 1.

Table 13. Existing Solar Resources Including Data Center Resources

Projects	Total (MW)	COD	PV Technology
ABQ Solar	2	4/8/2011	Fixed Tilt
Los Lunas I	5	6/1/2011	Fixed Tilt
Deming	5	8/3/2011	Fixed Tilt
Alamogordo	5	10/14/2011	Fixed Tilt
Las Vegas (Gallinas)	5	11/24/2011	Fixed Tilt
Manzano	8	10/18/2013	Fixed Tilt
Los Lunas II	2	10/17/2013	Fixed Tilt
Deming II	4	11/8/2013	Fixed Tilt
Otero	7.5	12/10/2013	Fixed Tilt
Prosperity	0.5	10/25/2011	Fixed Tilt
Sandoval County	8	2015	Single Axis Tracking
Meadowlake	9	2015	Single Axis Tracking
Cibola County	6	2015	Single Axis Tracking
Solar PV Tier 1	40	2016	Single Axis Tracking

New Projects	Total (MW)	COD	Technology
Data Center 1 Solar 1 30 MW	30	2018	Single Axis Tracking
Data Center 1 Solar 3 100 MW	100	2018	Single Axis Tracking
Solar PV 2016 RFP	49.5	2018	Single Axis Tracking
Direct Solar Project	50	2020	Single Axis Tracking
Data Center 1 Solar 2 50 MW	50	2021	Single Axis Tracking

Total by 2022	386.5

Solar shapes were developed from data downloaded from the National Renewable Energy Laboratory ("NREL") National Solar Radiation Database ("NSRDB") Data Viewer. Data was available for the years 1998 through 2015. Data was downloaded from 6 different cities within the PNM balancing area and the

projects were matched with a city for modeling purposes. Historical solar data from the NREL NSRDB Data Viewer included variables such as temperature, cloud cover, humidity, dew point, and global solar irradiance. The data obtained from the NSRDB Data Viewer was then used as an input into NREL's System Advisory Model ("SAM") for each year and city to generate the hourly solar profiles based on the solar weather data for both a fixed solar photovoltaic (PV) plant and a tracking solar PV plant. Inputs in SAM included the DC to AC ratio of the inverter module and the tilt and azimuth angle of the PV array. Data was normalized by dividing each point by the input array size of 4,000 kW DC. Solar profiles for 1980 to 1998 were selected by using the daily solar profiles from the day that most closely matched the total load out of the corresponding data for the days that we had for the 17-year interval. The profiles for the remaining years 1998 to 2015 came directly from the normalized raw data. Figure 4 shows the average output by hour of day for one of the city's fixed and tracking profiles.

Figure 4. Average Solar Profile
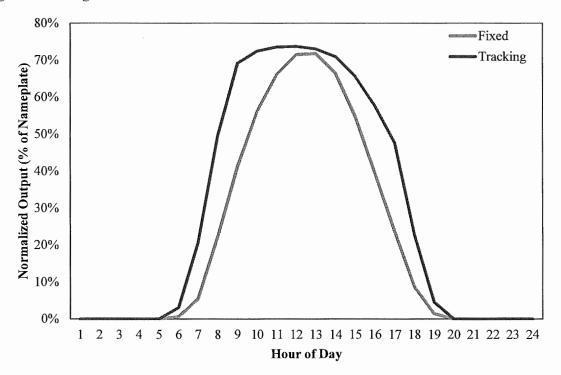
Table 14 displays the wind resources modeled in the study up to 2023. Generic expansion wind resources can be found in previous Table 1.

Table 14. Wind Resources

Projects	Total (MW)	COD
NMWEC + Repower	200	2000
Red Mesa	102	2011
Data Center 1 Wind	165	2020
Total by 2023	467	

For the wind resources, 5 years of hourly data was available from the NM Wind Energy Center and Red Mesa wind projects. Based on the raw data, there was little to no correlation with load or weather variables. Therefore, instead of developing a weather/wind shape relationship, Astrapé used the 5 years of data and allowed the model to randomly draw days from those years. The draws were done by season and load level. For example, in July during a peak load period, the model draws from daily historical July shapes when load is above a specific threshold. By performing the wind modeling in this manner, we ensured that our capacity factors and wind output from hour to hour reflect historical profiles[6]. Figure 5 shows the average profiles by hour of day and month. Wind projects included in the expansion plan in previous Table 1 were given a 44.5% capacity factor. These projects were given similar patterns to the existing wind but were scaled up to the higher capacity factor value.

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[6] If Astrapé had instead attempted to develop a neural net system for the weather to wind relationship, it is likely that the profiles would have not reflected the hour to hour movement that was seen in history which is important in system flexibility analysis.
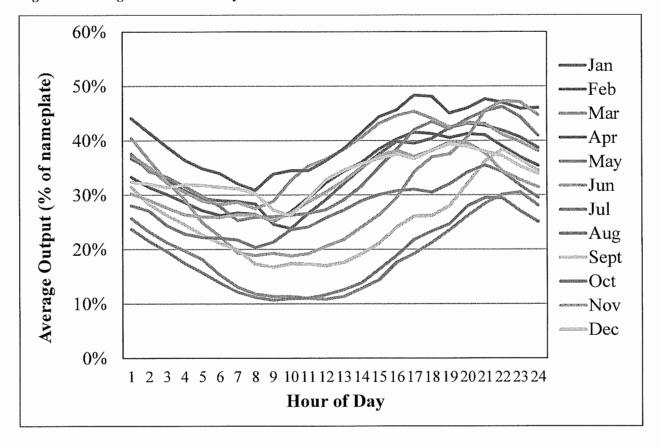
Figure 5. Average Wind Profiles by Month

The 10 MW geothermal resource was treated as a must run resource for this study.

J. Stand Alone Battery and Hybrid Battery Modeling

Standalone batteries in SERVM are modeled with max discharge and charge capacities, cycle efficiency, ramp rates, EFOR, and duration. Batteries are optimized to serve both energy and ancillary services within the model. Generally, the batteries are used for energy arbitrage within the PNM system. Due to the intra-hour modeling and imperfect knowledge within SERVM, the capacity, energy, and flexibility value is captured.

For a combined solar and battery installation, in order to receive the investment tax credits on the battery, the battery must be charged by the solar for the first 5 years of operation. In SERVM, this constraint is respected for the first 5 years of the resource. After 5 years, the battery can charge from either the solar resource or the grid. Due to transmission system limitations some of the hybrid projects have a total

output capability that is less than the sum of the individual solar and battery capacities. SERVM also respects this constraint during its operations of the solar/battery project.

K. Load, Wind, and Solar Uncertainty Development

For purposes of understanding the economic and reliability impacts of renewable profile uncertainty, Astrapé captures the implications of unpredictable intra-hour volatility. To develop data to be used in the SERVM simulations, Astrapé used five-minute data for solar resources, wind resources, and load. Within the simulations, SERVM commits to the expected net load and then must react to intra-hour volatility as seen in history.

Intra-Hour Forecast Error and Volatility

Within each hour, all three components of net load (load, wind, and solar), can move unexpectedly due to both natural variation and forecast error. SERVM attempts to replicate this uncertainty, and the conventional resources must be dispatched to meet the changing net load patterns. An example of the volatile net load pattern compared to a smooth intra-hour ramp is shown in Figure 6.
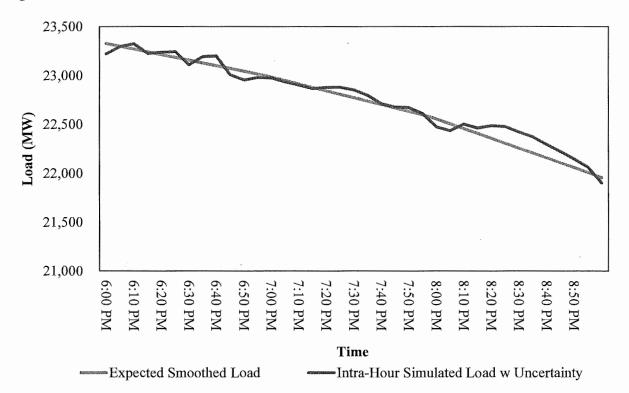
Figure 6. Volatile Net Load vs. Smoothed Net Load

The intra-hour distributions of variation used in the simulation is shown in Table 15. The 5-minute variability in load is quite low ranging mostly between +/-3% on a normalized basis.

Table 15. PNM Load Volatility

Normalized Divergence (%)	Probability (%)
-5	0.000
-4.5	0.001
-4	0.002
-3.5	0.002
-3	0.002
-2.5	0.012
-2	0.050
-1.5	0.412
-1	2.526
-0.5	48.076
0	45.571
0.5	2.573
1	0.598
1.5	0.145
2	0.018
2.5	0.008
3	0.003
3.5	0.000
4	0.001
4.5	0.000
5	0.001
5.5	0.000
6	0.000

The variability of the solar base level is much higher, ranging from -16% to 18% with the majority of movements ranging between +/-7%. The system must have enough online reserves to cover these 5-minute moves as all quick start capacity still requires 10 minutes for startup. Table 16 shows the data volatility for the base, 502 MW level data, and Table 17 shows the volatility of the many different penetration levels (502 MW, 801 MW, 1,061 MW, 1,261 MW, 1,471 MW, 1,771 MW, 2,071 MW, 2,371 MW, 2,671 MW, 2,971 MW, and 3,271 MW). As the solar penetration increases, the normalized volatility distribution tightens due to diversity across the fleet.

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Table 16. PNM Base (502 MW) Solar Volatility

Normalized Divergence (%)	Normalized Output (%)									
	0	10	20	30	40	50	60	70	80	90
-17					0.0					
-15.6			0.0	0.0	0.0			0.0		
-14.2		0.0	0.0	0.0	0.1	0.1		0.0	0.0	
-12.8			0.1	0.1	0.1	0.1	0.1	0.1	0.0	
-11.4		0.0	0.2	0.1	0.1	0.2	0.1	0.0	0.0	
-10		0.1	0.4	0.5	0.8	0.8	0.4	0.2	0.1	
-8.6		0.2	0.3	0.4	1.0	0.8	0.4	0.3	0.1	0.0
-7.2		0.5	2.1	2.7	3.0	3.2	1.8	1.6	0.9	0.1
-5.8		1.1	1.7	2.7	2.5	2.9	2.3	1.5	1.0	0.3
-4.4	0.0	2.2	3.5	3.6	3.9	4.5	2.8	2.7	2.0	0.9
-3	0.6	17.5	18.0	17.6	17.6	16.2	13.0	12.1	10.4	7.9
-1.6	2.1	14.8	13.7	12.8	13.4	12.9	14.4	15.8	14.4	14.0
-0.2	96.7	41.3	30.9	28.1	27.1	29.8	45.2	46.7	57.1	67.4
1.2	0.5	14.9	13.4	15.2	11.6	9.4	7.4	8.2	5.5	4.8
2.6	0.1	5.5	8.3	7.1	7.8	6.6	4.1	4.1	3.3	2.3
4		1.9	5.7	6.2	6.9	7.6	4.6	4.3	3.5	1.7
5.4		0.1	1.0	1.4	1.6	2.0	1.0	0.9	0.7	0.3
6.8			0.6	1.0	1.6	2.3	1.4	1.0	0.7	0.3
8.2			0.1	0.2	0.3	0.4	0.4	0.3	0.1	0.1
9.6			0.1	0.1	0.2	0.2	0.2	0.1	0.1	
11			0.0		0.2	0.2	0.3	0.1	0.1	0.0
12.4				0.0	0.1	0.1	0.0	0.0	0.0	
13.8					0.0	0.0	0.0	0.0		
15.2					0.0		0.0			
16.6							0.0			
18					0.0					
19.4										

Table 17. PNM Solar Volatility Level Comparison

Normalized Divergence (%)	Probability (%)										
	502 MW	801 MW	1,061 MW	1,261 MW	1,471 MW	1,771 MW	2,071 MW	2,371 MW	2,671 MW	2,971 MW	3,271 MW
-17.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-15.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-14.2	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-12.8	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-11.4	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-10.0	0.15	0.07	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
-8.6	0.16	0.08	0.05	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00
-7.2	0.72	0.43	0.30	0.23	0.16	0.07	0.04	0.03	0.01	0.01	0.01
-5.8	0.75	0.54	0.41	0.32	0.27	0.27	0.21	0.15	0.12	0.08	0.06
-4.4	1.23	1.01	0.83	0.73	0.63	0.95	0.80	0.66	0.55	0.46	0.38
-3.0	6.31	5.81	5.40	5.09	4.75	3.41	3.11	2.82	2.57	2.34	2.18
-1.6	7.44	7.90	8.09	8.24	8.33	14.04	14.21	14.35	14.44	14.48	14.46
-0.2	73.69	76.11	77.85	78.94	80.04	74.34	75.37	76.37	77.21	77.98	78.63
1.2	4.25	4.06	3.79	3.59	3.37	5.09	4.73	4.36	4.04	3.76	3.52
2.6	2.20	1.90	1.65	1.51	1.34	1.28	1.14	0.99	0.84	0.73	0.65
4.0	2.00	1.46	1.22	1.05	0.88	0.39	0.28	0.21	0.17	0.13	0.11
5.4	0.43	0.30	0.21	0.14	0.11	0.10	0.08	0.05	0.04	0.02	0.01
6.8	0.43	0.22	0.13	0.10	0.08	0.03	0.01	0.01	0.00	0.00	0.00
8.2	0.09	0.04	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.6	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.0	0.05	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.4	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.8	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The variability of the wind base level is also much higher, ranging from -35% to 40% with the majority of movements ranging between -11% to 7%. The system must have enough online reserves to cover these 5-minute moves as all quick start capacity still requires 10 minutes for startup. Table 18 shows the data volatility for the base, 467 MW level data, and Table 19 shows the volatility of the 12 different levels (467 MW, 627 MW, 827 MW, 1,027 MW, 1,127 MW, 1,427 MW, 1,727 MW, 2,027 MW, 2,627 MW, 2,927 MW, and 3,227 MW). Similar to solar, the normalized wind volatility distribution dampens as wind penetration increases.

Table 18. PNM Base (467 MW) Wind Volatility

Normalized Divergence (%)	Normalized Output (%)									
	0	10	20	30	40	50	60	70	80	90
-35	0.0									
-32		0.0								
-29	0.0	0.0		0.0		0.0				
-26	0.0	0.0	0.0	0.0						
-23	0.0	0.0		0.0	0.0	0.0	0.0			
-20	0.0	0.1	0.1	0.1	0.0	0.0	0.0			
-17	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.2	0.1
-14	0.2	0.3	0.3	0.3	0.4	0.3	0.1	0.1	0.1	0.5
-11	0.5	0.6	0.9	1.0	0.9	0.9	0.7	0.7	1.0	0.6
-8	2.1	2.3	2.9	3.1	3.0	3.4	3.1	3.4	4.0	3.9
-5	10.9	11.8	12.8	13.4	13.2	14.0	14.1	16.2	16.5	17.6
-2	60.4	57.7	53.9	51.5	53.3	50.1	51.0	46.6	44.3	42.7
1	21.2	21.3	22.2	23.6	22.1	24.0	24.5	25.7	25.9	26.8
4	3.5	4.1	5.0	5.0	5.0	4.8	4.8	5.8	6.4	5.9
7	0.8	1.2	1.3	1.1	1.3	1.4	1.1	1.2	1.2	1.3
10	0.2	0.3	0.3	0.4	0.4	0.5	0.3	0.2	0.3	0.2
13	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.4
16	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	
19	0.0	0.0	0.0	0.0	0.0	0.0				
22	0.0	0.0	0.0	0.0	0.0					
25			0.0	0.0						
28				0.0						
31										
34										
37										
40		0.0								
43										

Table 19. PNM Wind Volatility Level Comparison

Normalized Divergence (%)	Probability (%)										
	467 MW	627 MW	827 MW	1,027 MW	1,127 MW	1,427 MW	1,727 MW	2,027 MW	2,627 MW	2,927 MW	3,227 MW
-35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-17	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-14	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-11	0.8	0.5	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0
-8	2.8	2.0	1.3	0.8	0.9	0.6	0.4	0.3	0.1	0.1	0.1
-5	12.7	11.2	9.5	7.0	7.4	5.8	4.6	3.6	2.4	1.9	1.6
-2	54.5	60.0	65.3	72.6	71.7	76.5	80.3	83.3	87.8	89.4	90.8
1	22.5	21.6	20.3	17.6	17.9	15.8	13.9	12.3	9.5	8.3	7.4
4	4.5	3.5	2.5	1.5	1.6	1.0	0.7	0.5	0.2	0.2	0.1
7	1.1	0.7	0.4	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0
10	0.3	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
13	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

L. Demand Response Modeling

Demand response programs are modeled as resources in the simulations. They are modeled with specific contract limits including seasonal capability, hours per year, and hours per day constraints. Table 20 shows a breakdown of the demand response modeled in the study. The resources are called when temperatures in the region meet a specific threshold. For the modeling, Astrapé and PNM agreed to set the dispatch of these resources where they would be called on for an average of 50 hours per year but would be available for all hours of every summer.

Table 20. Demand Response Resources

	Power Saver Program	Peak Saver Program
Capacity (MW)	38.25	15.75
Season	June-Sept	June-Sept
Hours Per Year	100	100
Hours Per Day	4	6

M. External Market Modeling
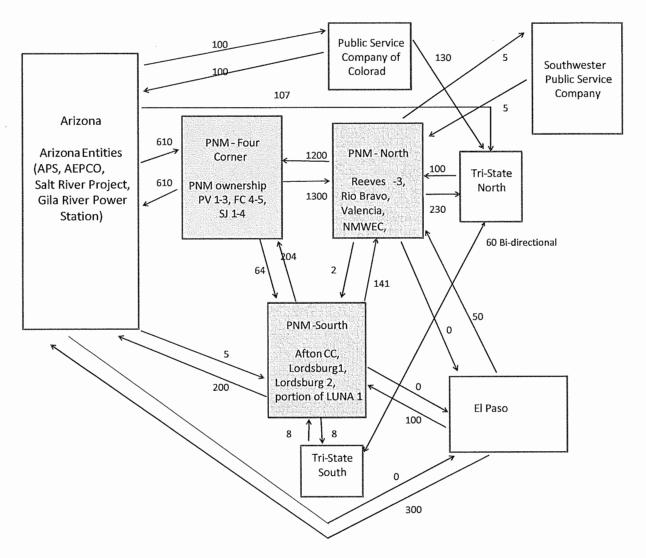
For a utility the size of PNM, the market plays a significant role in reliability results. If several of PNM's large generators were experiencing an outage at the same time (even if loads weren't extremely high), and PNM did not have access to surrounding markets, there is a high likelihood of unserved load. The market representation used in SERVM was developed through consultation with PNM staff, FERC Forms, EIA Forms, and reviews of IRP information from neighboring regions. Table 21 shows the breakdown of capacity for each external region captured in the modeling. Each external region was modeled with enough capacity to meet reasonable reliability targets. While it is expected that reserves could be higher than this in the short term, it is not appropriate to incorporate such an assumption since it would represent an ability of PNM to lean heavily on external regions to meet reserve margin assuming that these external regions would have excess capacity perpetually. By setting the study up this way, only weather diversity and generator outage diversity are being captured amongst neighboring utilities.

Table 21. External Regions

	Arizona Entities	EPE	PSCO	SWPSC
Summer Peak Load Forecast (MW)	18,800	1,956	6,270	5,147
Nuclear (MW)	1,824	624	0	0
Coal/Combined Cycle (MW)	15,111	369	5,265	3,617
Peaking (MW)	4189	871	1,338	1,949
Storage (MW)	176	145	437	0
PV (MW)	3,700	695	1,002	190
Wind (MW)	0	0	3,494	2,450
DR (MW)	165	30	63	51
Total Nameplate Capacity (MW)	25,165	2,734	11,599	8,257

The study topology including transmission capability is shown in Figure 7. The SERVM model dispatches each region's resources to load and then allows regions to share energy on an hourly basis based on economics but subject to transmission constraints. Changes in energy purchases are not allowed intra-hour. Regulating and spinning reserves are not allowed to be purchased from external regions, but the additional hourly energy purchased allows for PNM to lower the dispatch of its own units to serve these ancillary services. Given the deficiency in load side generation in the PNM–North region, a substantial amount of energy will be transferred from the Four Corners Region and PNM–South. For these purposes, SERVM allows the PNM balancing area to be committed and dispatched together to a common system load. This includes PNM-North, PNM-Four Corners, PNM-South, Tri-State North, and Tri-State South. Then this smaller system can purchase and sell resources to the external region as appropriate.

Figure 7. Study Topology with Transmission Limits
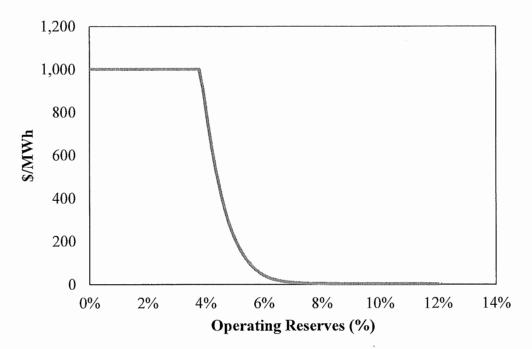
*All transmission constraints are in MW

In addition to the constraints placed in the topology, the overall import capability into the PNM Balancing area was limited from external resources to 150 MW day ahead purchase and a 150 MW non-firm purchase.

The transfers within the PNM balancing area were based on the production cost of the resources. The cost of transfers between external regions and PNM are based on marginal costs with a $10/MWh profit margin. In cases where a region is short of resources, scarcity pricing is added to the marginal costs. As a

region's hourly reserve margin approaches zero, the scarcity pricing for that region increases. Figure 8 shows the scarcity pricing curve that was used in the simulations. It should be noted that the frequency of these scarcity prices is very low because in the majority of hours, there is plenty of capacity to meet load after the market has cleared[7].

Figure 8. Scarcity Pricing Curve

<hr>

[7]The market clearing algorithm within SERVM attempts to get all regions to the same price subject to transmission constraints and the $10/MWh profit margin. If a region's original price is $1,000/MWh based on the conditions and scarcity pricing in that region alone, it is highly probable that a surrounding region will provide enough capacity to that region to bring prices down to reasonable levels.

N. Ancillary Service Requirements

For this study, three distinct ancillary services were modeled: regulating reserves, spinning reserves, and non-spinning reserves. Traditional contingency reserves are defined as spinning and non-spinning reserves. Four percent of load was required for 10 min regulating reserves at all times, which equates to approximately 100 MW during peak conditions and 60 MW on average. Only units with Automatic Generation Control (AGC) can serve this need. Firm load would be shed to maintain this regulation requirement. The spinning requirement was varied as a percent of load to ensure flexibility reliability metrics are met for the replacement resource combination being modeled. SERVM commits enough resources to meet this requirement, but in the scenario where resources are not available, the spinning requirement can be reduced to zero. The non-spin requirement was set to 4% of load.

O. Cost of Renewable Curtailment

Renewable curtailment occurs during over-generation periods when the system cannot ramp down fast enough to meet net load or when all online generators are dispatched at minimum but are still producing more than system load needs. There was no additional penalty included for renewable curtailment other than the cost associated with generation that was not used to serve load.

IV. SERVM Model and Methodology

The SERVM model is a chronological generation commitment and dispatch model that allows users to simulate electric systems down to 1-minute intervals taking into account all unit constraints while co-optimizing energy and ancillary services. Many planning models do not take into account all unit constraints and do not dispatch on a chronological basis, all of which are essential in understanding intra-hour system flexibility and renewable integration costs. SERVM outputs both physical reliability metrics such as $LOLE_{CAP}$ and $LOLE_{FLEX}$ as well as total system balancing area costs of every scenario simulated. When SERVM commits and dispatches resources to net load, it doesn't have perfect knowledge of the load and renewable profiles on a 5-minute interval. SERVM is used by entities across the U.S. including the Southern Company, TVA, Duke Energy, ERCOT, SPP, MISO, Pacific Gas & Electric, and the California Public Utilities Commission for resource adequacy and renewable integration analysis. Because of its rapid commitment and dispatch engine, SERVM is able to simulate thousands of iterations varying load, generator outages, and renewable profiles across a multi area topology. Since most reliability events are high impact, low probability events, evaluating thousands of iterations is essential. As discussed previously, SERVM utilized 36 years of historical weather and load shapes, 7 points of economic load growth forecast error, and 5 iterations of unit outage draws for each scenario to represent the full distribution of realistic scenarios. The number of yearly simulation cases equals 36 weather years * 7 load forecast errors * 5 unit outage iterations = 1,260 total iterations for each scenario modeled. The 1,260 iterations represent full year simulations at 5-minute intervals.

An example of probabilities given for each case is shown in Table 22. Each weather year is given equal probability and each weather year is multiplied by the probability of each load forecast error point to calculate the case probability.
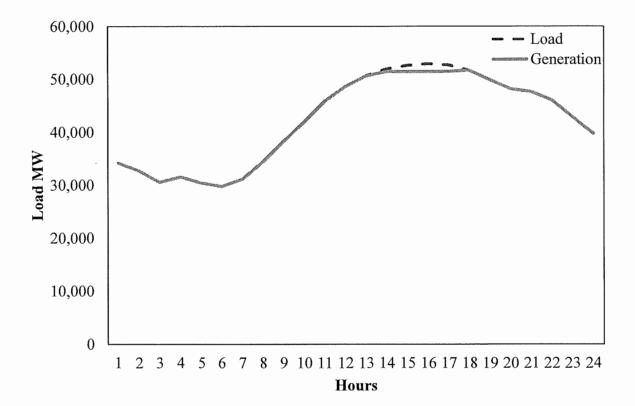
Table 22. Case Probability Example

Weather Year	Weather Year Probability	Load Multipliers due to Load Forecast Error	Load Multiplier Probability	Case Probability
1980	2.78%	95.00%	5.00%	0.14%
1980	2.78%	97.00%	10.00%	0.28%
1980	2.78%	99.00%	15.00%	0.42%
1980	2.78%	100.00%	40.00%	1.11%
1980	2.78%	101.00%	15.00%	0.42%
1980	2.78%	103.00%	10.00%	0.28%
1980	2.78%	105.00%	5.00%	0.14%
1981	2.78%	95.00%	5.00%	0.14%
1981	2.78%	97.00%	10.00%	0.28%
1981	2.78%	99.00%	15.00%	0.42%
1981	2.78%	100.00%	40.00%	1.11%
1981	2.78%	101.00%	15.00%	0.42%
1981	2.78%	103.00%	10.00%	0.28%
1981	2.78%	105.00%	5.00%	0.14%

For each case, and ultimately each iteration, SERVM commits and dispatches resources to load and ancillary service requirements by region on a 5-minute basis. As discussed in the load and renewable uncertainty sections, SERVM does not have perfect knowledge of the load or renewable resource output as it determines its commitment. SERVM begins with a week-ahead commitment, and as the prompt hour approaches the model is allowed to make adjustments to its commitment as units fail and more certainty around load and renewable output is gained. Ultimately, SERVM forces the system to react to these uncertainties while maintaining all unit constraints such as ramp rates, startup times, and min-up and min-down times. During each iteration, Loss of Load Expectation (LOLE) is calculated and the model splits LOLE into two categories based on the definition outlined in the following paragraphs: (1) $LOLE_{CAP}$ and (2) $LOLE_{FLEX}$.

(1) LOLE$_{CAP}$: number of loss of load events due to capacity shortages, calculated in events per year. Figure 9 shows an example of a capacity shortfall which typically occurs across the peak of a day.

Figure 9. LOLE$_{CAP}$ Example
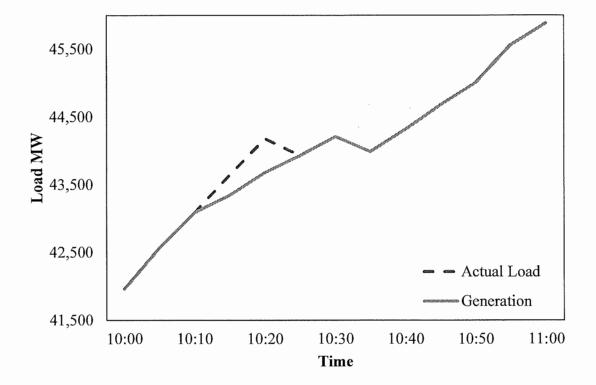
The industry standard is to maintain 1 LOLE$_{CAP}$ event every 10 years which is equivalent to 0.1 LOLE$_{CAP}$ per year. As discussed in the 2017 IRP, a utility the size of PNM will have difficulty meeting 0.1 LOLE$_{CAP}$ due simply to the fact that its largest single contingency is over 10% of its peak load (230 MW/2,072 MW of load) versus a 20,000 MW load system whose largest unit (1,000 MW) only makes up 5% of its peak load. For these reasons, PNM and Astrapé recommend maintaining an LOLE$_{CAP}$ of 0.2 events per year which equates to 2 events in 10 years.

(2) LOLE$_{FLEX}$: number of loss of load events due to system flexibility problems, calculated in events per year. In other words, there was enough capacity installed but not enough flexibility to meet the net load ramps, or startup times prevented a unit coming online fast enough to meet the unanticipated ramps.

Figures 10 shows an LOLE$_{FLEX}$ example. The vast majority of LOLE$_{FLEX}$ events fall under the intra-hour problem seen in this figure. These events are typically very short in duration and are caused by a rapid decline in solar or wind resources over a short time interval.

Figure 10. Intra-hour LOLE$_{FLEX}$

This is a new metric introduced by SERVM, so no industry standard is currently set to capture reliability due to flexibility issues. Generally, these type of flexibility events are short, less than an hour, and low in magnitude compared to traditional LOLE$_{CAP}$ events. For this analysis, the 2023 replacement resources were studied to maintain a 0.2 LOLE$_{CAP}$ and 0.2 LOLE$_{FLEX}$.

Other key metrics recorded for each iteration are (3) renewable curtailment and (4) total costs.

(3) Renewable curtailment: Renewable curtailment occurs during over-generation periods when the system cannot ramp down fast enough to meet net load.

(4) Total System Net Present Value (NPV): A 20 year NPV of Production Costs + Net Purchase Costs + Fixed Costs of the incremental replacement resources in the Balancing Area. Production costs include all fuel burn, variable O&M, startup costs, and CO_2 costs. Net Purchase costs represent any costs for purchases of power from entities minus any sales to external entities. Production costs and fixed costs were discounted at 7.2% to calculate the NPV for each replacement combination.

V. RFP Evaluation Results

All Renewable Replacement Resource Combinations

Astrapé began by constructing replacement resource combinations including only the best priced renewable resources so it could inspect the reliability impact on the system of all renewable replacement resources. These included solar only (975 MW), wind only (1,199 MW), and wind/solar portfolios (975 MW solar and 1,199 MW wind). System reliability measured by both $LOLE_{CAP}$ and $LOLE_{FLEX}$ was significantly worse than acceptable. The $LOLE_{CAP}$ values were higher than 5 events per year in 2023. To achieve the necessary $LOLE_{CAP}$ threshold and the $LOLE_{FLEX}$ threshold, additional dispatchable capacity resources would have to be added to the portfolio and operating guidelines would have to be amended to provide more operating reserves which both would increase costs. This analysis confirmed that renewable-only replacement resources were not a valid option. Future analysis would only include replacement resource combinations which included dispatchable capacity resources such as energy storage and gas options.

Base Load Replacement Resource

A single combined cycle offer was evaluated. With a capacity of 445 MW, nearly all of the projected need could be met by a single resource. However, large resources carry unique risks. While these resources offer low dispatch costs, their contribution to reliability is affected by the fact that the loss of the entire unit would have a significant impact on reliability and especially $LOLE_{CAP}$. The initial analysis showed that $LOLE_{CAP}$ of this replacement resource was higher than the 0.2 $LOLE_{CAP}$ threshold. To achieve 0.2 $LOLE_{CAP}$ while including the combined cycle offer, additional resources would be needed

resulting in higher costs and offsetting the benefit of selecting a large efficient resource. In the end, this resource was compared to other replacement resource combinations and did not provide a low cost option.

Tier 1 and Tier 2 Modeling of All Resource Types

Combinations of Tier 1 offers were modeled using the previously discussed simulation methodology and inputs. The combinations were normalized for reliability by enforcing a 0.2 $LOLE_{CAP}$ and 0.2 $LOLE_{FLEX}$ was met. $LOLE_{CAP}$ was normalized by adding and removing capacity while $LOLE_{FLEX}$ was normalized by changing the spinning reserve assumption. High spinning reserve assumptions allow the system to meet load during periods when intermittent resources drop off suddenly. However, there is a cost to increasing spinning reserves which is included in the fuel cost of each replacement resource combination.

Table 23 shows the extensive combinations that were simulated as part of the Tier 1 Modeling. As discussed previously, the lowest cost Tier 1 wind resource of 140 MW was selected as an RPS resource and is included in every replacement resource combination. The next best wind resource was substantially higher so additional wind was only evaluated as part of the Tier 2 Modeling. The Tier 1 combinations were set up to understand which capacity resource would best integrate the different levels of solar to provide reliability and lowest cost options while also showing the amount of solar capacity that is economic. The capacity resources included bookends from all battery/renewable options to all gas options as shown in Table 23. The battery options included solar/battery hybrids and standalone storage while the gas options included LM6000s (aeroderivatives), reciprocating engines, and frame machines. The solar resources were based on the HDR "best in class" analysis and included 0 MW to 700 MW as shown in the table. These combinations resulted in 81 combinations for the Tier 1 modeling to determine a least cost set of replacement resources that also met reliability metrics. There were no constraints put on technology or project size in this initial Tier 1 analysis.

Table 23. Tier 1 Modeling Combinations

Resource Replacement Combination	Technology Type	LM6000	Recips	Frame	Battery	Solar	Wind

		MW	MW	MW	MW	MW	MW
Tier 1 - 1	Battery/Renewable	0	0	0	530	300	140
Tier 1 - 2	Battery/Renewable	0	0	0	530	350	140
Tier 1 - 3	Battery/Renewable	0	0	0	490	500	140
Tier 1 - 4	Battery/Renewable	0	0	0	490	650	140
Tier 1 - 5	Battery/Renewable	0	0	0	490	700	140
Tier 1 - 6	Battery/Renewable	0	0	0	520	300	140
Tier 1 - 7	Battery/Renewable	0	0	0	520	350	140
Tier 1 - 8	Battery/Renewable	0	0	0	520	500	140
Tier 1 - 9	Battery/Renewable	0	0	0	480	650	140
Tier 1 - 10	Battery/Renewable	0	0	0	480	700	140
Tier 1 - 11	Battery/Renewable	0	0	0	530	300	140
Tier 1 - 12	Battery/Renewable	0	0	0	510	350	140
Tier 1 - 13	Battery/Renewable	0	0	0	450	500	140
Tier 1 - 14	Battery/Renewable	0	0	0	410	650	140
Tier 1 - 15	Battery/Renewable	0	0	0	410	700	140
Tier 1 - 16	Gas/Battery/Renewable	423	0	0	0	0	140
Tier 1 - 17	Gas/Battery/Renewable	423	0	0	0	300	140
Tier 1 - 18	Gas/Battery/Renewable	423	0	0	0	350	140
Tier 1 - 19	Gas/Battery/Renewable	384	0	0	0	500	140
Tier 1 - 20	Gas/Battery/Renewable	384	0	0	0	650	140
Tier 1 - 21	Gas/Battery/Renewable	384	0	0	0	700	140
Tier 1 - 22	Gas/Battery/Renewable	269	0	0	150	300	140
Tier 1 - 23	Gas/Battery/Renewable	269	0	0	150	350	140
Tier 1 - 24	Gas/Battery/Renewable	269	0	0	150	500	140
Tier 1 - 25	Gas/Battery/Renewable	269	0	0	150	650	140
Tier 1 - 26	Gas/Battery/Renewable	269	0	0	150	700	140
Tier 1 - 27	Gas/Battery/Renewable	0	423	0	0	0	140
Tier 1 - 28	Gas/Battery/Renewable	0	406	0	0	300	140
Tier 1 - 29	Gas/Battery/Renewable	0	406	0	0	350	140
Tier 1 - 30	Gas/Battery/Renewable	0	389	0	0	500	140
Tier 1 - 31	Gas/Battery/Renewable	0	389	0	0	650	140
Tier 1 - 32	Gas/Battery/Renewable	0	389	0	0	700	140

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Tier 1 - 33	Gas/Battery/Renewable	0	271	0	150	300	140
Tier 1 - 34	Gas/Battery/Renewable	0	271	0	150	350	140
Tier 1 - 35	Gas/Battery/Renewable	0	271	0	150	500	140
Tier 1 - 36	Gas/Battery/Renewable	0	271	0	150	650	140
Tier 1 - 37	Gas/Battery/Renewable	0	271	0	150	700	140
Tier 1 - 38	Gas/Battery/Renewable	231	237	0	0	0	140
Tier 1 - 39	Gas/Battery/Renewable	192	220	0	0	300	140
Tier 1 - 40	Gas/Battery/Renewable	192	203	0	0	350	140
Tier 1 - 41	Gas/Battery/Renewable	192	203	0	0	500	140
Tier 1 - 42	Gas/Battery/Renewable	192	203	0	0	650	140
Tier 1 - 43	Gas/Battery/Renewable	192	203	0	0	700	140
Tier 1 - 44	Gas/Battery/Renewable	154	118	0	150	300	140
Tier 1 - 45	Gas/Battery/Renewable	154	101	0	150	350	140
Tier 1 - 46	Gas/Battery/Renewable	154	101	0	150	500	140
Tier 1 - 47	Gas/Battery/Renewable	154	118	0	150	650	140
Tier 1 - 48	Gas/Battery/Renewable	154	118	0	150	700	140
Tier 1 - 49	Gas/Battery/Renewable	0	271	196	0	0	140
Tier 1 - 50	Gas/Battery/Renewable	0	220	196	0	300	140
Tier 1 - 51	Gas/Battery/Renewable	0	220	196	0	350	140
Tier 1 - 52	Gas/Battery/Renewable	0	220	196	0	500	140
Tier 1 - 53	Gas/Battery/Renewable	0	203	196	0	650	140
Tier 1 - 54	Gas/Battery/Renewable	0	203	196	0	700	140
Tier 1 - 55	Gas/Battery/Renewable	0	101	196	150	300	140
Tier 1 - 56	Gas/Battery/Renewable	0	85	196	150	350	140
Tier 1 - 57	Gas/Battery/Renewable	0	85	196	150	500	140
Tier 1 - 58	Gas/Battery/Renewable	0	68	196	150	650	140
Tier 1 - 59	Gas/Battery/Renewable	0	68	196	150	700	140
Tier 1 - 60	Gas/Battery/Renewable	269	0	196	0	0	140
Tier 1 - 61	Gas/Battery/Renewable	231	0	196	0	300	140
Tier 1 - 62	Gas/Battery/Renewable	231	0	196	0	350	140
Tier 1 - 63	Gas/Battery/Renewable	231	0	196	0	500	140
Tier 1 - 64	Gas/Battery/Renewable	192	0	196	0	650	140
Tier 1 - 65	Gas/Battery/Renewable	192	0	196	0	700	140

Tier 1 - 66	Gas/Battery/Renewable	115	0	196	150	300	140
Tier 1 - 67	Gas/Battery/Renewable	77	0	196	150	350	140
Tier 1 - 68	Gas/Battery/Renewable	77	0	196	150	500	140
Tier 1 - 69	Gas/Battery/Renewable	77	0	196	150	650	140
Tier 1 - 70	Gas/Battery/Renewable	77	0	196	150	700	140
Tier 1 - 71	Gas/Battery/Renewable	0	0	392	0	0	140
Tier 1 - 72	Gas/Battery/Renewable	0	0	392	0	300	140
Tier 1 - 73	Gas/Battery/Renewable	0	0	392	0	350	140
Tier 1 - 74	Gas/Battery/Renewable	0	0	392	0	500	140
Tier 1 - 75	Gas/Battery/Renewable	0	0	392	0	650	140
Tier 1 - 76	Gas/Battery/Renewable	0	0	392	0	700	140
Tier 1 - 77	Gas/Battery/Renewable	0	0	392	150	300	140
Tier 1 - 78	Gas/Battery/Renewable	0	0	392	150	350	140
Tier 1 - 79	Gas/Battery/Renewable	0	0	392	150	500	140
Tier 1 - 80	Gas/Battery/Renewable	0	0	392	150	650	140
Tier 1 - 81	Gas/Battery/Renewable	0	0	392	150	700	140

The results of these combinations showed that Replacement Combination Tier 1 – 23 was the least cost option that met reliability criteria. Table 24 shows the total NPV for the Top 20 combinations as well as a breakdown of the fixed and variable costs of each. The top 2 portfolios included the same amount of gas, battery, and wind resources and only varied by 50 MW of solar. The battery resource reduces renewable curtailment by allowing the solar generation during the day to be stored and used later in the afternoon and evening hours while also providing ancillary services. Based on the HDR analysis and pricing, the 300 MW solar/150 MW battery offer was the lowest cost battery option.

Table 24. Top 20 2023 Replacement Resource Combinations With No Technology or Project Size Constraints

Resource Replacement Combination #	Category	LM6000	Recips	Frame	Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs
		MW	MW	MW	MW	MW	MW	M$	M$	M$
Tier 1 - 23	Gas/Battery/Renewable	269	0	0	150	350	140	$4,619	$411	4,207
Tier 1 - 22	Gas/Battery/Renewable	269	0	0	150	300	140	$4,622	$411	4,210
Tier 1 - 45	Gas/Battery/Renewable	154	101	0	150	350	140	$4,644	$451	4,192
Tier 1 - 67	Gas/Battery/Renewable	77	0	196	150	350	140	$4,658	$412	4,246
Tier 1 - 44	Gas/Battery/Renewable	154	118	0	150	300	140	$4,662	$476	4,186
Tier 1 - 24	Gas/Battery/Renewable	269	0	0	150	500	140	$4,665	$411	4,254
Tier 1 - 16	Gas/Battery/Renewable	423	0	0	0	0	140	$4,683	$432	4,251
Tier 1 - 66	Gas/Battery/Renewable	115	0	196	150	300	140	$4,687	$453	4,233
Tier 1 - 46	Gas/Battery/Renewable	154	101	0	150	500	140	$4,687	$451	4,236
Tier 1 - 56	Gas/Battery/Renewable	0	85	196	150	350	140	$4,688	$452	4,235
Tier 1 - 33	Gas/Battery/Renewable	0	271	0	150	300	140	$4,701	$533	4,168
Tier 1 - 34	Gas/Battery/Renewable	0	271	0	150	350	140	$4,702	$532	4,170
Tier 1 - 55	Gas/Battery/Renewable	0	101	196	150	300	140	$4,703	$477	4,226
Tier 1 - 14	Battery/Renewable	0	0	0	410	650	140	$4,704	$439	4,265
Tier 1 - 68	Gas/Battery/Renewable	77	0	196	150	500	140	$4,708	$412	4,296
Tier 1 - 13	Battery/Renewable	0	0	0	450	500	140	$4,710	$496	4,214
Tier 1 - 17	Gas/Battery/Renewable	423	0	0	0	300	140	$4,713	$443	4,270
Tier 1 - 18	Gas/Battery/Renewable	423	0	0	0	350	140	$4,716	$443	4,273
Tier 1 - 71	Gas/Battery/Renewable	0	0	392	0	0	140	$4,721	$383	4,338

The full Tier 1 offer matrices showing all 81 options are included in the Appendix of the report. The results were insightful. The analysis shows that the 350 MW of solar is an optimal level given the submitted RFP offers. The lowest cost all battery/renewable case was substantially more expensive then the option that included both battery and gas. Filling the entire capacity need with battery is more expensive because it forces in the higher cost battery options which are more expensive than competing gas alternatives. The analysis shows that additional battery in addition to the least cost solar/battery combination should be further analyzed as part of the Tier 2 analysis. From a gas perspective, the aeroderivative options were more economic than either the frame or reciprocating engines in all cases.

The aeroderivatives and frame offers had similar fixed costs but the aeroderivatives provide more flexibility, especially given their low minimum capacity levels. The reciprocating engines provide more flexibility and slightly cheaper energy costs, but those benefits do not overcome the fixed cost premium on these offers.

Tier 2 Modeling was performed next around the best combination found in the Tier 1 Modeling. The Tier 2 resources included the next lowest cost wind resources, combined renewable/battery, and standalone battery options which were further down in HDRs evaluation ranking. Table 25 shows those combinations and results ranked. The top ranked combination added 20 MW of battery that was included in the next best priced combined solar/battery option which also allowed for one less aeroderivative to be selected in order to meet reliability criteria. The lowest NPV from the Tier 1 Modeling was 4,619 million dollars (highlighted in gray in the table) versus an NPV of 4,593 million dollars which was the least cost combination from the Tier 2 Modeling. As expected, the more expensive wind projects did not improve the economics.

Table 25. Tier 2 Results With No Technology or Project Size Constraints

Resource Replacement Combination #	Tier 1/Tier 2	LM6000	Recips	Frame	Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs
Tier 2 - 1	Tier 2	231	0	0	170	370	140	$4,593	$410	$4,183
Tier 2 - 2	Tier 2	231	0	0	170	350	140	$4,595	$398	$4,197
Tier 1 - 23	Tier 1	269	0	0	150	350	140	$4,619	$411	$4,207
Tier 2 - 3	Tier 2	269	0	13	150	350	140	$4,624	$417	$4,208
Tier 2 - 4	Tier 2	192	0	0	210	350	140	$4,626	$429	$4,197
Tier 2 - 5	Tier 2	231	0	0	190	350	140	$4,629	$431	$4,197
Tier 2 - 6	Tier 2	192	0	0	210	500	140	$4,632	$410	$4,221
Tier 2 - 7	Tier 2	77	0	0	350	350	140	$4,650	$454	$4,196
Tier 2 - 8	Tier 2	192	0	0	250	350	140	$4,664	$479	$4,185
Tier 2 - 9	Tier 2	192	0	0	200	350	140	$4,679	$451	$4,228
Tier 2 - 10	Tier 2	308	0	0	100	350	140	$4,688	$455	$4,233
Tier 2 - 11	Tier 2	231	0	0	150	350	340	$4,697	$382	$4,315
Tier 2 - 12	Tier 2	192	0	0	150	350	540	$4,751	$354	$4,397

Ownership RFP

The original set of bids in the Tier 1 and Tier 2 Modeling did not include many ownership options. The utility owned bids were limited due to a lack of bidders having NM state contractor licenses. Because some original bidders were automatically rejected for that reason, PNM solicited additional utility owned battery proposals through a supplement to the original RFP in order to ensure a range of ownership battery options would be evaluated. Once those bids were received, HDR provided Astrapé the least cost ownership battery options based on $/kW-yr to be incorporated into the analysis which would remove gas or battery PPA offers. These were 100 MW, 150 MW, and 200 MW least cost battery options with 2 hour and 4 hour storage capability provided in the May RFP. Due to lack of investment tax credit benefits, these large ownership options did not improve upon the best portfolio found in the Tier 2 Modeling which included combined battery and solar projects.

Based on the Tier 1 and Tier 2 Modeling, the least cost replacement resource combination consisted of 6 aeroderivatives totaling 231 MW, and two combined solar/battery projects consisting of 300 MW solar/150 battery and 50 MW solar/20 MW battery.

Risk Analysis

As part of the Company's review, PNM asked Enovation Partners to review this least cost set of replacement resources with a focus on energy storage since it included a 150 MW battery. Enovation Partners as expressed in Mr. Kemp's testimony recommended that initial energy storage implementation by PNM should not be beyond 2% - 5% of the system peak load and that individual projects should be between 10 MW and no more than 40 MW.

With this adjusted risk profile, PNM requested that Astrapé provide further modeling that replaced the 170 MW of battery options with smaller available projects of up to 40 MW. The Tier 1 and Tier 2

unconstrained modeling determined that the 350 MW of solar and some level of the aeroderivatives would provide the most economic combination of replacement resources. Using the least cost PPA and ownership battery options including the combined solar/battery projects that were 40 MW and less, many permutations were developed to determine the least cost combination that met reliability. Some of the larger PPAs options were re-priced to provide 40 MW projects. These options are shown in Table 26 below.

Table 26. Battery Options for Constrained Modeling

Battery Configuration	Ownership/PPA	Duration (Hours)	Battery Size (MW)
Combined Solar/Battery	PPA	4	300 solar/40 battery
Combined Solar/Battery	PPA	4	50 solar/20 battery
Stand Alone Battery	PPA	4	40
Stand Alone Battery	PPA	4	40
Stand Alone Battery	PPA	4	40
Stand Alone Battery	PPA	4	40
Stand Alone Battery	Ownership	2	40
Stand Alone Battery	Ownership	2	30

Total combined battery options ranging from 20 MW to 170 MW were simulated and those results are shown in Table 27. Seven combinations were within 3 million NPV of each other. The lowest cost combination consisted of all battery PPAs. Given that battery ownership is preferred and the differences in economics are negligible, PNM selected the combination that included 7 aeroderivatives consisting of 269 MW, combined solar/battery project consisting of 300 MW of solar and 40 MW of battery, combined solar/battery project consisting of 50 MW of solar and 20 MW of battery, and two standalone battery ownership projects consisting of 40 MW and 30 MW. This combination totals 269 MW of gas, 350 MW of solar, and 130 MW of battery and is referred to by the Company as Scenario 1 and the Company's proposed plan.

Table 27. Constrained Battery Combinations Sorted by Least Cost

Resource Replacement Combination	LM6000	PPA Battery	Ownership Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs
	MW	MW	MW	MW	MW	M$	M$	M$
Constrained - 1	269	140	0	350	140	$4,677	$470	$4,207
Constrained - 2	307	100	0	350	140	$4,678	$461	$4,217
Constrained - 3 (Proposed Plan)	269	60	70	350	140	$4,678	$472	$4,206
Constrained - 4	345	40	0	350	140	$4,678	$430	$4,248
Constrained - 5	307	60	40	350	140	$4,679	$469	$4,210
Constrained - 6	269	140	0	370	140	$4,679	$482	$4,198
Constrained - 7	269	60	70	370	140	$4,679	$483	$4,196
Constrained - 8	269	100	40	350	140	$4,683	$476	$4,207
Constrained - 9	231	140	30	350	140	$4,693	$485	$4,208
Constrained - 10	345	60	0	350	140	$4,696	$456	$4,240
Constrained - 11	231	100	70	350	140	$4,698	$491	$4,207
Constrained - 12	269	140	0	500	140	$4,702	$449	$4,253
Constrained - 13	307	100	0	500	140	$4,708	$442	$4,266
Constrained - 14	345	0	40	350	140	$4,711	$457	$4,254
Constrained - 15	345	40	0	500	140	$4,718	$430	$4,288
Constrained - 16	345	60	0	350	140	$4,724	$474	$4,250
Constrained - 17	383	20	0	350	140	$4,726	$470	$4,256
Constrained - 18	345	60	0	500	140	$4,735	$456	$4,280
Constrained - 19	383	40	0	350	140	$4,758	$503	$4,255

Table 28 shows the reliability metrics for Scenario 1 – the Proposed Plan. Reliability metrics of the other combinations studied are included in the Appendix.

Table 28. Reliability Metrics for Scenario 1

Study Year	LOLE Cap	LOLE Flex	Renewable Curtailment MWh	Renewable Curtailment %
2023	0.19	0.14	293,011	6.88%
2028	0.13	0.17	258,099	4.90%
2033	0.05	0.16	294,445	4.32%

VI. Additional Scenarios to Compare to the Proposed Plan

The Company requested Astrapé run 3 additional scenarios to compare against the proposed plan. These were developed by PNM's resource planning department and respect the 40 MW battery size project limit. These included the following:

- Scenario 1 – This scenario is the proposed least cost plan from the modeling discussed above. It includes seven aeroderivatives consisting of 269 MW, a combined solar/battery project consisting of 300 MW of solar and 40 MW of battery, a combined solar/battery project consisting of 50 MW of solar and 20 MW of battery, and two standalone battery ownership projects consisting of 40 MW and 30 MW

- Scenario 2 - San Juan Location Preference Alternative Scenario – This scenario included the least cost resources in the San Juan Location which included 7 aero derivatives and 1 Frame machine.

- Scenario 3 - No New Fossil Fuel Alternative Scenario – This scenario included the least cost battery projects that were less than 40 MW and renewable resources. It included 500 MW of solar and 11 battery projects summing to 410 MW. The 11 different battery projects included 7 PPA options and 4 ownership options.

- Scenario 4 - All Renewable Replacement Scenario – This scenario includes all renewable capacity. This scenario includes all wind and solar PPA projects consisting of 1,200 MW of wind and 975 MW of solar.

These scenarios were treated in the same manner as all the other combinations that were simulated as part of the Tier 1 and Tier 2 Modeling approach. Table 29 shows those results. Of the 4 replacement scenarios put forth by the Company, the proposed plan is the most economic. Scenario 2 has an NPV of 54 million dollars more than Scenario 1 while Scenario 3 has an NPV of 156 million dollars higher than Scenario 1. The next table shows the reliability of the replacement scenarios compared to the proposed

plan. This shows that additional capacity resources would be required for both Scenario 3 and 4 demonstrating that the economics shown in Table 29 are conservative. The costs would increase to ensure reliability. CO_2 emissions in millions tons are also included in the results below.

Table 29. Additional Scenarios Provided by the Company

Resource Replacement Combination	LM6000	Frame	PPA Battery	Owned Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs	2023 CO_2
	MW	MW	MW	MW	MW	MW	M$	M$	M$	Million tons
Scenario 1 – Proposed Plan	269	0	60	70	350	140	$4,678	$472	$4,206	2.9
Scenario 2 – SJ preferred	269	196	0	0	0	140	$4,732	$465	$4,267	3.1
Scenario 3 – No Gas	0	0	260	150	500	140	$4,834	$615	$4,219	2.6
Scenario 4 – All renewable	0	0	0	0	975	1,199	$5,452	$73	$5,380	2.5

Table 30. Reliability Metrics of Additional Scenarios Provided by the Company

Resource Replacement Combination	LOLE Cap	LOLE Cap	LOLE Cap	LOLE Flex	LOLE Flex	LOLE Flex
	Events per Year					
Year	2023	2028	2033	2023	2028	2033
Scenario 1 – Proposed Plan	0.19	0.13	0.05	0.14	0.17	0.16
Scenario 2 – SJ preferred	0.21	0.07	0.03	0.16	0.17	0.16
Scenario 3 – No Gas	0.36	0.29	0.27	0.10	0.06	0.06
Scenario 4 – All renewable	5.63	2.52	1.01	3.35	0.73	0.17

VI. High Gas/ CO_2 Sensitivity

The top combinations in the Tier 1, Tier 2, and Battery Constrained Modeling were simulated under the High Gas/ CO_2 Sensitivity. The unconstrained Tier 1 and Tier 2 Modeling results are in Table 31. The top combination that appeared in the Base gas/CO_2 pricing also is the top ranked bid in the High Gas/CO_2 sensitivity. The best all battery/renewable combination was more competitive as expected in the High Gas/ CO_2 sensitivity.

Table 31. High Gas/ CO_2 Sensitivity: Tier 1 and Tier 2 Top Replacement Resource Combinations

Technology Type	LM6000	Recips	Frame	Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs
	MW	MW	MW	MW	MW	MW	M$	M$	M$
Gas/Battery/Renewable	231	0	0	170	350	140	$5,198	$398	4,800
Gas/Battery/Renewable	192	0	0	210	500	140	$5,200	$410	4,790
Battery/Renewable	0	0	0	410	650	140	$5,210	$439	4,771
Gas/Battery/Renewable	192	0	0	210	350	140	$5,218	$429	4,789
Gas/Battery/Renewable	77	0	0	350	350	140	$5,219	$454	4,765
Gas/Battery/Renewable	231	0	0	190	350	140	$5,226	$431	4,794
Gas/Battery/Renewable	269	0	0	150	350	140	$5,232	$411	4,820
Battery/Renewable	0	0	0	410	700	140	$5,235	$439	4,797
Battery/Renewable	0	0	0	450	500	140	$5,240	$496	4,744
Gas/Battery/Renewable	192	0	0	250	350	140	$5,248	$479	4,769
Gas/Battery/Renewable	269	0	0	150	500	140	$5,260	$411	4,849
Gas/Battery/Renewable	192	0	0	200	350	140	$5,274	$451	4,822
Gas/Battery/Renewable	269	0	0	150	650	140	$5,300	$413	4,887
Gas/Battery/Renewable	0	271	0	150	350	140	$5,304	$532	4,771
Gas/Battery/Renewable	308	0	0	100	350	140	$5,304	$455	4,849
Gas/Battery/Renewable	0	271	0	150	500	140	$5,326	$532	4,794
Battery/Renewable	0	0	0	510	350	140	$5,343	$590	4,754
Gas/Battery/Renewable	0	271	0	150	650	140	$5,375	$534	4,841
Battery/Renewable	0	0	0	530	300	140	$5,391	$625	4,766
Gas/Battery/Renewable	269	0	196	0	0	140	$5,427	$465	4,962

The constrained modeling results for the High Gas/ CO_2 sensitivity are shown in Table 32. These results showed a similar pattern with there being small differences in the top few replacement resource combinations. This analysis shows that even under higher gas and CO_2, the proposed plan which provides a diverse resource set is robust.

Table 32. High Gas/ CO_2 Sensitivity: Constrained Resource Combinations

Resource Replacement Combination	LM6000	PPA Battery	Ownership Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs
	MW	MW	MW	MW	MW	M$	M$	M$
Constrained – 1	269	140	0	370	140	$5,276	$482	$4,795
Constrained – 2	269	140	0	350	140	$5,278	$470	$4,808
Constrained - 3 - Proposed Plan	269	60	70	350	140	$5,281	$472	$4,810
Constrained – 4	269	100	40	350	140	$5,283	$476	$4,807
Constrained – 5	307	60	40	350	140	$5,284	$469	$4,815
Constrained – 6	307	100	0	350	140	$5,285	$461	$4,824
Constrained – 7	269	140	0	500	140	$5,285	$449	$4,836
Constrained – 8	231	140	30	350	140	$5,290	$485	$4,805
Constrained – 9	231	100	70	350	140	$5,297	$491	$4,806
Constrained - 10	307	100	0	500	140	$5,308	$442	$4,867
Constrained - 11	345	60	0	350	140	$5,330	$456	$4,874
Constrained - 12	345	60	0	500	140	$5,343	$456	$4,887

The Company Scenario Modeling is in Table 33. Scenario 4 which includes all renewable was not simulated since there was no way to have that scenario solve from a reliability perspective. Scenario 1 is still the most economic among the scenarios even with the High Gas/ CO_2 future. As expected, Scenario 3 – No Gas improved while Scenario 2 – SJ preferred became less economic compared to Scenario 1.

Table 33. High Gas/ CO_2 Sensitivity: Additional Scenarios

Resource Replacement Combination	LM6000	Frame	PPA Battery	Owned Battery	Solar	Wind	Total NPV
	MW	MW	MW	MW	MW	MW	M$
Scenario 1 – Proposed Plan	269	0	60	70	350	140	$5,281
Scenario 2 – SJ preferred	269	196	0	0	0	140	$5,427
Scenario 3 – No Gas	0	0	260	150	500	140	$5,371

IX. Conclusions

Based on the evaluation performed by Astrapé, the proposed plan of replacement resources including 350 MW of solar, 130 MW of battery, and 269 MW of gas meets reliability criteria and provides reasonable costs given the technology constraints imposed. These replacement resources provide a diverse set of resources and take advantage of the lowest cost renewable, battery, and gas offers submitted into the RFP.

X. Appendix

Renewable Only Replacement Resource Combinations

LM6000 MW	Recip MW	Frame MW	Battery MW	Solar MW	Wind MW	Total NPV M$	NPV Fixed Costs M$	NPV Production Costs M$	LOLE Cap 2023 Events Per year	LOLE Cap 2028 Events Per year	LOLE Cap 2033 Events Per year	LOLE Flex 2023 Events Per year	LOLE Flex 2028 Events Per year	LOLE Flex 2033 Events Per year
0	0	0	0	0	1199	$4,958	$53	4,905	5.82	2.44	1.41	2.44	0.40	0.07
0	0	0	0	975	0	$4,729	$20	4,709	12.72	5.16	2.68	0.32	0.04	0.15
0	0	0	0	975	1199	$5,452	$73	5,380	5.63	2.52	1.01	3.35	0.73	0.17

Base Load Replace Resource Combinations

LM6000 MW	Recip MW	CC MW	Battery MW	Solar MW	Wind MW	Total NPV M$	NPV Fixed Costs M$	NPV Production Costs M$	LOLE Cap 2023 Events Per year	LOLE Cap 2028 Events Per year	LOLE Cap 2033 Events Per year	LOLE Flex 2023 Events Per year	LOLE Flex 2028 Events Per year	LOLE Flex 2033 Events Per year
0	0	445	0	300	140	$4,785	$561	4,224	0.43	0.14	0.06	0.35	0.20	0.16

Tier 1 Modeling

LM6000 MW	Recip MW	Frame MW	Battery MW	Solar MW	Wind MW	Total NPV M$	NPV Fixed Costs M$	NPV Production Costs M$	LOLE Cap 2023 Events Per year	LOLE Cap 2028 Events Per year	LOLE Cap 2033 Events Per year	LOLE Flex 2023 Events Per year	LOLE Flex 2028 Events Per year	LOLE Flex 2033 Events Per year
0	0	0	530	300	140	$4,827	$625	4,202	0.10	0.22	0.23	0.11	0.10	0.07
0	0	0	530	350	140	$4,824	$625	4,199	0.16	0.22	0.21	0.13	0.20	0.08
0	0	0	490	500	140	$4,793	$564	4,229	0.14	0.12	0.14	0.13	0.16	0.09

0	0	0	490	650	140	$4,837	$566	4,271	0.11	0.09	0.09	0.15	0.16	0.08
0	0	0	490	700	140	$4,858	$566	4,292	0.12	0.10	0.07	0.13	0.15	0.11
0	0	0	520	300	140	$4,919	$690	4,229	0.23	0.33	0.33	0.10	0.17	0.09
0	0	0	520	350	140	$4,917	$690	4,227	0.16	0.25	0.34	0.10	0.20	0.09
0	0	0	520	500	140	$4,941	$690	4,250	0.15	0.15	0.19	0.16	0.16	0.09
0	0	0	480	650	140	$4,938	$631	4,307	0.14	0.12	0.13	0.12	0.16	0.12
0	0	0	480	700	140	$4,955	$631	4,325	0.12	0.13	0.12	0.17	0.16	0.12
0	0	0	530	300	140	$4,827	$625	4,202	0.11	0.23	0.25	0.11	0.18	0.07
0	0	0	510	350	140	$4,789	$590	4,199	0.13	0.17	0.20	0.15	0.22	0.06
0	0	0	450	500	140	$4,710	$496	4,214	0.15	0.15	0.16	0.15	0.10	0.08
0	0	0	410	650	140	$4,704	$439	4,265	0.23	0.16	0.12	0.17	0.16	0.15
0	0	0	410	700	140	$4,729	$439	4,290	0.20	0.16	0.11	0.16	0.16	0.13
423	0	0	0	0	140	$4,683	$432	4,251	0.23	0.08	0.06	0.15	0.17	0.11
423	0	0	0	300	140	$4,713	$443	4,270	0.13	0.04	0.02	0.09	0.21	0.11
423	0	0	0	350	140	$4,716	$443	4,273	0.13	0.05	0.02	0.10	0.18	0.12
384	0	0	0	500	140	$4,738	$411	4,327	0.18	0.05	0.04	0.14	0.17	0.13
384	0	0	0	650	140	$4,800	$393	4,407	0.17	0.07	0.02	0.10	0.19	0.12
384	0	0	0	700	140	$4,834	$393	4,440	0.16	0.07	0.01	0.19	0.19	0.10
269	0	0	150	300	140	$4,622	$411	4,210	0.16	0.07	0.04	0.10	0.14	0.12
269	0	0	150	350	140	$4,619	$411	4,207	0.16	0.05	0.03	0.13	0.18	0.13
269	0	0	150	500	140	$4,665	$411	4,254	0.16	0.05	0.03	0.18	0.15	0.13
269	0	0	150	650	140	$4,726	$413	4,313	0.13	0.06	0.02	0.15	0.15	0.16
269	0	0	150	700	140	$4,768	$413	4,355	0.13	0.05	0.03	0.15	0.14	0.11
0	423	0	0	0	140	$4,807	$609	4,198	0.25	0.08	0.07	0.12	0.19	0.13

0	406	0	0	300	140	$4,800	$595	4,205	0.15	0.07	0.03	0.14	0.15	0.13
0	406	0	0	350	140	$4,801	$595	4,206	0.14	0.05	0.03	0.14	0.18	0.14
0	389	0	0	500	140	$4,827	$571	4,256	0.17	0.05	0.02	0.16	0.13	0.14
0	389	0	0	650	140	$4,896	$572	4,324	0.18	0.05	0.02	0.13	0.17	0.19
0	389	0	0	700	140	$4,930	$572	4,358	0.16	0.07	0.02	0.16	0.20	0.14
0	271	0	150	300	140	$4,701	$533	4,168	0.22	0.07	0.05	0.12	0.15	0.10
0	271	0	150	350	140	$4,702	$532	4,170	0.15	0.08	0.04	0.14	0.15	0.12
0	271	0	150	500	140	$4,743	$532	4,211	0.13	0.05	0.04	0.16	0.15	0.12
0	271	0	150	650	140	$4,806	$534	4,273	0.17	0.03	0.03	0.14	0.14	0.15
0	271	0	150	700	140	$4,839	$534	4,305	0.15	0.04	0.03	0.12	0.16	0.11
231	237	0	0	0	140	$4,788	$581	4,208	0.13	0.06	0.03	0.11	0.16	0.13
192	220	0	0	300	140	$4,759	$539	4,221	0.17	0.06	0.02	0.11	0.13	0.10
192	203	0	0	350	140	$4,741	$514	4,227	0.19	0.05	0.03	0.12	0.17	0.13
192	203	0	0	500	140	$4,792	$514	4,278	0.19	0.06	0.02	0.12	0.19	0.13
192	203	0	0	650	140	$4,864	$516	4,349	0.16	0.04	0.01	0.09	0.15	0.15
192	203	0	0	700	140	$4,901	$516	4,385	0.15	0.04	0.02	0.11	0.18	0.09
154	118	0	150	300	140	$4,662	$476	4,186	0.16	0.05	0.04	0.11	0.13	0.07
154	101	0	150	350	140	$4,644	$451	4,192	0.17	0.10	0.06	0.11	0.15	0.08
154	101	0	150	500	140	$4,687	$451	4,236	0.18	0.05	0.04	0.10	0.17	0.12
154	118	0	150	650	140	$4,765	$478	4,288	0.14	0.04	0.02	0.08	0.14	0.14
154	118	0	150	700	140	$4,807	$478	4,330	0.16	0.05	0.04	0.11	0.14	0.09
0	271	196	0	0	140	$4,811	$586	4,225	0.20	0.06	0.03	0.11	0.14	0.10
0	220	196	0	300	140	$4,774	$523	4,252	0.19	0.06	0.03	0.13	0.18	0.11
0	220	196	0	350	140	$4,777	$523	4,254	0.18	0.05	0.03	0.12	0.18	0.11

0	220	196	0	500	140	$4,831	$523	4,308	0.14	0.06	0.02	0.13	0.14	0.11
0	203	196	0	650	140	$4,891	$500	4,391	0.13	0.07	0.03	0.16	0.10	0.13
0	203	196	0	700	140	$4,930	$500	4,430	0.14	0.05	0.01	0.13	0.18	0.10
0	101	196	150	300	140	$4,703	$477	4,226	0.16	0.05	0.06	0.09	0.13	0.09
0	85	196	150	350	140	$4,688	$452	4,235	0.17	0.08	0.03	0.08	0.13	0.11
0	85	196	150	500	140	$4,739	$452	4,287	0.11	0.06	0.04	0.11	0.11	0.09
0	68	196	150	650	140	$4,782	$429	4,353	0.15	0.05	0.03	0.11	0.12	0.11
0	68	196	150	700	140	$4,833	$429	4,403	0.16	0.05	0.03	0.12	0.13	0.06
269	0	196	0	0	140	$4,732	$465	4,267	0.21	0.07	0.03	0.16	0.17	0.16
231	0	196	0	300	140	$4,729	$437	4,292	0.19	0.05	0.02	0.14	0.15	0.10
231	0	196	0	350	140	$4,733	$437	4,296	0.15	0.06	0.03	0.14	0.20	0.14
231	0	196	0	500	140	$4,790	$437	4,353	0.12	0.03	0.02	0.14	0.17	0.15
192	0	196	0	650	140	$4,847	$411	4,436	0.15	0.04	0.01	0.13	0.18	0.13
192	0	196	0	700	140	$4,887	$411	4,477	0.16	0.06	0.03	0.13	0.17	0.08
115	0	196	150	300	140	$4,687	$453	4,233	0.10	0.07	0.03	0.13	0.14	0.11
77	0	196	150	350	140	$4,658	$412	4,246	0.14	0.07	0.04	0.13	0.12	0.09
77	0	196	150	500	140	$4,708	$412	4,296	0.13	0.05	0.04	0.13	0.14	0.09
77	0	196	150	650	140	$4,771	$414	4,358	0.17	0.06	0.03	0.10	0.11	0.14
77	0	196	150	700	140	$4,819	$414	4,406	0.16	0.06	0.03	0.13	0.13	0.08
0	0	392	0	0	140	$4,721	$383	4,338	0.43	0.13	0.09	0.13	0.18	0.21
0	0	392	0	300	140	$4,757	$393	4,364	0.22	0.09	0.05	0.12	0.16	0.13
0	0	392	0	350	140	$4,763	$393	4,370	0.21	0.08	0.05	0.13	0.18	0.13
0	0	392	0	500	140	$4,826	$393	4,432	0.18	0.09	0.02	0.15	0.12	0.16
0	0	392	0	650	140	$4,908	$395	4,513	0.21	0.07	0.02	0.16	0.17	0.10

0	0	392	0	700	140	$4,951	$395	4,556	0.19	0.05	0.02	0.18	0.19	0.09
0	0	392	150	300	140	$4,794	$521	4,274	0.06	0.03	0.01	0.13	0.13	0.13
0	0	392	150	350	140	$4,796	$521	4,276	0.05	0.02	0.01	0.13	0.16	0.14
0	0	392	150	500	140	$4,849	$521	4,329	0.04	0.01	0.01	0.12	0.14	0.10
0	0	392	150	650	140	$4,914	$522	4,392	0.05	0.02	0.01	0.10	0.12	0.13
0	0	392	150	700	140	$4,966	$522	4,444	0.05	0.01	0.01	0.11	0.12	0.06

Tier 2 Modeling

LM6000	Recip	Frame	Battery	Solar	Wind	Total NPV	NPV Fixed Costs	NPV Production Costs	LOLE Cap 2023	LOLE Cap 2028	LOLE Cap 2033	LOLE Flex 2023	LOLE Flex 2028	LOLE Flex 2033
MW	MW	MW	MW	MW	MW	M$	M$	M$	Events Per year	Events Per year	Events Per year	Events Per year	Events Per year	Events Per year
231	0	0	150	350	340	$4,697	$382	4,315	0.23	0.08	0.06	0.14	0.17	0.13
192	0	0	150	350	540	$4,751	$354	4,397	0.20	0.11	0.05	0.17	0.12	0.15
192	0	0	200	350	140	$4,679	$451	4,228	0.23	0.12	0.07	0.13	0.20	0.18
308	0	0	100	350	140	$4,688	$455	4,233	0.15	0.07	0.04	0.13	0.15	0.20
231	0	0	170	350	140	$4,595	$398	4,197	0.19	0.11	0.04	0.16	0.13	0.18
192	0	0	210	500	140	$4,632	$410	4,221	0.14	0.07	0.05	0.16	0.18	0.16
77	0	0	350	350	140	$4,650	$454	4,196	0.22	0.16	0.14	0.12	0.11	0.12
192	0	0	250	350	140	$4,664	$479	4,185	0.11	0.08	0.04	0.13	0.14	0.19
231	0	0	190	350	140	$4,629	$431	4,197	0.15	0.09	0.03	0.15	0.16	0.16
192	0	0	210	350	140	$4,626	$429	4,197	0.20	0.12	0.05	0.14	0.15	0.10
269	0	13	150	350	140	$4,624	$417	4,208	0.14	0.06	0.03	0.14	0.19	0.12

Battery Constrained Modeling Combinations

| LM6000 | Recip | Frame | Battery | Solar | Wind | Total NPV | NPV Fixed Costs | NPV Production Costs | LOLE Cap 2023 | LOLE Cap 2028 | LOLE Cap 2033 | LOLE Flex 2023 | LOLE Flex 2028 | LOLE Flex 2033 |
MW	MW	MW	MW	MW	MW	M$	M$	M$	Events Per year	Events Per year	Events Per year	Events Per year	Events Per year	Events Per year
345	0	0	40	500	140	$4,718	$430	4,288	0.17	0.05	0.03	0.14	0.18	0.16
345	0	0	40	350	140	$4,711	$457	4,254	0.22	0.06	0.04	0.10	0.19	0.13
307	0	0	100	350	140	$4,678	$461	4,217	0.16	0.09	0.03	0.15	0.16	0.21
345	0	0	60	350	140	$4,696	$456	4,240	0.12	0.05	0.04	0.13	0.16	0.14
307	0	0	100	350	140	$4,679	$469	4,210	0.15	0.07	0.04	0.18	0.19	0.22
269	0	0	140	500	140	$4,702	$449	4,253	0.12	0.07	0.03	0.13	0.20	0.15
307	0	0	100	500	140	$4,708	$442	4,266	0.15	0.05	0.04	0.11	0.14	0.11
269	0	0	140	350	140	$4,683	$476	4,207	0.16	0.11	0.05	0.16	0.15	0.17
383	0	0	20	350	140	$4,726	$470	4,256	0.18	0.06	0.03	0.15	0.15	0.15
383	0	0	40	350	140	$4,758	$503	4,255	0.12	0.04	0.02	0.12	0.18	0.14
345	0	0	60	350	140	$4,724	$474	4,250	0.16	0.08	0.04	0.11	0.16	0.13
345	0	0	40	350	140	$4,678	$430	4,248	0.22	0.07	0.04	0.17	0.15	0.14
345	0	0	60	500	140	$4,735	$456	4,280	0.14	0.05	0.03	0.11	0.17	0.17
231	0	0	170	350	140	$4,693	$485	4,208	0.21	0.16	0.06	0.12	0.12	0.13
231	0	0	170	350	140	$4,698	$491	4,207	0.19	0.14	0.06	0.14	0.11	0.11
269	0	0	140	350	140	$4,677	$470	4,207	0.15	0.07	0.04	0.16	0.15	0.16
269	0	0	130	350	140	$4,678	$472	4,206	0.19	0.13	0.05	0.14	0.17	0.16

269	0	0	140	370	140	$4,679	$482	4,198	0.16	0.08	0.04	0.15	0.16	0.20
269	0	0	130	370	140	$4,679	$483	4,196	0.17	0.10	0.06	0.18	0.14	0.18

BEFORE THE NEW MEXICO PUBLIC REGULATION COMMISSION

IN THE MATTER OF PUBLIC SERVICE)
COMPANY OF NEW MEXICO'S)
CONSOLIDATED APPLICATION FOR)
APPROVALS FOR THE ABANDONMENT,) 19-_____-UT
FINANCING, AND RESOURCE REPLACEMENT)
FOR SAN JUAN GENERATING STATION)
PURSUANT TO THE ENERGY TRANSITION ACT)

AFFIDAVIT

STATE OF ALABAMA)
) ss
COUNTY OF JEFFERSON)

      NICK WINTERMANTEL, Principal, Astrape Consulting, upon being duly sworn according to law, under oath, deposes and states: I have read the foregoing **Direct Testimony of Nick Wintermantel** and it is true and accurate based on my own personal knowledge and belief.

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SIGNED this ___20___ day of June, 2019.

_____
NICK WINTERMANTEL

SUBSCRIBED AND SWORN to before me this __2⁰__ day of June, 2019.

_____
NOTARY PUBLIC IN AND FOR
THE STATE OF ALABAMA

My Commission Expires:

___5/31/22___

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┌─────────────────────────────────────┐
│   ....STATE OF....    TAYLOR KNOX    │
│  : NOTARY :    My Commission Expires │
│  : PUBLIC :        May 31, 2022      │
│   ...ALABAMA...                      │
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