New Mexico In-state Energy Storage: Market Status and Anticipated Growth

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RETA

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IMPORTANT NOTICE:

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1 Executive Summary

This report summarizes a proposed approach to assessing energy storage market status and anticipated growth to meet New Mexico's Renewable Portfolio Standard (RPS) goals. It is intended to only address siting of storage co-located with large-scale renewable generation, connected to the transmission system at least 100 kilovolts (kV) or higher, or connected to the sub transmission system (less than 100 kV). Promotion of storage projects to be pursued and in development by 2026 and operating by 2030 is also presented.

A case study is described in Section 3 outlining potential development paths for storage sizing and installation timelines. ***Only the RPS market is analyzed*** given uncertainties related to future energy contract volumes, duration and Power Purchase Agreement pricing for the Export market.

1.1 Features of this Report

A short Glossary is presented after this section. ***Box sidebars*** provide background for a non-technical reader. This information is intended to enhance content in the main body of the report by discussing planning concepts and techniques, offering cautions or different perspectives on study approaches that may need further consideration.

The following Appendices are attached to this report:

- **A.1- Proposed Assessment Method for Energy Storage** provides supplemental content describing analysis steps to identify potential storage sites discussed in Section 4.
- **A.2- New Mexico's 2030 Net Demand Profile** describes the process used to derive a net demand profile for New Mexico's 2030 grid.
- **A.3-URL References** contains a list of documents and websites cited within the report's footnotes.

Energy Storage Benefits

Utility-scale storage can benefit New Mexico's grid through firming, transmission/ distribution deferral, peak shaving, voltage control, and ancillary services. Storage benefits are measured in terms of ***rated power*** (MW), ***stored energy*** (MWh) and ***duration of energy discharge*** (hours). Short-duration refers to 5 hours or less capacity; medium-duration at least 10 hours; long-duration 100 or more hours. Storage can be sited at generation, transmission and distribution levels; it can provide ***firming capacity*** which partly offsets the impact of variable output from renewable plants.

1.2 Introduction and Background

Development of grid-scale storage that supports dispatchable and reliable electricity from renewables is an important regional trend in the western U.S.[1]; ***the key issue is predicting when technologies will transition from demonstration phase to deployment phase***.

Energy storage serves as an enabling technology for renewables. Ultimately, it will become a critical component for the entire grid, augmenting resources from wind, solar and hydro, nuclear and fossil fuels, demand side assets while improving system efficiency. It can also support the efficient delivery of electricity for inflexible, baseload resources. This is due to the fact that energy storage can operate at partial output levels with low losses and can respond quickly to changes in electricity demand. Storing energy during off-peak hours and using that energy during peak hours saves money and prolongs the operating life of critical infrastructure components.

[1] In some cases, new transmission projects may be deferred, derated or avoided through non-wires solutions such as energy storage. The battery (or other technology) can be sited and operated to allow the grid to accommodate higher flow levels than it could without the battery.

The **Energy Transition Act** (ETA) established new renewable and zero-carbon emission portfolio standards for both utilities and rural electric cooperatives in New Mexico. Through implementation of the ETA, the state can become a national leader in clean energy. The law transitions New Mexico away from coal and toward clean energy, ensuring greater renewable energy production and reducing costs for consumers, and provides tens of millions of dollars of economic and workforce support for communities impacted by coal plant closures, as well as the development of renewable replacement power in San Juan County. The ETA renewable energy requirements[2] are:

- **40%** renewable energy by **2025**
- **50%** renewable energy by **2030**
- **80%** renewable energy by **2040**
- **100%** zero-carbon energy by **2045**

Under the ETA, New Mexico will need to substantially increase the penetration of renewable energy as a percentage of sales beyond 2030[3]. Several thousand megawatts of in-state renewable additions beyond the existing and firmly planned facilities will be required to achieve the ETA targets by 2045 and PNM's emissions target by 2040[4], without considering the potential for the supply of out-of-state programs and markets identified in this study. In the early phase of planning, electric utilities will be faced with the reality that upgrading flexibility of transmission networks is cost-effectively achieved by adding more transmission lines, not by adding dedicated storage. However, as renewable generation grows, the net economic benefits of adding storage capacity also increases.

The ability to implement energy storage in New Mexico is constrained by technology costs, siting, policy, incentives, and performance limitations. Four candidate technologies were selected for near- to mid-term application in New Mexico: battery, renewables-sourced hydrogen, natural gas-sourced hydrogen and pumped hydro. Adding fuel cell technology to the allowable set of options could potentially extend cycle durations up to a week but at much higher cost. There are currently four battery-based storage demonstrations at grid-scale operating in New Mexico, with several projects tied to renewable generation; additional implementation of battery-based storage is planned through 2025.

Example: Residential Load Leveling

A ***virtual power plant*** (VPP) consists of energy storage units similar to Tesla's 13.5 kWh Powerwalls installed by residential owners; these units are controllable by the host utility during system-wide emergencies. On August 17, 2022 California called its first VPP emergency response event. 2,342 units participated on PG&E's grid,268 units participated on SCE 's grid. The VPP produced as much as ***16 MW of power*** within PG&E's service area – performing as a distributed power plant. Powerwall owners were paid $2 per kWh of discharged energy as an incentive.

Three phases of deployment can be used to describe the extent to which storage technology has reached commercial viability: Deployed, Demonstration and Early-stage. ***"Deployed"*** indicates established technology at scale; ***"Demonstration"*** indicates pre-commercial technology which is being tested for market application; and ***"Early-stage"*** indicates technology which requires investments involving considerable risk but potentially leading to later commercialization. None of the technologies identified for deployment in this report are early-stage candidates.

[2] Stated as a percentage of annual electric energy sold to New Mexico's electric customers; this program will be implemented as an extension of existing RPS requirements.

[3] ETA's 80% milestone will consist primarily of renewable energy additions, however the remaining 20% is described as "zero-carbon" which could include nuclear or clean coal/gas with sequestration.

[4] PNM will achieve over 70% emissions-free operation by 2032 with the planned exits from San Juan and Four Corners power plants; the company additionally plans a transition to 100% emissions-free energy by 2040.

Table 1 summarizes the key features of each storage technology.

Table 1. Storage Candidates for Development[5]

Technology; Phase	Scale; Response Time	Rated Capacity; Duration	Cost $/kWh, Spread	NM Relevance
Batteries (Li Ion, Flow, other); ***Deployed***	Grid, Commercial and Residential; Mid-term (4 hours) Fast (seconds)	Less than 100 MW; 4 to 8 hours	362-392 +/-30%	Most likely economic opportunity
Fuel Cells, Natural gas or Hydrogen; ***Demonstration***	Grid, Commercial and Residential; Mid- to Long-term, Seasonal, Slow	100 MW or larger; 10 hours or more	279-349 +/-50%	Possible future economic opportunity
Pumped Hydro; ***Deployed***	Grid; Long-term, Seasonal Moderate (10 seconds to minutes)	Greater than 1000 MW; 8 hours or more (limited by reservoir)	168-264 +/-30%	Major infrastructure required; water resource issue

The capability of these new energy storage technologies does not fit neatly into the traditional categories of generation, transmission, distribution, or load. A storage technology can serve a variety of functions that fit into all categories within the span of a day. For example, energy storage can charge from the energy grid and act as load. It can discharge into the grid and act as generation. And, it can serve transmission or distribution functions and provide relevant services. Energy storage must be added to the grid in a manner that clearly delineates the required services of each plant which maximizes value-added functions and minimizes potential conflicts with utility operations. There is broad industry consensus that utilities will need more operational flexibility to reliably serve loads as the resource mix evolves to include more renewable energy resources. Specifically, batteries can rapidly change from a charge to discharge status in a fraction of a second, faster than conventional thermal plants, making them a suitable resource for short-term ancillary services[6] support such as primary frequency response and regulation. Eventually, batteries can also provide longer-duration services such as load-following and ramping services to ensure supply meets demand[7].

1.3 Study Findings

Growth of renewables will create a variety of potential needs for utility-scale energy storage in New Mexico. Table 2 summarizes two storage market development cases based on ICF’**s** 50% build level; each case utilizes a mix of 2.5-, 5- and 7.5-hour storage units. These cases describe a “notional” timeline, they are not intended to be a prescriptive forecast of actual development. Instead, each case is presented as one outcome of a range of possible outcomes.

Prior to storage discharge, sample hours exhibit an average (demand) up ramp of 560 MW; this value can be reduced 50% or more through consistent application of a coordinated storage control strategy. Through extended

[5] See Ref. 1; tabulated $/kWh values equal the value of discharged energy based on a probable range of near-term capital costs.
[6] Ancillary services consist of operating measures necessary to support transmitting electric power from seller to purchaser, given obligations of control areas and utilities. FERC required that a transmission provider’s open access transmission tariff include six ancillary services as part of providing basic transmission service to a customer. All New Mexico IOUs have established these services and offer the required options.
[7] See Ref. 2.

cycling, the installed fleet of storage units can be used to serve other functions beyond load leveling. Total discharged energy could exceed 280,000 MWh per year which represents an average of one charge/discharge cycle per day for all units.

Case 1 is estimated to cost $294 Million; ***Case 2*** is estimated to cost $261 Million[8]. Reductions in storage payback will require subsidized initial costs and scaling battery plants to larger (combined) unit sizes to reduce fixed costs of construction and interconnection. When battery costs fall below approximately $300 per kWh, either through advances in technology or subsidies, the addition of a large battery plant to solar or wind projects will become more competitive.

Kalmia recommends that ***NM RETA designate one or more New Mexico counties as zones favorable for energy storage development***. In general, power flow analysis should indicate whether the zone is likely to exhibit changing P/A ratios as solar capacity grows within the area. Appendix A (Table A-1) lists a subset of New Mexico counties, projected solar capacity, host 345-kV substations and line segments identified for Collector Plans 1,2 and 3. A combination of factors such as co-location with ICF's proposed transmission lines, access to a host substation and higher projected solar capacity will add more justification to selection of sites for storage projects.

A more detailed presentation of Conclusions and Recommendations is listed in Section 5.

[8] Costs based on the installation schedule listed in Table 2 using lithium-ion or flow battery technology.

2 Glossary

Capacity	Load carrying ability expressed in megawatts (MW) of generation transmission or other electrical equipment.
Demand	Rate at which electric energy is delivered expressed in kilowatts (kW), megawatts (MW), or gigawatts (GW) at a given instant or averaged over any designated interval of time. A Megawatt equals 1000 kilowatts or 1 million watts.
DER	Distributed Energy Resources are often power generation resources located close to load centers; they can be used to provide value to grid operations by employing devices such as batteries.
Load Factor	Average load divided by the peak load in a specified time period; an important metric used to measure utilization of supply resources.
ETA	Energy Transition Act [§62-18 NMSA 1978], enacted in 2019; expanded statewide RPS requirements and establishes a pathway for a low-carbon energy transition in New Mexico.
FERC	Federal Energy Regulatory Commission, regulator of interstate transmission service.
Firming	Operating strategy to allow power output from a renewable power generation plant, such as wind or solar, to be maintained at a committed level for a period of time.
ICF	Technical author of RETA's transmission studies; ICF International Inc., Fairfax, VA.
IOU	Investor-owned utilities; in New Mexico, Public Service Company of New Mexico (PNM), El Paso Electric Company (EPE) and Southwestern Public Service Company (SPS) serve IOU functions.
kWh, MWh	The unit of energy equal to that expended in one hour at a rate of one thousand watts (kilowatt-hours or kWh) or one million watts (megawatt-hours or MWh); one MWh equals 3,412,000 BTUs.
NMPRC	New Mexico Public Regulation Commission.
NM RETA	New Mexico Renewable Energy Transmission Authority, sponsor of this study.
REC	Renewable energy certificate; issued when one MWh of electricity is generated and delivered to the grid from a renewable energy plant.
RPS	Renewable Portfolio Standard; the Renewable Energy Act [§62-16 NMSA 1978] and the implementing rule, Renewable Energy for Electric Utilities, NMPRC, 17.9.572 NMAC (11/30/98 as amended through 5/4/21) established an RPS applicable to all investor-owned and rural electric cooperative utilities in New Mexico.

Up ramp, Down ramp	Near-instantaneous changes in demand which could adversely affect grid stability, frequency control and generator dispatch are called ***ramps;*** a sudden rise in demand is called Up ramp, a drop in demand is called Down ramp.
WECC	Western Electricity Coordinating Council, primary planning organization for the 14-state Western US.

3

3 Development of In-State Storage Capacity

This section outlines a proposed approach to assess energy storage market status and anticipated growth to meet New Mexico's RPS goals; recommendations discussed in Section 4 address the issue of whether storage projects should be pursued by NM RETA.

Growth of renewables will create a variety of potential needs for energy storage in New Mexico; it can serve novel grid functions such as firming, transmission/ distribution deferral, peak shaving or shifting, voltage control, and ancillary services. These broader categories include daily use of storage to accomplish arbitrage[9] and load leveling. To satisfy the latter function, plant owners charge storage units during periods of excess generation and discharge power or energy during periods of excess demand to more efficiently coordinate the dispatch of generating resources. An intended benefit of this strategy would be to accomplish reduction of demand variability during peak periods.

There are four top-level issues that need to be included in this analysis in order to estimate market potential for energy storage in New Mexico's grid; they are:

- New Mexico's Demand Profile
- Storage Capacity Forecast
- Target Demand for Load Leveling
- Market Growth and Economics

Sections 3.1, 3.2 discuss the process of estimating a demand profile and its use as the key input to modeling storage capacity in New Mexico. Operation of energy storage to accomplish load leveling is discussed in Section 3.3. Market and economic factors impacting the viability of grid-scale storage are discussed in Section 3.4. In evaluating these issues, a possible outcome in the energy storage market is presented for the year 2030; this forecast provides valuable insight for implementing energy storage projects over the coming decade

3.1 New Mexico's Demand Profile

Net demand is used to quantify hourly levels of power generation required after subtracting the expected contribution from renewable generation and other DER[10] technologies. Due to the impact of renewable generation, the aggregate demand profile of New Mexico's grid will be substantially modified by 2030[11]. Hourly samples were assembled to represent four "typical" months of the year (January, April, July and October). For each hour, wind and solar energy generated for in-state consumption was subtracted from the forecasted statewide demand, producing a "net" demand profile[12] [13].

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[9] Arbitrage involves charging storage when energy prices are low and discharging during more expensive peak hours.

[10] DER Distributed Energy Resources include a wide range of technologies such as solar PV, wind turbines, fuel cells, battery storage, electric vehicles, and demand response programs.

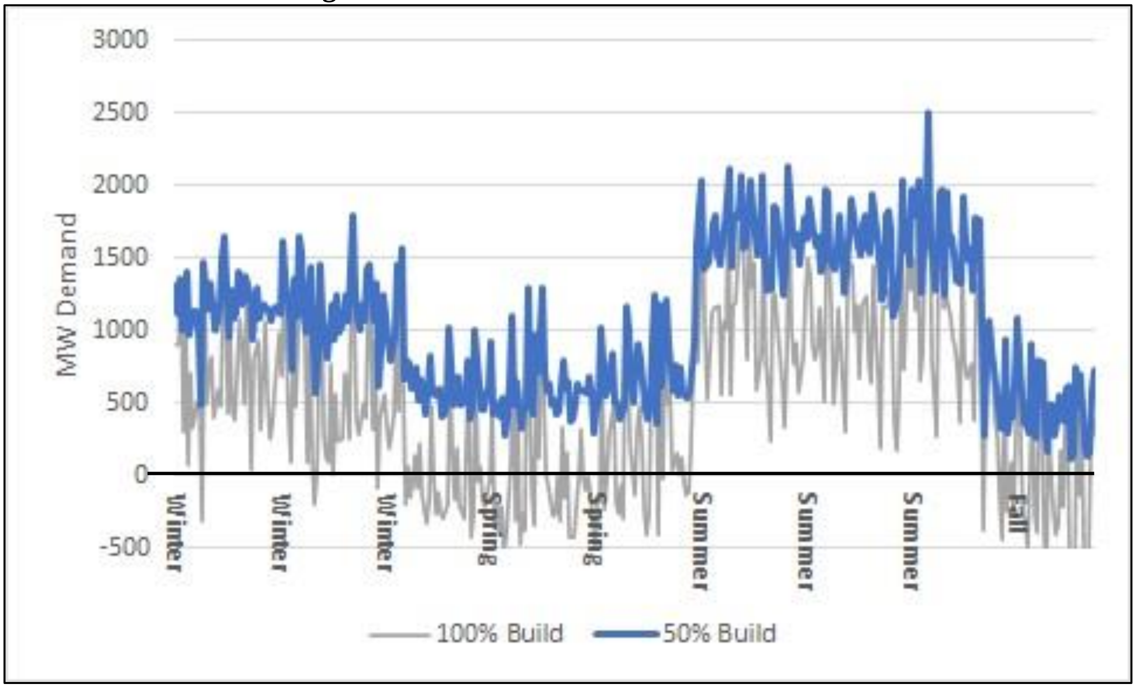
[11] See Ref.4; expected changes in the demand profile result in sudden and steep changes in demand, as well as the timing of peak periods shifting away from traditional patterns. This may cause problems in maintaining grid stability and efficiency by forcing utilities to cycle large fossil power plants.

[12] Forecasted renewable capacity assumes higher Export load, expanded federal incentives and Unlimited Transmission as reported by ICF; grid losses were not included in this analysis.

[13] The demand profile contains 1,753 hours; additional data will be needed to improve modeling accuracy during off-peak hours of the year since it is not sufficient to capture requirements for long duration storage such as periods when wind/solar are unavailable for two or more days.

Figure 1 displays the estimated in-state 2030 net demand profile, subdivided into four seasonal fractions, which are associated with hourly sampling in the typical months.

Figure 1. In-State 2030 Net Demand Profile



ICF's ***Business as Usual (BAU) Scenario*** considered a status quo outlook for the key forecast parameters, with no changes to current policy, transmission access or cost, and normal expected demand growth; this corresponds to the 100% Build plotline in Figure 1[14]. The 50% Build plotline is defined by the same BAU Scenario but without ICF's ***Economic Additions*** of renewables included. It represents a less aggressive deployment outcome.[15]

The general trend seen in this graph is a reduction of net demand as renewable percentages increase. 50% Build exhibits a distinct annual peak while 100% Build begins to exhibit bimodal peaks in both winter and summer. By 2030, ICF forecasts substantial changes in New Mexico's net demand profile will occur primarily to the development of renewables[16].

The black plotline in Figure 1 indicates an approximate level of balanced renewable supply relative to in-state demand. As shown, for the spring/fall seasons, a negative or excess output condition may occur for ICF's 100% Build scenario. Excess renewable generation could be curtailed, sold to the export market or diverted to energy storage depending on market conditions, the status of the neighboring Balancing Authorities, and interregional transmission.

[14] See Ref. 3, Table 23.

[15] Kalmia estimates a 2 in 4 chance of reaching 50% build by 2030 and less than a 1 in 4 chance of reaching 100% buildout by 2030. The rate of development required to reach 100% build requires yearly increases in transmission capacity that are inconsistent with recent commissioning rates. 50% build includes projects in mature development stages that can achieve commercial operation by 2030 (excluding projects that may be proposed and are Economic Additions, but have yet to reach critical early milestones).

[16] BAU adds 3,800 MW of solar capacity and 3,149 MW of wind capacity to New Mexico's generation mix; in addition, approximately 40% of generated renewable energy is utilized in-state and 60% is exported.

Average demand for all seasons will also decrease greatly and daily demand profiles will exhibit ***non-recurring variability*** to different degrees[17]. Variability will become a significant concern for utility operators, since it is likely to exceed the range of variation that can be readily managed by re-dispatching conventional generating plants during daily or weekly periods. For example, 50% Build results in an average hour-to-hour variation of 372 MW; this value is over 40% higher than the variation of a statewide demand profile lacking renewable generation. Assuming ICF's 100% Build forecast is developed, an average hour-to-hour variation of 601 MW could occur. Other impacts to New Mexico's net demand profile are expected (see sidebar at right).

Detail on the method used to estimate New Mexico's 2030 Demand Profile are provided in Appendix A.2.

3.2 Storage Capacity Forecast

A storage capacity forecast is presented in this section based on ICF's 50% Build of renewable capacity. It was derived by scaling RPS storage capacity in proportion to the forecasted level of renewable development[18]. Key inputs include planning ratios reported by an in-depth review of seventeen recent utility planning studies with over 400 storage development scenarios from the European and US grids.

Storage can be added to new renewable projects as the in-state energy market develops post-2022; the information tabulated in Table 2 describes a "notional" timeline, ***it is not intended to be a prescriptive forecast of actual development.*** Instead, it is presented as one outcome of a range of possible outcomes that will be influenced by a set of technical and regulatory initiatives already underway[19]. The installed nameplate capacity equals 160 MW (power rating) and 3,080 MWh (energy rating); by operating all units over multiple charge/discharge cycles, a total of 35,000 MWh or more could be delivered to the grid by 2030.

Load Factor Impacts

Load factor equals ***average power divided by peak power*** summed over a specified time period. Electric utilities must provide power to all customers within their service area, based on the maximum amount needed (peak power) ***as-if*** it is utilized at any given time. During many hours of the year, a utility does not supply peak power, but must install the capacity to do so. Customers who use electricity in a way that reduces peak power results in less strain on grid infrastructure and higher load factors. ***Energy storage*** is a mitigating measure that can help accomplish this goal.

[17] Demand variability typically results from a set of factors such as customer behavior, weather and location. Renewable generation will add variability over short periods which is due to factors that compound the weather-sensitive demand component. In order to offset these effects, energy storage can be added to the grid to target periods that coincide with periods of higher variability.

[18] Ref. 3, Table 9, indicates the forecasted share of in-state storage capacity equals 320 MW in the year 2030, or 160 MW if scaled to 50% Build. Storage capacity estimates are derived from planning ratios assigned to three categories: Solar Dominate, Balanced, and Wind Dominant; New Mexico's grid is forecasted to operate with Wind Dominant capacity through 2030, although the RPS fraction is trending toward Balanced condition.

[19] See discussion in Section 4.3, Other Storage Development Factors.

Table 2. In-State Storage Capacity Forecast

		Case 1- No. units			Case 2- No. units		
Year	Discharge MWh	2.5 hour	5.0 hour	7.5 hour	2.5 hour	5.0 hour	7.5 hour
2022	190	1	0	0	1	0	0
2023	190	1	0	0	1	0	0
2024	3,180	2	1	0	5	1	0
2025	8,780	2	3	0	7	3	2
2026	14,380	2	5	0	8	5	3
2027	20,390	3	7	1	8	7	5
2028	23,400	3	8	2	12	11	6
2029	29,400	4	10	3	19	13	9
2030	35,000	4	12	3	26	18	12

Table 2 summarizes two storage market development cases; each case utilizes a mix of 2.5-, 5- and 7.5-hour storage units. Two cases are shown: ***Case 1***: 19 storage plants are installed; unit power equals 9 MW, capacities range from 25 to 70 MWh. Up to 760 charge/discharge cycles per year are required by 2030; ***Case 2***: 56 storage plants are installed; unit power equals 3 MW, capacities range from 10 to 25 MWh. Up to 1330 charge/discharge cycles per year are required by 2030. Both cases contribute equivalent levels of storage power and energy, but their unit capacities differ by a factor of three. Case 1 utilizes "large" storage units, Case 2 utilizes "small" storage units. These size categories are likely to shift upwards as costs decline and unit capacities increase[20], however they are fully scalable i.e., multiple units could be combined into a single larger storage plant.

Table 2 indicates storage capacity is required to grow at an annual rate of 20% per year; by 2030, sufficient capacity is operable to discharge 35,000 MWh over the range of tabulated durations. Case 1 is estimated to cost $294 Million; Case 2 is estimated to cost $261 Million if all units are installed on the schedule listed in Table 2. These costs are based on expected values for lithium-ion or flow battery installations. The probable level of storage development is assumed to be significantly lower prior to 2025; this occurs due to high storage development costs and lack of a defined market within New Mexico that rewards developers for achieving specific levels of variability reduction with favorable pricing tariffs.

3.3 Target Demand for Load Leveling

To estimate the approximate range of grid demand (and number of hours) to be mitigated by energy storage, an analysis of New Mexico's net demand profile near system peak is described in this section[21]. Comments related to this forecast include the following cautions and observation:

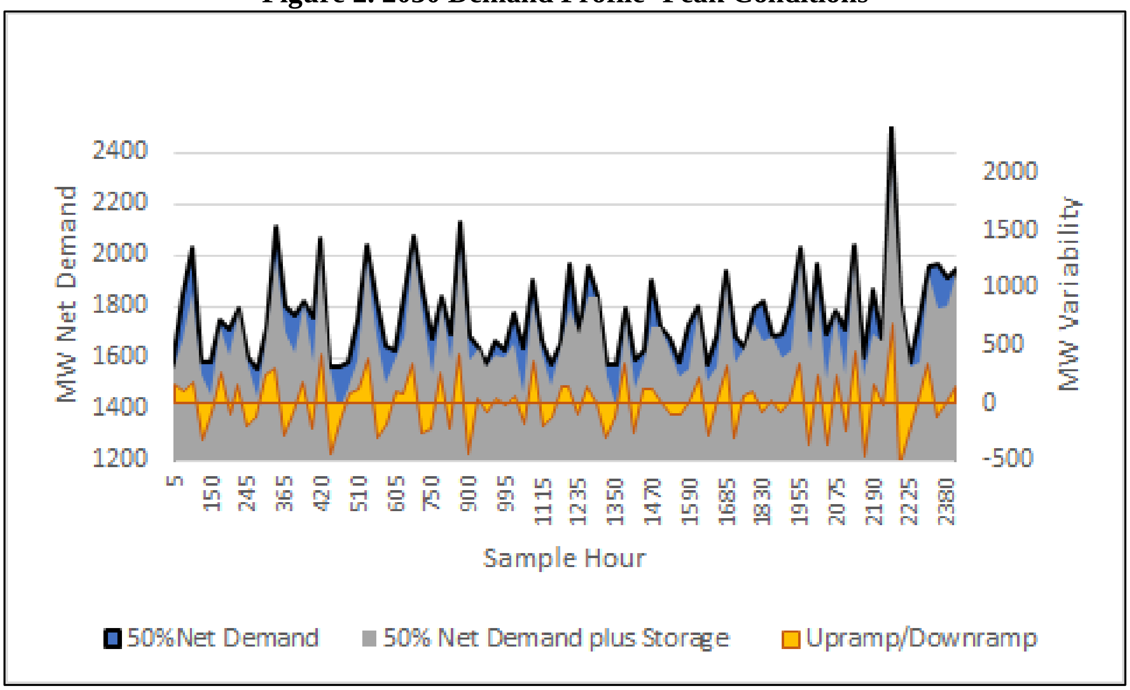
- All time-based values are presented as ***point estimates***; however, a range of values is possible for any given hour of the year. This occurs mainly due to imprecision in estimating hourly demand and renewable supply.

[20] See Ref. 5, Figures ES-1, ES-2; DOE's tabulated cost projections for storage capacity through year 2030 indicate a general trend of cost reductions equaling 3.3% per year.
[21] The demand profile is based on a sampled data set containing 1,753 hours; additional data will be needed to improve modeling accuracy during off-peak hours of the year.

- The mix of 2.5-, 5- and 10-hour storage units in Cases 1, 2 is presented as a "***feasible***" set of options that represent a larger set. For example, if longer-duration storage technology becomes readily available at significantly lower cost before 2030, a different mix could easily result.
- Alternately, a large collection of smaller units could be operated remotely to function as a single unit (see sidebar, Battery Energy Costs).
- Through extended cycling, the installed fleet of storage units can be used to serve other functions beyond load leveling. Total discharged energy could exceed 280,000 MWh per year which represents an average of one charge/discharge cycle per day for all units[22]. By shifting function from load leveling to arbitrage during off-peak periods, overall storage economics will improve as utilization is increased.
- These cases result in an annual (capacity) growth rate of approximately 20%, based on required MWh additions; it suggests there must be a significant economic incentive for developers to add storage capacity, given the high rate of installation.

Figure 2 displays the hourly demand 2030 (black) plotline for 50% Build.

Figure 2. 2030 Demand Profile- Peak Conditions



From left to right, Figure 2 displays hours in chronological order, totaling approximately 2,400 hours during the summer months. Although most of the sampled hours will occur during July's peak conditions, hours in June and August could also be included. It is important to note that, in this graphic, adjacent hours on this plot are generally

[22] See Ref. 6.

not representative of contiguous events[23] [24].

Note that "50% Net Demand plus Storage" captures the effect of renewable generation ***plus*** storage contribution to demand. Hour-to-hour variations in net demand primarily attributable to renewable plant output[25] will occur during the plotted intervals; this pattern is displayed in the ***orange plotline***[26]. Across all of the plotted hours, a series of up ramp and down ramp events are observed. Down ramp events would not require storage discharge but may require storage charging and dispatch of conventional generation to accomplish load leveling. The ***grey plotline*** displays net demand following displacement by energy storage. The probable range of demand variation that cannot be mitigated by proposed storage capacity is displayed as a blue area in Figure 2; it will occur during summer daytime hours.

Because the grid lacks large-scale storage, utility generation must adjust in real time to match demand over periods of minutes to hours. Hourly demand typically varies over the day, week, and year, with potentially large variations from hour-to-hour. Storage can charge and discharge over a day, in order to yield a relatively flat supply equal to the daily average of hourly demand; over a week at the weekly average, or over the year at the annual average. Given sufficient capacity, energy storage could help to decouple electricity supply needs from variable electricity demand.

Prior to storage discharge, sample hours exhibit an average up ramp of 560 MW; this value can be reduced 50% or more through consistent application of a coordinated storage control strategy[27].

3.4 Market Growth and Economics

The potential storage market can be conveniently subdivided into Export and In-state (RPS) fractions which are likely to differ in relation to the types of technology that can be economically sited. As noted in Section 1.5, three technology options were selected in part due to their current status as Deployed or Demonstration phase; they provide a wide range of capacity and duration features for grid operation. Each option is positioned in different development phases, with batteries offering the most economic near-term option for deployment. A wide range of delivered energy costs ($/kWh) are likely, depending on the technology selected (see sidebar at right). Timeframe response, rated capacity and duration are also key metrics for valuing storage impact within grid operations.

Battery Energy Costs

Battery grid storage has achieved significant growth in the past decade. But the market will require ***subsidized initial costs and scaling battery plants*** to larger (combined) unit sizes to reduce fixed costs of construction and interconnection. The energy cost metric equals cost paid each year divided by rated stored energy. Costs (see Ref. 5) for fully installed 100 MW, 10-hour battery systems are: lithium-ion LFP ($356/kWh), lead-acid ($356/kWh), lithium-ion NMC ($366/kWh), and vanadium RFB ($399/kWh).

[23] Only the largest up ramp or down ramp events near annual peak were sampled; the demand profile indicates at least 85 hours near system peak could be mitigated by storage (mostly up-ramp events). The average interval between events is approximately 40 hours which suggests sufficient re-charge time is available to prepare for the next up-ramp.

[24] Kalmia's analysis assumes routine use of look-ahead forecasting which requires wind and solar hourly output to be scheduled prior to each daily demand peak. When an event interval time was less than five hours, no storage discharge is assumed to occur since charging time is inadequate.

[25] Depending on the time of day, variations can also be attributed to other causes such as customer behavior which is compounded by sudden reductions in renewable output (***up-ramp***) or increases in renewable output (***down-ramp***).

[26] Note that the scale for demand variability is plotted on the right (vertical) scale in Figure 2.

[27] In this analysis, storage is controlled to minimize demand variability and maximize state-of-charge; only 17 of 85 up ramp events require operation at maximum power 160 MW. During the remaining events, storage is operating at an average power of 85 MW.

In the global market, utility-scale battery projects as recently as 2018 were being sized at 50 MW or less, but planned projects are being sized at larger capacities in the 100-500 MW range[28]. Although a majority of these projects are in the U.S., none are located in New Mexico. Given significant unknowns related to timing of technology development and the market entry of longer duration batteries, the actual buildout is likely to result in a mix of units from both cases. It is possible that a short-term acceleration of smaller solar PV projects could favor Case 2 storage sizing while larger wind farms could favor Case 1 storage sizing. Shorter duration 2.5-hour batteries are readily available in 2022; 5- to 7-hour duration batteries will become more economic in the post-2025 period and later. This analysis assumes 10-hour duration batteries will begin field trials around 2025 with economic deployment occurring after 2027.

Kalmia's market model used to derive results shown in Table 2 suggests simple payback periods for battery storage units may be marginally economic based on a PPA storage adder of $10 per MWh[29], $362 per kWh delivered energy cost and 10% annual carrying charge. When battery levelized energy costs fall below approximately $300 per kWh, either through advances in technology or subsidies, the addition of a large battery plant to solar or wind projects will become more competitive[30]. This estimate is based solely on the cost of energy delivered and, as mentioned in the caveat above, does not include the additional value of providing necessary services and capacity needed by utilities to meet operational and reliability requirements while fulfilling renewable mandates.

[28] See Ref. 7; larger, centrally located battery plants will typically operate for 3 to 5 hours duration and 500 MWh energy rating or higher.
[29] See Ref. 3, Section 3.4 (Townsite solar storage plant).
[30] This cost threshold will be determined by a variety of factors related to the installed mix of storage durations, average unit size, unit efficiency and annual number of charge/discharge cycles. DOE's projected "Grand Challenge" costs for a variety of competing storage technologies approach $300/kWh in 2030 based on aggressive learning rates.

4 Siting of Energy Storage Projects

To provide context to the material presented in this report, siting and interconnection of energy storage is described in Figure 3.

Figure 3. Options for Storage Siting[31]

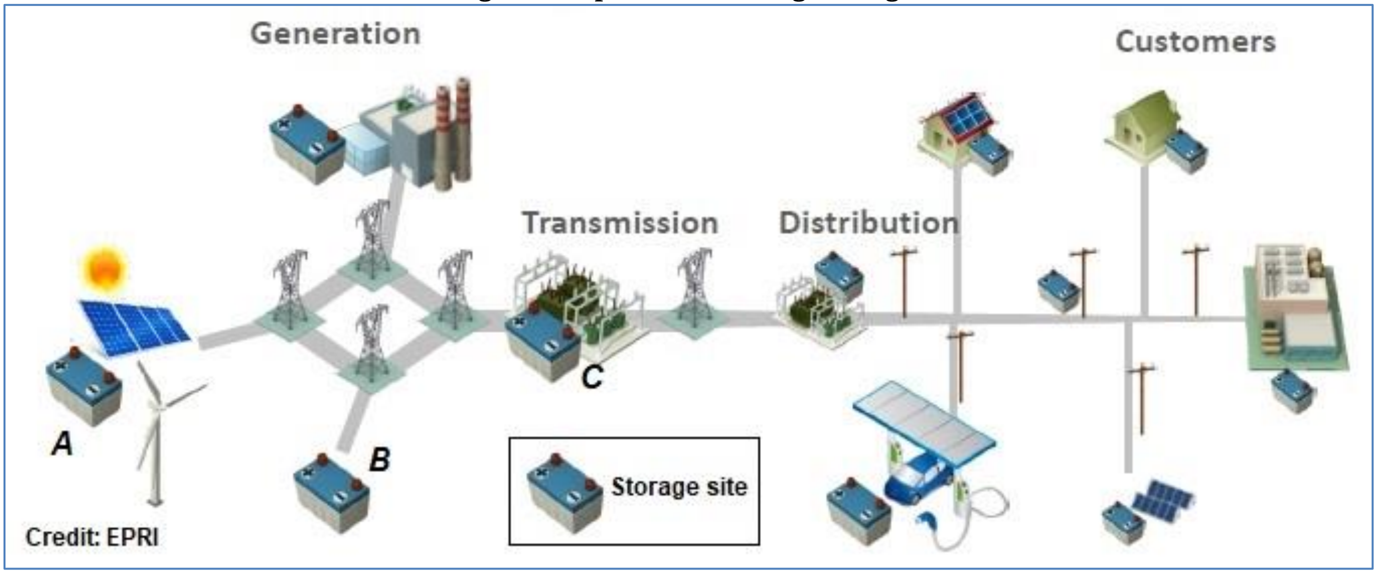


Figure 3 indicates storage could be sited at generation, transmission and distribution levels within the grid. While customer-owned storage located within the distribution system or near end-use points is certainly a possible option, this report is intended to only address potential siting of storage at A, B, and C. Each site can be described as:

- A represents a storage plant co-located with large-scale renewable generation;
- B represents a bulk storage plant connected to the transmission system (at least 100 kilovolts kV or higher);
- C represents a bulk storage plant connected to the sub transmission system (less than 100 kV).

4.1 Analysis Factors

Due to the manner in which storage will be controlled and depending on the point of interconnection, plant capacities and the duration of charge/discharge cycles will vary widely. The choice of storage technology will primarily determine these ratings. The labels "***nodes***" and "***substations***" are used interchangeably, based on terminology applied in power flow (PF) analysis. Also, storage sites and nodes are discussed in a similar manner, since each storage site will consist of a storage unit connected to a node, typically through a step-up station.

Factors impacting NM RETA's selection of transmission projects may include the extent to which ICF's "Non-Transmission Alternatives"[32] could ***defer, reduce or eliminate the need for new line capacity***. Given that most of the new transmission investments proposed by ICF are either 345-kV lines or substations, reduction of capacity is

[31] See Ref. 8.
[32] See Ref. 9, pages 94-96.

the most likely near-term outcome[33].

Using the study approach outlined in Appendix A (Figure A-1), a series of preparatory steps should be conducted. These steps require extraction of power flow data from NM RETA's recent transmission studies[34] and identification of key technical factors that influence siting. The study method discussed in this section benefits from low analysis complexity and low data intensity; it can be described as a "hybrid" approach suited for early-phase storage development. Ultimately, Steps 7 through 8 require re-solving both ICF power flow cases with proposed storage plants inserted into the grid model.[35]

A set of top-level questions need to be addressed as siting analysis begins:

1. Should New Mexico "counties" be used as the standard sampling area or should sampling be specifically related to local features[36] of the grid? If counties are not used, what criterion should be used to select features?

2. For counties with large numbers of potential sites, how should peak-to-average (P/A) ratios[37] be averaged to down-select a smaller set of options?

3. What power flow criteria should be used to identify transmission circuits carrying higher flow attributable to solar-generated power?

4. In terms of storage capacity, should ICF's stated 6-8 hours duration or longer durations be applied?[38]

5. How should rating criteria be applied to down-select sites?

In terms of importance, answers to questions 1,3, and 5 will have a greater impact on study results than questions 2 and 4.

[33] Reductions in conductor sizing and installation of lower-capacity substation transformers or ancillary equipment would be required. ICF's transmission Collector Plans reported costs of $300 to $650 per (peak) kW-Year of installed capacity, assuming 7% carrying charges. Storage incentives could be derived from incremental savings related to these costs.

[34] This data must be re-formatted in IEEE common exchange (text) format which allows results to be easily imported to spreadsheets, sorted and searched for various features that are relevant to storage siting.

[35] ICF's power flow model could be used iteratively to analyze siting options with existing transmission constraints. This approach yields results earlier in the study sequence (prior to Step 4) but it requires high analysis complexity and data intensity. By using pre-solved power flow cases with new transmission capacity already inserted, more detailed analysis is deferred until after Step 6.

[36] Local features include voltage levels in operation, county electric demand and supply plus the degree to which power can be imported or exported from adjacent counties.

[37] P/A ratios equal peak transmission line flow divided by average flow; in the context of this report, they are intended to represent an area containing multiple transmission lines. Variations in line flow over time and at different location within the grid will cause P/A ratios to constantly change, however estimating accuracy can be relaxed at this step in the analysis.

[38] The required storage duration will be determined by the expected variability of load and generation as well as opportunities for importing energy off-grid.

While Kalmia recommends counties be used as the sampling area related to question #1 for ease-of-analysis, there may be more technically justified approaches to consider. These options would be based on how specific locations with higher P/A ratios are connected at various voltage levels via lines and substations. Rules must be identified to select specific connection features as being more favorable.

The answer to question #3 could utilize use shift factors[39]. It would require executing a series of power flow cases to evaluate how larger plants will inject power throughout New Mexico's grid in 2030. This analysis is likely to result in more accurate identification of those transmission circuits which carry higher levels of flow that can be "tagged" to solar-generated power.

Question #5 is focused on applying criteria that determine storage performance such as capacity, duration and cost. Since storage options can be easily scaled among this set of features, rules should be specified to ensure the study outcome falls within a fairly narrow range[40]. The tradeoffs are usually complex and not generally suited for a screening study intended to only identify higher priority locations within New Mexico's grid.

4.2 Storage Development by Geographic Zones

In terms of identifying a strategic approach to enable developers to proactively site energy storage siting, Kalmia's review indicates a key hurdle preventing this outcome is lack of technical, public information describing how storage is best employed within New Mexico's grid. Careful application of the proposed study method will result in a product that can be useful to the practical concerns that developers are facing. Kalmia proposes that ***one or more New Mexico counties be designated as zones favorable for energy storage development.*** In general, power flow analysis should indicate whether the zone is likely to exhibit changing P/A ratios as solar capacity grows within the area. These zones would serve as "hosts" with the following features:

- Higher projected levels of solar-generated power
- Electrical access to one or more of ICF's proposed 345 kV transmission circuits (via step-up stations)
- Sufficient number of potential interconnection points[41]
- Predictable response to changes in P/A ratio

Alternately a state-wide contour map could be released to interested developers highlighting broader zones within the future grid that may exhibit high P/A ratios. The contour intervals should be presented over wide bands, rather than more precise values. P/A ratios may be unstable in some areas as increasing levels of renewable power are injected into the grid. Since most of the value realized by storage operation is also likely to occur in future years, risk associated with forecasting key power flow inputs could also skew any results that are publicized. So, the contour map may ultimately have less value to developers than specifying smaller county-size zones for siting.

Developers will be favorably attracted to sites exhibiting ***easily-managed variations in line flow*** with P/A ratios trending upward but not-to-exceed extreme values. If operation at extremes is required, the developer will be forced to upsize storage capacity or suffer from insufficient capacity to manage peak flows. The "extreme" threshold will be determined by the type of storage technology employed and the fraction of total line flow that storage capacity

[39] This approach has been used by California's Renewable Energy Transmission Initiative project since 2012 to analyze flow impacts that can be assigned to a large number of renewable plants.
[40] See Ref. 11 for an overview of the current storage technology market; the expected range of storage costs is shown in Section 1.2 (Table)1.
[41] Interconnection difficulty is affected by various factors such as operating voltage, queue access and ownership rights.

represents at a specific site. Additionally, energy storage could serve as a complimentary measure which renewable developers employ to improve overall project economics.

A zonal development approach would be similar to designating CREZ[42], with the exception that adding storage capacity to a specific zone would be intended to defer, reduce or eliminate ICF's planned transmission capacity rather than spur development of new capacity. The CREZ process was initiated by power flow studies similar to the approach proposed in this report, but more detailed follow-on studies addressing local grid issues, similar to "hosting" capacity studies in utility distribution (low-voltage) systems, are usually needed. Developers are often familiar with the types of information available from hosting studies, so RETA may choose proactively to format some of the key storage siting details in the same manner to clearly communicate these findings.

Interconnection of Generating Facilities (17.9.569 NMAC)

This rule sets forth requirements and a screening process for New Mexico utilities and project developers. It applies to all generating facilities with a rated capacity up to and including 10 MW. "Generator" means any device producing electrical energy including ***energy storage technologies***. Projects such as utility-scale storage may not qualify for the Simplified or Fast Track process, and will require a full inter-connection study unless rated at 2.0 MW or less.

4.3 Other Storage Development Factors

One recent survey of state-level programs[43] identified five types of storage incentives needed to foster development of a storage market: Procurement Targets; Regulatory Adaptation; Demonstration Projects; Financial Incentives and Consumer Protection. Notably, New Mexico has only begun to implement two of five incentives (Regulatory Adaptation and Demonstration Projects); some states have implemented three or more incentives.

Regulatory Adaptation requires utilities to apply an integrated system planning process by representing storage as one of a set of DER[44] options. New Mexico's IOUs evaluate storage as a part of the current Integrated Resource Planning process, for submittal to the NM PRC on a three-year cycle. Related factors supporting orderly storage development includes readily-available guidance such as technical and procedural standards that clearly outline the requirements and specific parameters related to storage technology[45] [46]. New Mexico currently lacks a detailed interconnection standard that applies to storage plants. While many provisions of 17.9.569 NMAC may apply, other requirements will need to be added.

Demonstration Projects allow the benefits and logistics of energy storage deployment to be studied on an incremental basis. For example, a survey of fifteen energy storage demonstration projects funded by the American Recovery and Reinvestment Act indicates participants better understand the permitting and construction challenges involved in developing energy storage projects; deficiencies were identified in current building and electric codes; and operators were allowed to learn the

[42] The Texas PUC approved the CREZ (Competitive Renewable Energy Zones) concept in 2008 in response to a directive from the Legislature. The plan calls for erecting new transmission lines (spanning more than 2,300 miles) to bring wind power generated in western areas to cities in the Central and East Texas.
[43] See Ref. 12.
[44] DER Distributed Energy Resources.
[45] "Integrated Resource Plans for Electric Utilities" 17.7.3 NMAC requires storage to be evaluated as a viable supply option. Specifically, 17-7-3-9 E(2) NMAC requires the load and resources table to contain appropriate components from the load forecast ***with energy storage resources***. 17.7.3.9F(1) NMAC also requires the utility shall consider all feasible supply-side, ***energy storage***, and demand-side resources and document whether the (storage) resource is replacing/adding capacity or energy, dispatchability, lead-time requirements, flexibility and efficiency of the resource.
[46] See Ref. 13; a series of questions related to developer concerns need to be addressed.

operational and economic characteristics of energy storage in a lower risk, lower-cost setting. While each state generally identifies a need for improved understanding of how energy storage operates on the grid, three models for pursuing that goal have been used: funded, authorized, and facilitated. To date New Mexico has generally followed the ***authorized*** approach.

Two NMPRC-approved projects are planned as a part of the San Juan Generating Station replacements; one is also planned to serve El Paso Electric in southeast New Mexico. WECC's regional planning model also identifies a small set of proposed utility-scale storage projects through 2025. The type of storage listed has not been specified, however 3- to 5-hour battery storage is the probable choice for implementation in these timeframes. A total of 2,420 MWh of storage capacity is listed[47].

5 Conclusions and Recommendations

The following conclusions and recommendations were discussed in Sections 2, 3 and 4 of this report:

- Growth of renewables will create a variety of potential needs for utility-scale energy storage in New Mexico; storage can serve novel grid functions such as firming, transmission / distribution deferral, peak shaving or shifting, voltage control, and ancillary services. These broader categories include daily use of storage to accomplish arbitrage and load leveling.

- The storage capacity cases presented in Section 3.2 (Table 2) describe a "notional" timeline ***they are not intended to be a prescriptive forecast of actual development.*** Instead, it is presented as one outcome of a range of possible outcomes that will be influenced by a set of technical and regulatory initiatives already underway..

- The installed nameplate storage capacity in this forecast equals 160 MW (power rating) and 3,080 MWh (energy rating); by operating all units over multiple charge/discharge cycles a total of 35,000 MWh could be delivered to the grid by 2030.

- Table 2 summarizes two storage market development cases based on the 50% build level; each case utilizes a mix of 2.5-, 5- and 7.5-hour storage units.

- Both development cases contribute equivalent levels of storage power and energy but their unit capacities differ by a factor of three. Case 1 utilizes "large" storage units, Case 2 utilizes "small" storage units.

- Case 1 is estimated to cost $294 Million; Case 2 is estimated to cost $261 Million if all units are installed on the schedule listed in Table 2. These costs are based on expected values for lithium-ion or flow battery installations.

- Statistics for the modeled (2030 demand) profile indicates at least 85 hours near system peak could be impacted by storage (mostly up-ramp events). Within this set of sampled hours, the average interval between events is approximately 40 hours.

- Prior to storage discharge, sample hours exhibit an average up ramp of 560 MW; this value can be reduced 50% or more through consistent application of a coordinated storage control strategy.

- Through extended cycling, the installed fleet of storage units can be used to serve other functions beyond

[47] Capacity based on the ratio 4 MWh per MW; PNM has only documented battery power (MW) ratings but recent RFPs indicate a minimum duration of 4 hours are required.

load leveling. Total discharged energy could exceed 280,000 MWh per year which represents an average of one charge/discharge cycle per day for all units.

- Kalmia's RPS storage capacity forecast results in an annual growth rate of approximately 20%, based on required MWh additions; it suggests there must be a significant economic incentive for developers to add storage capacity, given the high rate of installation.

- Reductions in storage payback will require subsidized initial costs and scaling battery plants to larger (combined) unit sizes to reduce fixed costs of construction and interconnection. When battery costs fall below approximately $300 per kWh, either through advances in technology or subsidies, the addition of a large battery plant to solar or wind projects will become more competitive.

- Factors impacting NM RETA's selection of transmission projects may include the extent to which ICF's "Non-Transmission Alternatives" could defer, reduce or eliminate the need for new line capacity. Specifically, energy storage could serve as a complementary measure which developers employ to improve overall project economics.

- Kalmia recommends that ***NM RETA designate one or more New Mexico counties as zones favorable for energy storage development.*** In general, power flow analysis should indicate whether the zone is likely to exhibit changing P/A ratios as solar capacity grows within the area.

- NM RETA could alternately release a state-wide contour map to interested developers highlighting broader zones within the future grid that may exhibit high P/A ratios. The contour intervals should be presented over wide bands, rather than more precise values.

- Appendix A (Table A-1) lists a subset of New Mexico counties, projected solar capacity, host 345-kV substations and line segments identified for Collector Plans 1,2 and 3. A combination of factors such as co-location with ICF's proposed transmission lines, access to a host substation and higher projected solar capacity will add more justification to selection of sites for storage projects.

- Developers will be favorably attracted to sites exhibiting easily-managed variations in line flow, with P/A ratios trending upward but not-to-exceed extreme values.

- New Mexico has only begun to implement two of five incentives (Regulatory Adaptation and Demonstration Projects); some states have implemented three or more incentives. New Mexico currently lacks a detailed interconnection standard that applies to storage plants. While many provisions of 17.9.569 NMAC may apply, other requirements will need to be added.

APPENDICES

A.1 Proposed Assessment Method for Energy Storage

The following criteria related to siting analysis of energy storage were recommended by ICF[48]:

Metric 1 Frequency and persistence of overloads – Storage may not be the most viable solution if the transmission element is constraining[49] for significant hours, where storage is required to operate beyond standard durations, such as greater than 6-8 hours of discharge per day.

Metric 2 Peak-to-average (P/A) demand ratio – Areas with higher peak-to-average demand ratios indicate greater needs of peak-shaving capability. Those locations may benefit from deploying storage as a transmission alternative instead of building new transmission lines.

Metric 1 is less useful for storage siting since design criteria used during the utility planning process will tend to minimize or eliminate overloads. It should be considered a special condition, not the normal measure of storage value to the grid. Metric 2 is potentially more useful if the pattern of peak-to-average demand is fairly consistent on a given transmission circuit or bundled circuits. ICF states this condition is not met if large amounts of wind-generated energy are being transmitted since wind is more variable than solar[50]. Application of Metric 2 will be mainly useful if analysis is focused on transmission circuits carrying a majority of solar-generated power. This approach assumes storage is economic only for duration of less than 6 to 8 hours per day; as duration improves beyond 10 to 15 hours per day the range of potential storage sites will expand to other circuits and be capable of accommodating a different supply mix.

In relation to both metrics, obtaining metered utility data to support this analysis is fraught with a variety of difficulties. It will be difficult to ensure consistency in how meters are sampled, reported and correlated across many areas of New Mexico's grid. Therefore, power flow simulation is probably the only viable source of data at least for purposes of screening storage sites. This approach introduces other issues in relation to sampling and interpretation of results. ICF's power flow models are "snapshots" of an instant in time which can't be used to represent all hours of operation. ICF prepared power flow models[51] that represent two instants of time in the future. If storage analysis is based on these models, P/A ratios must be calculated with a simplifying assumption i.e., "average" demand at a specific location in the grid equals a combination of values from both off-peak and on-peak cases.

Note that sampling intervals corresponds to different years and grid conditions for ICF's power flow cases. Forecasted state-wide electric demand increases less than 200 MW between 2025 and 2030, however renewable supply increases over 1,500 MW over the same period[52]. Therefore, line flow due to increased demand is likely to be roughly constant but line flow due to increased supply (wind and solar additions) is changing rapidly in some

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[48] See Ref. 9; peak shaving is cited as an example of how storage could be operated in the grid i.e., to reduce peak flow during certain hours.

[49] "Constraining" refers to a transmission line's ability to carry power within rated limits which can be based on thermal capacity or voltage drop.

[50] ICF previously reported "Storage applications for wind are not as attractive as for solar because the wind generation profile is less diurnal in nature."

[51] 2025 winter off-peak power flow case (light load condition) and 2030 summer on-peak power flow case (peak load condition).

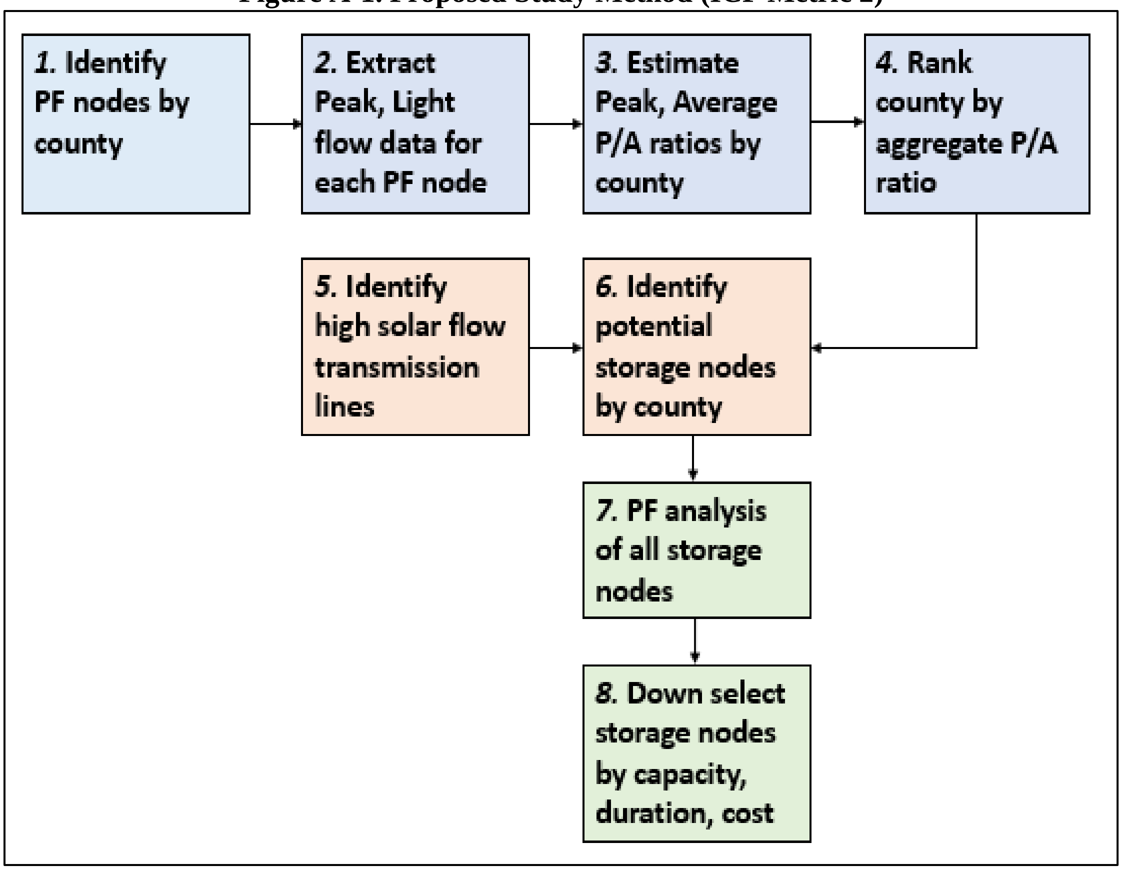
[52] Based on a spreadsheet prepared by Kalmia dated July 17, 2020, "ICF Table 2".

locations. So, combining 2025 and 2030 conditions adds error to the P/A ratio estimation. A larger fraction of the flow increase will probably occur near or at-peak[53], therefore use of a 2030 peak power flow case will tend to raise P/A ratios at grid locations transmitting larger amounts of peak solar energy and reduce P/A ratios for nodes transmitting mostly off-peak wind energy. Given that ICF is mainly recommending storage to mitigate solar flow, this is consistent with the overall approach being proposed in the next section.

A key sampling issue relates to grid location and averaging. In order to capture the effect of introducing storage at specific locations which are typically interconnected to a small set of nodes and lines, P/A ratios at each node should be averaged over the set of impacted components. In this report, it is assumed ***the averaging set corresponds to New Mexico counties*** which is a much larger area than likely needed for siting storage capacity, however it offers a larger number of interconnections to investigate for potential sites.

Figure A-1's flow chart displays eight proposed analysis steps used to identify potential storage sites in New Mexico's grid:

Figure A-1. Proposed Study Method (ICF Metric 2)



The general progression of analysis follows steps 1 to 8 in sequence.

Steps 1 through 4 involve data extractions from ICF's solved power flow cases which results in an initial estimation of all P/A ratios by node. At this stage, data will be organized by county in order to identify connected nodes and

[53] Mainly due to PPA pricing of renewable power, during peak hours the generated energy is more valuable as a resource. This pattern may be generally consistent between light- and peak-demand power flow cases; however, it is judged to be less of an analysis issue.

lines that fall within the county boundaries[54]; finally, an aggregate P/A ratio is estimated for the entire county, as-if it operates as a distinct grid unit. While the latter statement is not likely to be true in most counties, it is possible to re-configure some transmission components within the county boundary to approximate this operating condition which can further improve storage performance. ***Step 4*** results in a rank-order listing of counties by aggregate P/A ratio. To select feasible storage sites (nodes) within county boundaries, additional information will be provided in Steps 5, 6.

Steps 5 through 6 involve further data extractions from the peak power flow case to identify transmission circuits which carry higher levels of solar-generated power. While this analysis will identify only broad patterns of line flow attributable to solar plants, it ensures storage will be operated economically within the likely capacity and duration constraints of currently-available technology. P/A ratios estimated in Step 4 are combined with Step 5's results in Step 6 to identify candidate nodes within counties that may serve as storage sites.

Steps 7 through 8 require re-solving both power flow cases with proposed storage plants inserted into the grid model. While a staggered buildout of storage capacity could be analyzed over the 2025-2030 period (and beyond), it is probably more useful to re-solve the 2030 peak case as-if all proposed storage has been developed. Some consideration would be given to the cumulative amount of renewable supply added to the grid and the tradeoffs required to avoid overbuilding storage. Storage capacity and duration of charge/discharge must be approximately assigned at this step. The goal of this planning analysis is to ***defer, reduce or eliminate*** any new transmission lines, based on projects that ICF has identified. This analysis is not related to how storage performance could be optimized and controlled or whether storage is economically sized relative to local renewable capacity.

At the confidence level of a preliminary screening analysis, Step 8 will result in a down-selected list of candidate substations that could serve as viable storage sites. If any sites are identified for development, additional power flow analysis may be needed to confirm the conclusions from ICF's cases over a longer duration sequence. This study approach mainly provides a top-level screening of potential storage sites rather than a detailed Go/No Go analysis of sites, technologies and project return.

Method Improvements and Caveats

The proposed study method involves a series of simplifications and reduction in accuracy to allow the study to be conducted with minimal data. Given sufficient data and effort, use of more detailed methods and tools is possible as discussed below.

An obvious method refinement involves preparation of power flow cases that represent various levels of customer demand representing peak, shoulder and light power flow for each season. This approach would substantially refine estimated P/A ratios and provide more accuracy for site rankings. A minimum set would include winter and summer peak/light demand, plus shoulder- a total of six cases. A second refinement would add economic dispatch capability to the analysis process[55]. While add-on tools are generally available, it would require substantially greater data inputs to yield useful results. In fact, at this level of complication, the study process would probably require a broader scope of analysis to realize the types of benefits expected[56].

An outcome of Kalmia's recommendation to specify counties for P/A ratio averaging will create some degree of inaccuracy in storage siting. The sample size needed to capture siting impacts at high accuracy could be larger or

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[54] If lines do not terminate at nodes within a specific county, then they are treated as pass-through corridors and would not be considered for storage siting. In this case, the proposed storage siting would be shifted upline or downline to counties hosting connecting nodes.
[55] See Ref. 14; economic dispatch determines the output of electricity generation facilities (including storage), to meet the system load at the lowest possible cost subject to transmission and operational constraints.
[56] See Ref. 15; this study determined the "optimal" investments in renewable resources including energy storage technologies and new gas plants subject to an annual constraint on delivered renewable energy.

smaller, depending on the actual pattern of power flow through New Mexico's grid. To assess potential issues related to using this approach, Kalmia assembled the project data[57] shown in Table A-1.

Table A-1. Development Factors Affecting Storage Siting[58]

			ICF Line Segments		
County	Solar Capacity MW	Host Substation	Collector Plan 1	Collector Plan 2	Collector Plan 3
Bernalillo	247	Sandia	***L5***	***L5***	L4
Cibola	904	-	***L1,***L6	***L3***	L1,L5
Guadalupe	675	Guadalupe	***L4***,L6	***L3,L4***	L5
Lincoln	1,090	SunZia-East		L1,***L2***	
Rio Arriba	904	Ojo	***L2***,L3		L2,L3
San Juan	360	San Juan	***L2***		L3
San Miguel	1,225	-	***L4***	***L4***	L2
Santa Fe	613	Clines Corner	L3,***L4***	***L4***	L2
Socorro	575	Socorro-SunZia	***L1***,L6	L1,***L3***	L1,L5
Torrance	240	Western Spirit	***L5***,L6	L1,***L2,L3,L5***	L4,L5
Valencia	1,115	-	***L1***,L6	***L3***	L1

Table A-1 lists a subset of New Mexico counties, projected solar capacity[59], host 345-kV substation and line segments identified for Collector Plans 1,2 and 3. The ***bolded italicized*** line segments were identified as components of high-rank transmission projects[60]. A combination of factors such as co-location with ICF's proposed transmission lines, access to a host substation and higher projected solar capacity will add more justification to selection of sites for storage projects.

The listed transmission projects will require construction of new or uprated line corridors in 11 of 33 New Mexico counties. A subset of these counties could reasonably serve as hosts for storage plants if other favorable development factors are present, notably access to interconnect to a host substation which terminates at the proposed line segments. For example, Table A-1 indicates the "L5" segment connects to Sandia substation in Bernalillo County. A feasible interconnection for storage potentially exists at or near this location (to be verified by power flow analysis) since Sandia substation offers electrical access to a variety of 115 kV circuits throughout the Albuquerque area. For comparison, San Miguel County is identified in Table A-1 as hosting the "L4" line segment, however no host substation is accessible. In this case, storage must be sited either upline or downline at a nearby terminating node unless there are lower-voltage substations in the vicinity that interconnect to the proposed line. Other counties not listed in Table A-1 may offer opportunities for storage siting but the lack of accessibility to interconnect to a host substation[61] will be a limiting factor. This information suggests a careful evaluation of two alternatives is needed: a standard sample size (such as county) or a non-standard sample based on other criteria.

ICF's emphasis on areas of New Mexico's grid transmitting mainly solar-generated power also creates limitations

[57] See Ref. 16, Tables 5,6,7.
[58] See Ref. 17; Table A-1 contains results from a prior Kalmia analysis, page 9.
[59] Solar capacity projections were extracted from Ref. 16, Appendix A.
[60] ICF ranked proposed transmission lines in the order of importance. Higher ranked lines were expected to produce more reliability benefits to the system and hence should be considered as prime builds ahead of others.
[61] There are potential exceptions in DeBaca, Hildago, Luna, McKinley and Sandoval counties which should be evaluated.

on the proposed method. While storage begins to add more value as the fraction of solar-generated power increases, it constrains the value of siting storage prior to 2030. As the selection of storage technology improves and duration economically lengthens beyond 6 to 8 hours, it may become possible to realize benefits from both wind and solar generation[62]. At the current state of storage development, the best path forward is to limit the scope of such studies to technologies that are readily available through the year 2030 without assuming major breakthroughs in capacity or duration[63]. This suggests early evaluations of storage development can be less precise. Battery storage (BESS) is more commonly considered within the set of available options for utility storage siting in the near future. This choice will limit capacity to ranges of less than 100 MW and less than eight hours duration for charge/discharge cycles. Adding fuel cell technology to the allowable set of options could potentially extend cycle durations up to a week but at much higher cost.

Finally, the proposed study method is capable of only identifying “feasible” storage sites. ***Feasible siting*** implies that a number of sites could be reported as equally functional in the grid as well as ranked similarly. This approach results in clusters of sites that can’t be distinguished easily from each other; the reportable result is a list of sites (nodes) assigned to priority “tiers” such as High, Medium and Low development priority[64].

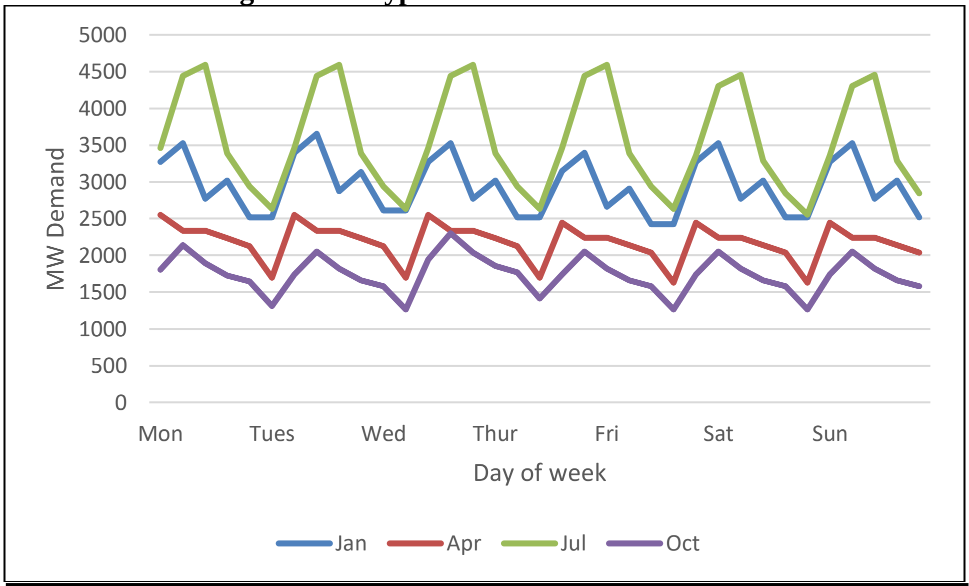
[62] See Ref. 18; NREL forecasts that this may occur as a “Phase 3” change in the storage market, in Kalmia’s opinion at least ten years or more are likely.
[63] Eventually multi-day, weekly and seasonal shifting of large amounts of stored energy will ultimately be needed as the percentage of renewables increases, certainly well before New Mexico reaches the ETA-mandated goal of 100% zero-carbon power by 2045 for IOUs.
[64] A more complex study could identify “optimal” sites. Using these methods, analysis is more precise and it results in a near-unique site ranking that offer higher or lower functionality.

A.2 New Mexico's 2030 Demand Profile

Hourly metered data representing typical weeks[65] was used in this study to construct a (net) demand profile. PNM's typical week data was combined into a chronological sequence and adjusted to fit New Mexico's 2030 annual peak, energy, and load factor.

Figure A-2 displays the four weeks' data corresponding to one week per season. Note that this data was averaged from a larger sample of day-to-day variations, actual demand on a given day will probably exhibit larger variations than shown, mainly due to weather. This data is useful for capturing the general pattern of variations likely to be observed, relative to expected renewable plant output.

Figure A-2. Typical Week Electric Demand



An adaptive search model was created to adjust the number of typical weeks required to fit the entire year's profile to forecasted annual peak, energy and load factor conditions. Table A-2 summarizes the adjustments required by aggregating forecasts from New Mexico's larger WECC utilities (PNM, EPE, TSGT).

Table A-2. Forecast Adjustments for 2030

Utility	2020 MW	2020 MWh	2030 MW	2030 MWh	Annual load factor
PNM	1,930	9,500,000	2,138	10,567,250	56.4%
EPE	2,034	8,198,000	2,327	8,892,218	43.6%
TSGT	753	4,103,250	922	5,156,250	63.8%
Total	4,717	21,801,250	5,387	**24,615,718**	**52.2%**

This table indicates that PNM's data exhibits an annual load factor[66]of 56.4% while the combined forecasts of all listed utilities will be significantly lower, 52.2%. Assuming time of peak demand is correlated among all three

[65] See Ref. 19; based on data reported by PNM. This profile is typical of utilities in the east-central area of New Mexico, however usage closer to Texas or Oklahoma may exhibit different demand profiles.
[66] See Ref. 20; load factor is a key indicator of how efficiently energy is being utilized. High load factor indicates that the grid is utilized more efficiently whereas underutilization results in a low load factor.

utilities[67], the forecasted 2030 peak equals 4,717 MW. Values highlighted in grey were used during the profile adjustment process. Table A-3 summarizes the results of modeling a sampled (1,753 hour) demand profile by fitting typical week data and aggregate values identified in Table A-2[68].

Table A-3. Typical Week Best-fit for 2030

Week	No. Weeks	Sum MWh
Jan	15	7,345,354
Apr	15	5,699,689
Jul	12	7,150,232
Jul_H	3	1,851,219
Oct	7	2,180,781
Total	52	24,227,275

Table A-3 indicates profile energy (Sum MWh) was modeled within 2% of the forecasted value shown in Table A-2. All hours' values were further scaled down uniformly by 53% to represent the RPS fraction of demand and energy; the resulting profile exhibits a load factor of 51.4% and annual peak of 2,792 MW.

Hourly renewable plant output was simulated by using NREL's System Advisor Model (SAM)[69]and scaled to wind and solar capacity consistent with ICF's forecasted 100% build. To create a net demand profile for the 50%, build the profile was sampled, uniformly scaled down by 50% and then subtracted from each hour's value of the adjusted demand profile previously described. This process resulted in significant modifications to the typical week profiles, as shown in Figure A-3.

Figure A-3. Typical Week (Net) Electric Demand at 50% Renewable Build

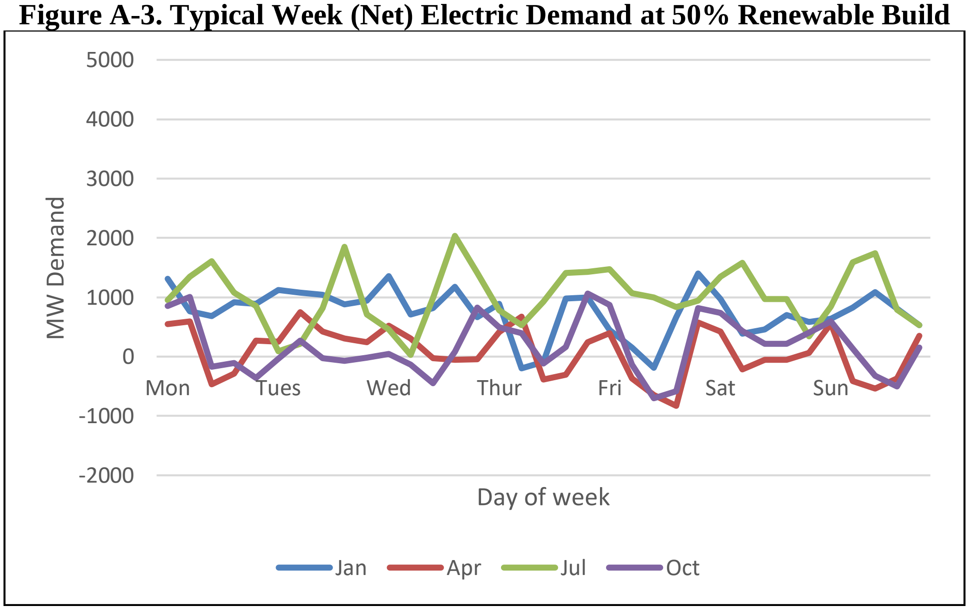


Figure A-3 indicates average demand for all seasons has decreased greatly and the recurring feature of daily demand profiles shown in Figure A-1 has been replaced by non-recurring variability to different degrees; this effect can be

67 This simplifying assumption results in a worst-case estimation of annual load factor. Some degree of non-correlation probably exists which will reduce forecasted 2030 peak demand.
68 In order to distinguish typical summer weeks from those at or near annual peak (usually occurring in July), an additional typical week was created from PNM's data. This series was labeled "Jul_H", it displays an abnormally high demand day on Tuesday.
69 See Ref. 21; SAM output includes renewable plant annual, monthly and hourly output; capacity factor, LCOE, NPV, payback and revenue.

attributed to hour-to-hour fluctuations in renewable plant output. Changes in demand patterns are measured, in part, by seasonal load factor; this quantity generally ***decreases by 2030*** from 59.6% in mid-summer to 12.2% in spring. The latter condition primarily results from an excess of wind-generated power which must be either curtailed, sold off-system or stored.

Note typical week profiles are sampled from a larger set of hours; the most important net demand features include hour-to-hour variations exhibited near or at the time of annual peak. As displayed, the profiles plotted in Figure A-2 do not capture that effect accurately, however it is discussed in the main body of this report.

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