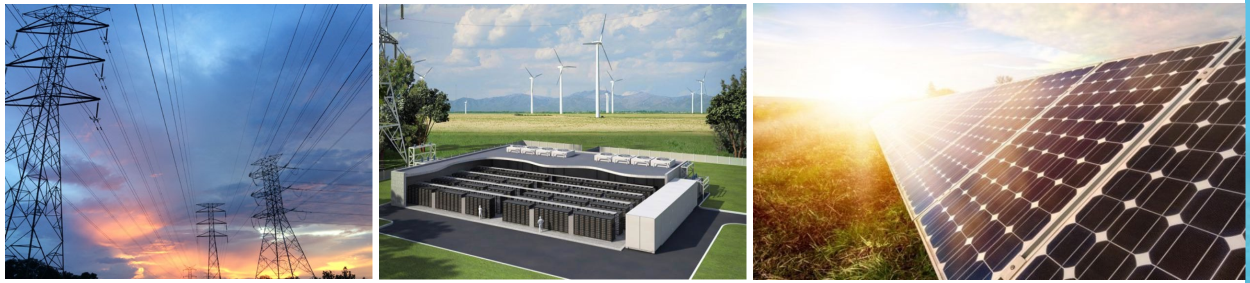
Power System Planning for Decarbonization & Energy Storage



Sandia National Laboratories

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2023 DOE OE Energy Storage Peer Review - October 26, 2023

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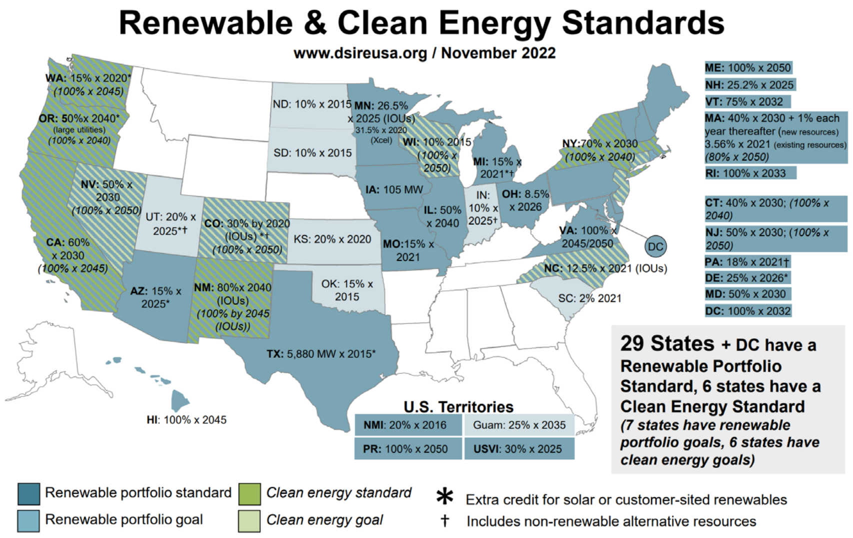
Overview

- Project Overview & Motivation
- Planning Framework
- Capacity Expansion Planning Model Overview
- Key Drivers for Investments in Energy Storage technologies
- Capacity Expansion Planning in New Mexico
- Reliability-based Energy Storage Sizing Case Study
- Conclusions & Future considerations

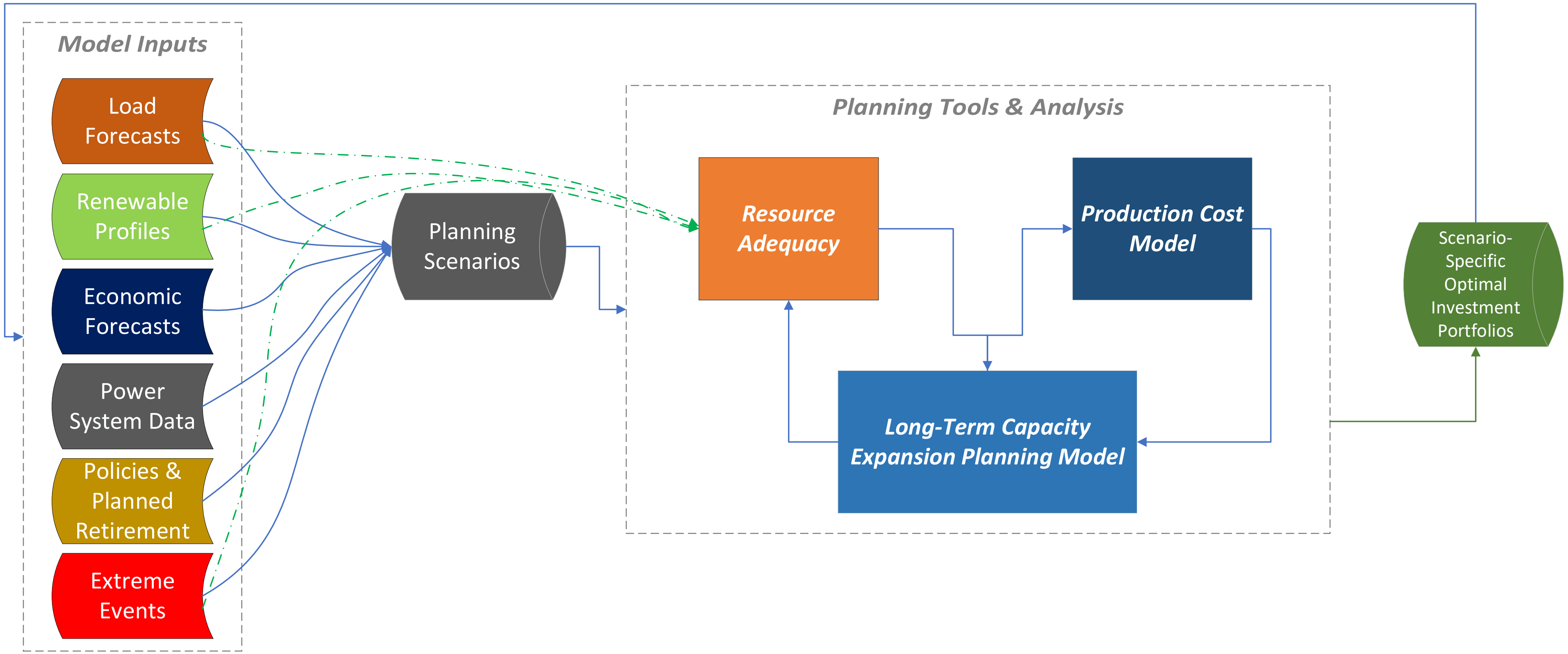
Project Overview & Motivation

- ***Public Service Company of New Mexico (PNM)*** & ***Sandia National Laboratories*** are currently in a Collaborative Research & Development Agreement (CRADA)
- ***Project Motivation***
  - Due to state legislation (e.g. New Mexico Energy Transitions Act (ETA)), power systems are transitioning from thermal-based generation to clean, renewable energy resources → ***Energy storage technologies will play a role!***
  - Need to evolve tools to evaluate future pathways towards grid decarbonization
- ***Project Goals & Outcomes***:
  - Collaborate with PNM Integrated Resource Planning group
  - Provide independent analysis on potential pathways to meet the requirements of the New Mexico Energy Transitions Act (ETA)
  - Develop open-source expansion planning tool
  - Develop capabilities and framework for planning for decarbonization and energy storage technologies at Sandia to support decision-makers on the siting and sizing of energy storage technologies



NC Clean Energy Technology Center. Renewable portfolio standards and clean energy standards, 2022.

Planning Framework – How can tools coordinate effectively?



Capacity Expansion Planning Model Overview

$$\min \sum_{y\in Y} \gamma_y * [\underbrace{C_y^G + C_y^T + R_y^{ES}}_{\text{Investment Costs}} + \underbrace{O_y^{FOM} + O_y^{VOM} + O_y^{Fuel} + P_y^{LS}}_{\text{Operational Costs}} - \underbrace{I_y^{PTC/ITC}}_{\text{Incentives}}]$$

Annual Costs:

C_y^G - Generation Inv.
C_y^T - Transmission Inv.
R_y^{ES} - ES Replacement
O_y^{FOM} - Fixed O & M
O_y^{VOM} - Variable O & M
O_y^{Fuel} - Fuel Cost
P_y^{LS} - Load Shed Penalty
$I_y^{PTC/ITC}$ - Tax Credit
γ_y - Discount factor

- Capacity expansion planning (CEP) models are ***exploratory***; designed to assess several ***future scenarios***
- Long term planning horizon (e.g. 20-30 years)
- Model is deterministic (perfect foresight); linear program optimization

Subject to:

- ***Energy Storage Constraints***
  - State-of-Charge Tracking
  - Charge/Discharge Limits
  - Min/Max SOC level
  - Seasonal balancing of ESS
  - Power & energy Sizing
- ***Thermal Generation***
  - Minimum stable level
  - Max. capacity limits
- ***Transmission Constraints***
  - Pipe & bubble (Zonal)
  - DC power flow (Nodal)
- ***Policy Constraints***
  - Renewable portfolio standards
  - Carbon emission reduction
  - Carbon intensity
- ***Generation Retirements***
- ***Operational Reserves***
  - Regulation, spinning, flexibility reserves
- ***Planning Reserve Margin***
  - Meeting system-wide reliability (x% over annual peak)
- ***Power Balance***
  - Meeting forecasted demand at zonal/nodal level for each time step

Key Model Outputs:

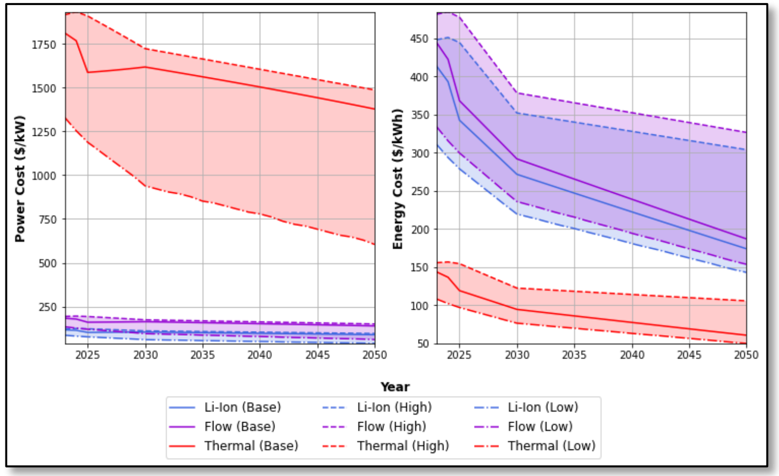
- Optimal generation expansion & transmission expansion (in progress)
- Siting of new resources
- Investment & Operational Costs
- Energy Storage (power & energy capacity)
- Policy Performance

E. Spyrou, J. L. Ho, B. F. Hobbs, R. M. Johnson and J. D. McCalley, "What are the Benefits of Co-Optimizing Transmission and Generation Investment? Eastern Interconnection Case Study," in IEEE Transactions on Power Systems, vol. 32, no. 6, pp. 4265-4277, Nov. 2017

Key Drivers for Investments in Energy Storage Technologies

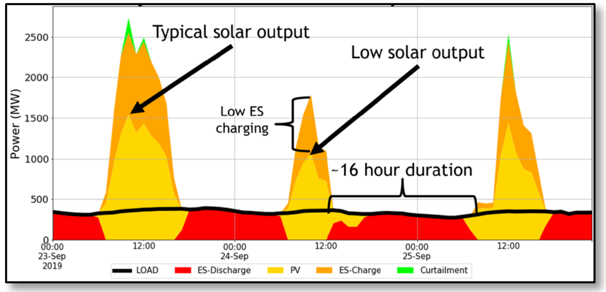
- It is important to understand the key drivers in expansion planning models that affect the investment decisions of energy storage (ES) technologies

Key Parameters & Modeling Considerations	Effect on Energy Storage Investment Decisions
ES duration	Optimizing power & energy capacities → Identifying system needs over time & technology selected
ES round-trip efficiency	Required installed capacities and operations
Investment Cost & Technology Maturation	Technologies selected & timing of investment
Renewable Penetration (Policies)	Sized to firm renewables & cover renewable energy lulls
Technology Lifetime	Effect on technology replacement costs
Temporal Resolution	Effect on system balancing & may overlook operational benefits of long duration technologies
Incentives	Investment tax credits (from IRA) favor ES deployment



Sample ES cost trajectories over time

https://atb.nrel.gov/; https://www.pnnl.gov/ESGC-cost-performance



Example dispatch plot during low PV production

- Other factors such as *degradation*, *seasonal shifting*, and *capacity credits* should also be considered, but have not been closely investigated to date

Capacity Expansion Planning in New Mexico

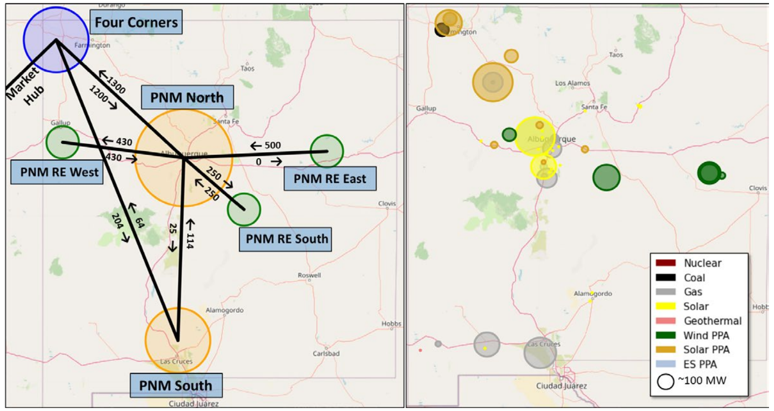
- ***Assumptions***:
  - PNM Zonal Model (pipe & bubble) – capturing location-specific renewable profiles for existing and candidate resources
  - Reference load forecast
  - NM ETA RPS (80% by 2040) & CO2 Policies (Carbon free by 2040)
  - Candidate Technologies:
    - 100m Wind (East only), Utility-scale PV, Li-Ion ES (2-10 hr. duration), Flow Battery (2-100 hr. duration), Thermal Energy Storage (4-100 hr. duration)
  - Temporal Resolution:
    - *Seasonal representative weeks* + *Peak Demand week* (5 weeks @ hourly timestep)
  - Optimizing energy storage power and energy capacity over time
  - Investment & operational costs: NREL ATB [1], PNNL cost database [2], & PNM public dataset
  - ***Planning scenarios*** developed based on retirement schedules, technology cost & maturation, and wind expansion options

C.J. Newlun, W. Olis, A. Bera, A. Benson, R.H. Byrne, T. Nguyen, J. Mitra "Planning for Grid Decarbonization in New Mexico: An Energy Storage Perspective" 2024 IEEE Electrical Energy Storage and Technologies (EESAT) (Under review, abstract accepted), San Diego, CA, 2024.

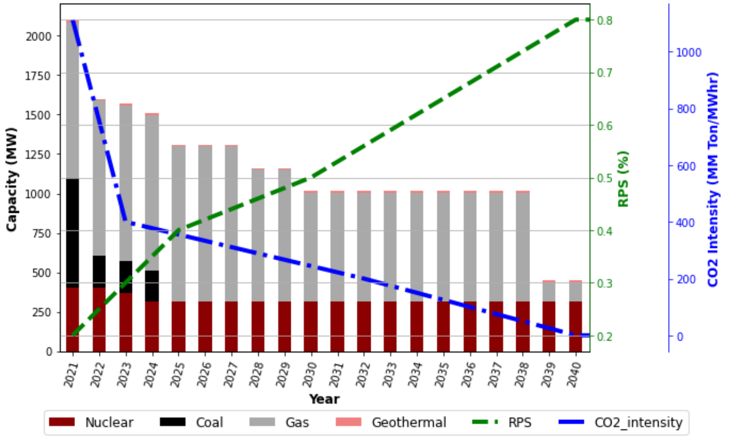
[1] https://atb.nrel.gov/

[2] https://www.pnnl.gov/ESGC-cost-performance

PNM Zonal Power System



New Mexico Energy Transition Act & PNM Thermal Retirements

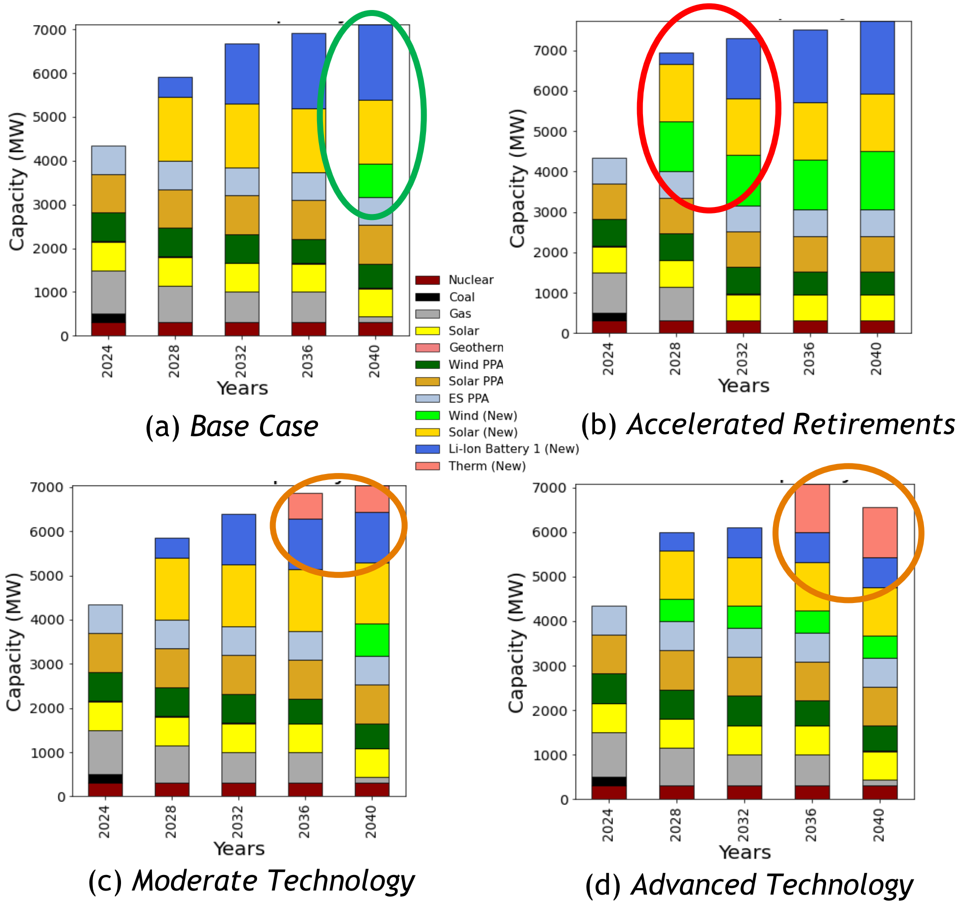


Planning Scenarios

	Base Case (BC)	*Accelerated Retirements (AR)*	*Moderate Technology (MT)*	*Advanced Technology (AT)*
Thermal Retirements	Scheduled	Accelerated	Scheduled	Scheduled
Energy Storage Cost	Base	Base	High	Low
Energy Storage Technology	Li-Ion	Li-Ion	Li-Ion Flow Thermal	Li-Ion Flow Thermal
Wind Expansion	East Only	All	East Only	All

Capacity Expansion Planning in New Mexico

Resource Expansion by Scenario



(a) *Base Case*

(b) *Accelerated Retirements*

(c) *Moderate Technology*

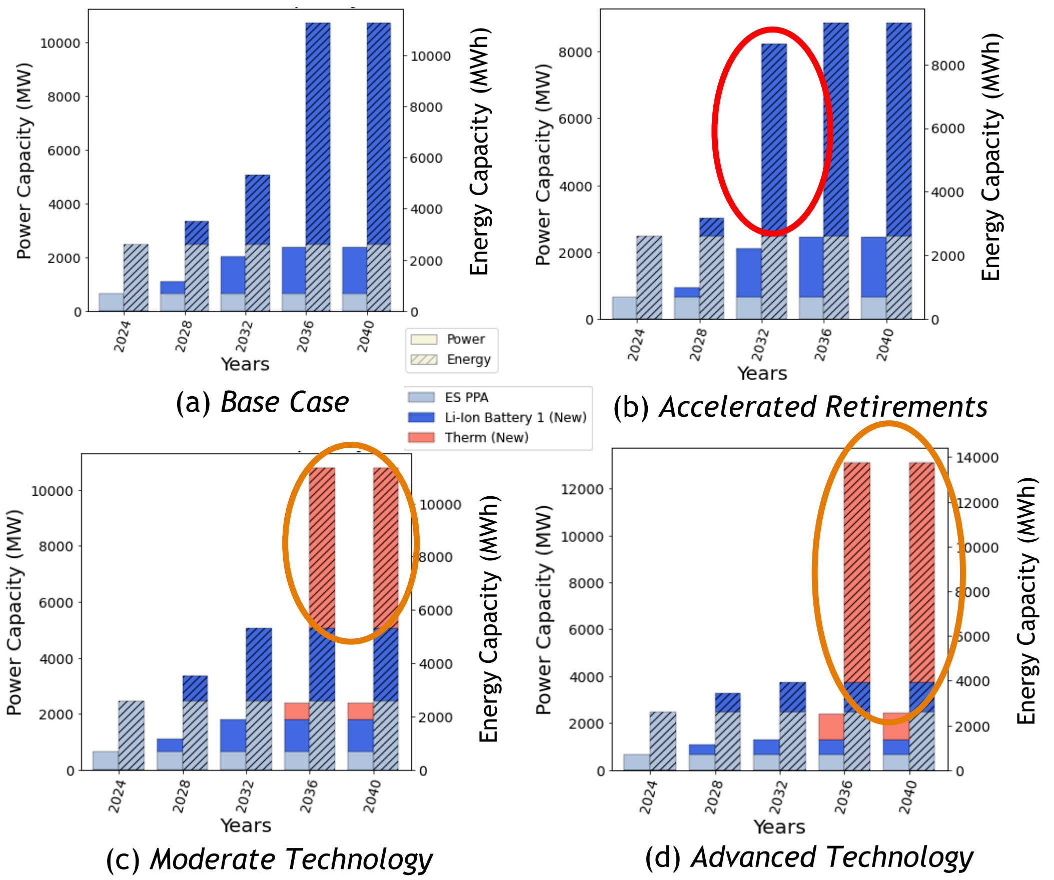
(d) *Advanced Technology*

Limited wind expansion *plays a role in optimal resource mix & ES required*

Accelerated retirements *results in earlier resource and ES adoption*

ES cost ***trajectories*** *promote and/or inhibit ES technology deployment*

Energy Storage Expansion by Scenario



(a) *Base Case*

(b) *Accelerated Retirements*

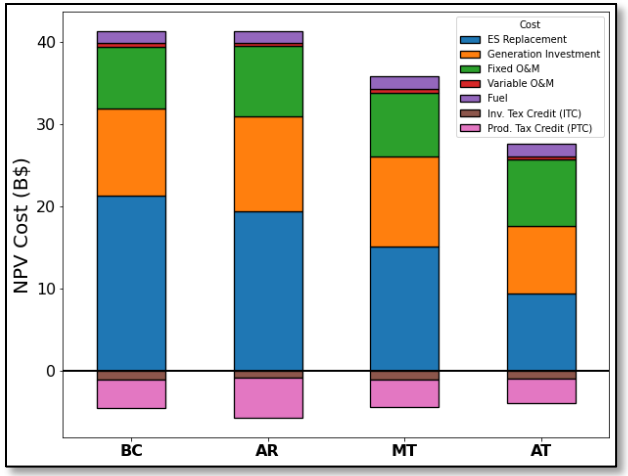
(c) *Moderate Technology*

(d) *Advanced Technology*

Capacity expansion model *allows for investigation into* ***resource expansion****, sizing of energy storage* ***power and energy*** *capacities, and* ***when*** *such investments should occur in the planning horizon*

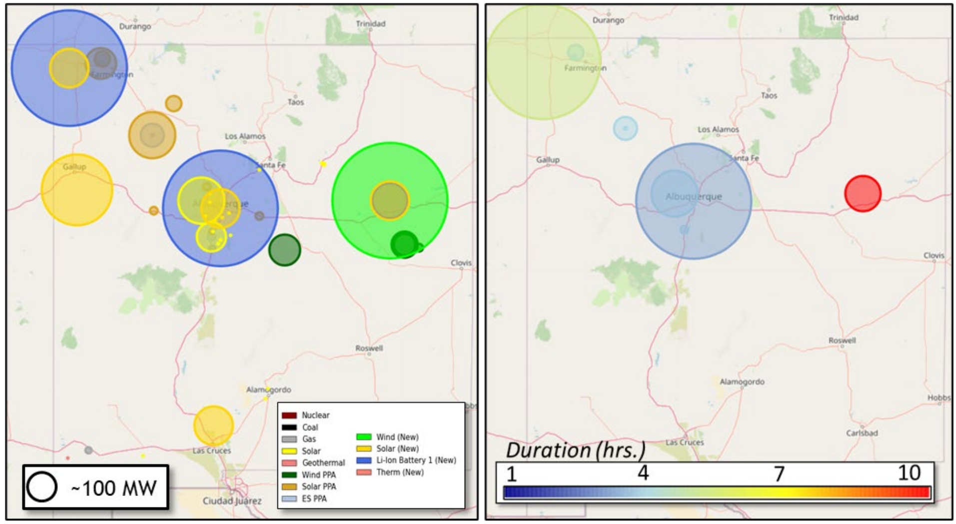
Capacity Expansion Planning in New Mexico

Investment & Operational NPV Cost Breakdown



- ***Key Takeaways***:
  - The ***Moderate*** and ***Advanced Technology*** scenarios resulted in relatively less expensive portfolios
  - The ***ES cost assumptions*** play a role in deployments and investment & operational costs
  - Model selects a ***geographically diverse*** ES portfolio in terms of capacity and duration to support renewable deployment

Base Case (BC)

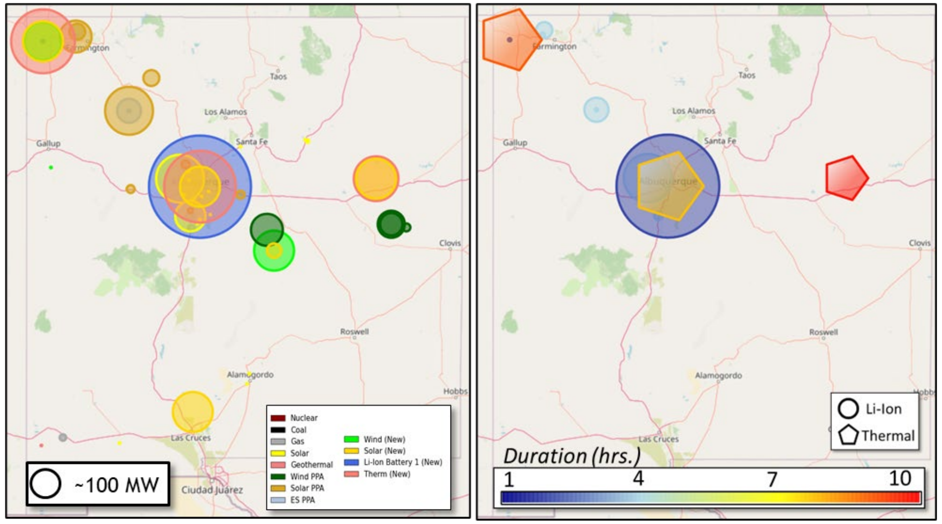


2040 Resource Portfolio

2040 ES Power & Energy

Locations of candidate investments are approximate

Advanced Technology (AT)

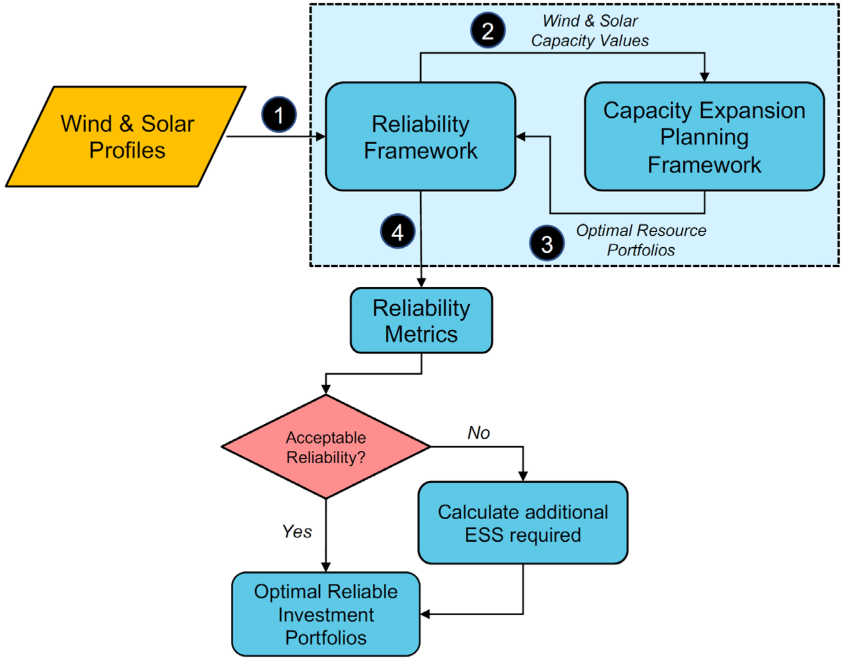


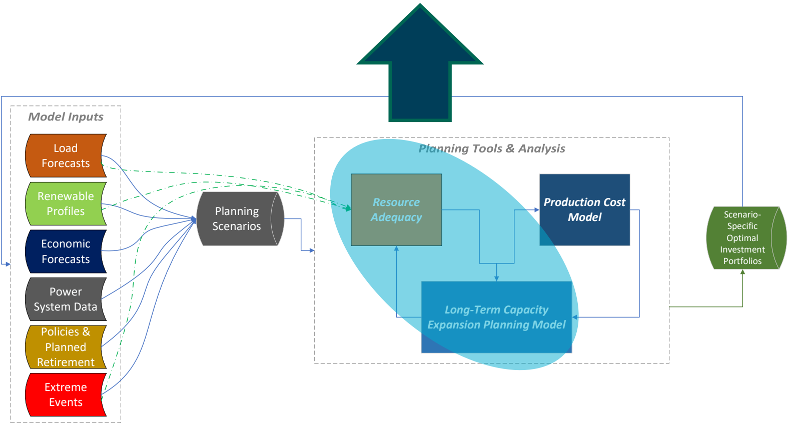
2040 Resource Portfolio

2040 ES Power & Energy

Deploying Capacity Expansion Planning with Resource Adequacy to Size Energy Storage – Case Study

High-Level Framework

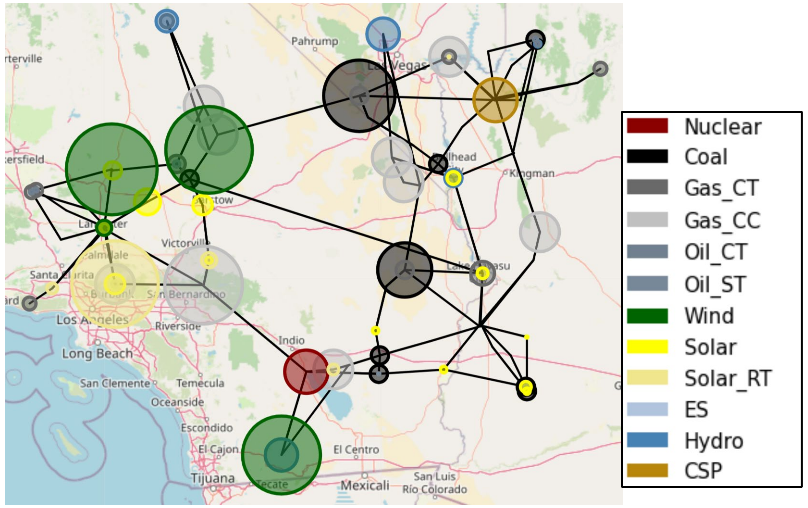




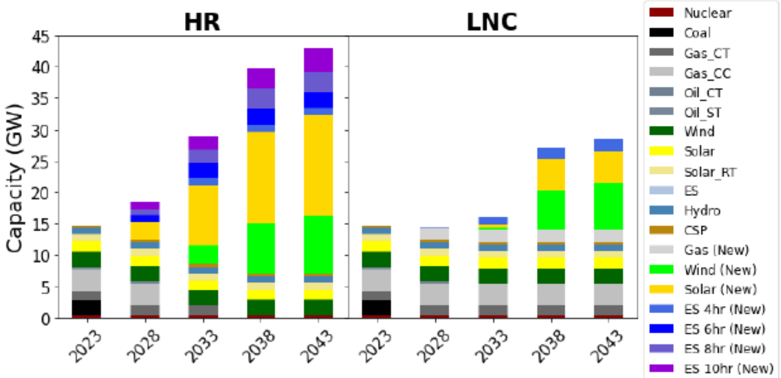
Scenarios

Variable \ Scenario	*High Renewable (HR)*	*Limited New Combustion (LNC)*
Candidate Technologies	Utility-scale Solar Utility-scale Wind ES (4-10 hr)	Utility-scale Solar Utility-scale Wind ES (4-10 hr) Gas CC (before 2033)
Retirements	Coal (2025) Oil (2030) Gas CC (2033) Gas CT (2038)	Coal (2025) Oil (2030) Gas CC (Not Retired) Gas CT (Not Retired)
RPS Policy	2028 - 30% 2033 - 40% 2038 - 70% 2043 - 100%	2028 - 30% 2033 - 40% 2038 - 70% 2043 - 80%

RTS-GMLC Test Case



Capacity Expansion Results



Resource Adequacy Results

TABLE II

RELIABILITY METRICS & ESS SIZES

Case No.	LOLH (h/y)	NEUE*	P_s (MW)	$\bar{r}$ (h)	α	t_s (h)	Q_s^{**} (MWh)
HR	11.57	0.0157	381	2.69	0.21	4.45	1694
LNC	9.94	0.0119	385	2.18	0.24	3.26	1254

*NEUE = normalized EUE (EUE expressed as a % of the load)

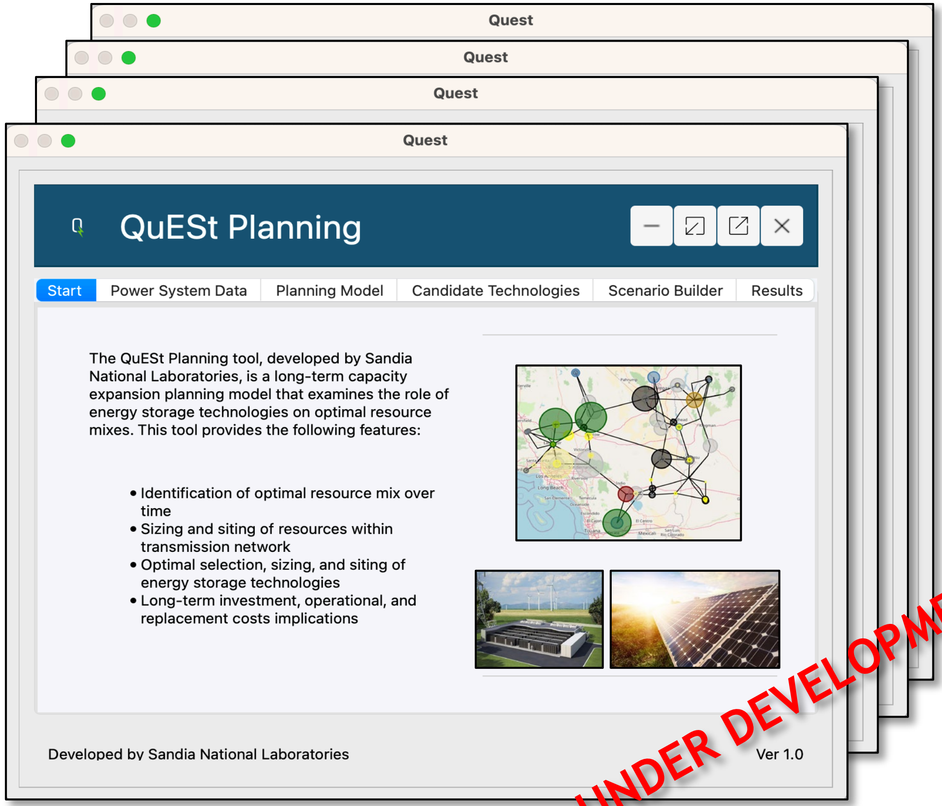
** Q_s = energy capacity of additional ESS (MWh)

High Renewable scenario results in higher energy LOLH, NEUE, and additional ES energy capacity required compared to ***Limited New Combustion*** scenario to maintain reliability

A. Bera, C. J. Newlun, W. Olis, T. Nguyen, J. Mitra, "Reliability-based Capacity Expansion Planning for Decarbonization with the Aid of Energy Storage," 2023 IEEE Innovative Smart Grid Technologies – Europe (Accepted), Grenoble, France, October 23-26, 2023.

QuESt Planning Tool

- **QuESt Planning** tool is under development
- Key features of the tool:
  - Identification of optimal resource mix
  - Sizing and siting of resources in transmission network
  - Optimal selection, sizing, and siting of energy storage technologies
  - Evaluation of long-term cost impacts
  - Scenario-based planning
- Incorporating into **QuESt Platform**
  - https://github.com/sandialabs/snl-quest
  - QuESt PI: Tu Nguyen, Sandia National Labs



The QuESt Planning tool, developed by Sandia National Laboratories, is a long-term capacity expansion planning model that examines the role of energy storage technologies on optimal resource mixes. This tool provides the following features:

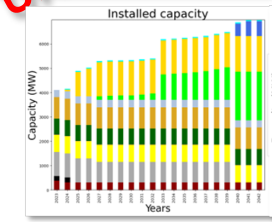
- Identification of optimal resource mix over time
- Sizing and siting of resources within transmission network
- Optimal selection, sizing, and siting of energy storage technologies
- Long-term investment, operational, and replacement costs implications

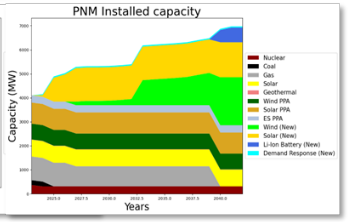
Developed by Sandia National Laboratories

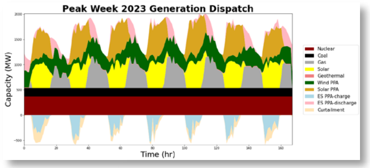
Ver 1.0

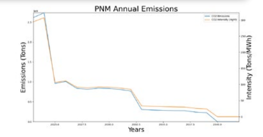
UNDER DEVELOPMENT

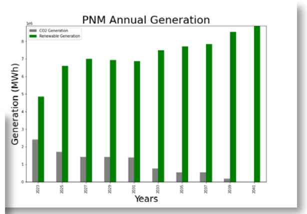
Sample Outputs & Visualizations

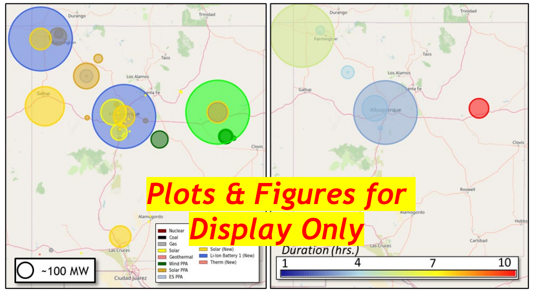












Plots & Figures for Display Only

Conclusions & Next Steps

- Coordination of planning tools will provide more insights into future investment solutions to achieve power system decarbonization
- Capacity expansion planning model is a powerful tool to evaluate decarbonization pathways and experiment with future planning scenarios but can get complex
- Several factors play a role in the investment and deployment of ES technologies
- Coupling CEP and RA models provide an iterative approach to identifying the amount of ES required to meet system reliability and decarbonization goals
- ***Next Steps***:
  - Planning tool development for QuESt
  - Planning framework & CEP/RA coordination for PNM system
  - Evaluate role of transmission expansion and broad range of ES technologies in CEP model
  - Investigate temporal representation in the CEP model (extreme events or tight margin time periods)

Accomplishments & Acknowledgements

Accomplishments:

- C.J. Newlun, W. Olis, A. Bera, A. Benson, R.H. Byrne, T. Nguyen, J. Mitra "Planning for Grid Decarbonization in New Mexico: An Energy Storage Perspective" 2024 IEEE Electrical Energy Storage and Technologies (EESAT) (Under review, abstract accepted), San Diego, CA, 2024.
- A. Bera, C. J. Newlun, W. Olis, T. Nguyen, J. Mitra, "Reliability-based Capacity Expansion Planning for Decarbonization with the Aid of Energy Storage," 2023 IEEE Innovative Smart Grid Technologies – Europe (Accepted), Grenoble, France, October 23-26, 2023.
- C.J. Newlun, "Power System Planning for Decarbonization & Energy Storage", Presentation to the stakeholders of the Public Service Company of New Mexico (PNM) Integrated Resource Planning process, August 22, 2023. - Oral Presentation
- A. Bera, A. Benson, and T. Nguyen, "Reliability-based Sizing of Energy Storage for Systems with Very High Renewable Penetration." 2023 IEEE Power & Energy Society General Meeting (PESGM), Orlando, FL, July 2023.

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Thank You!

Questions?

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