Power System Planning for Decarbonization & Energy Storage



Sandia National Laboratories Energy Storage Program

Cody Newlun, Atri Bera, Walker Olis

Presentation to PNM Stakeholders – August 22, 2023

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2023-08206PE

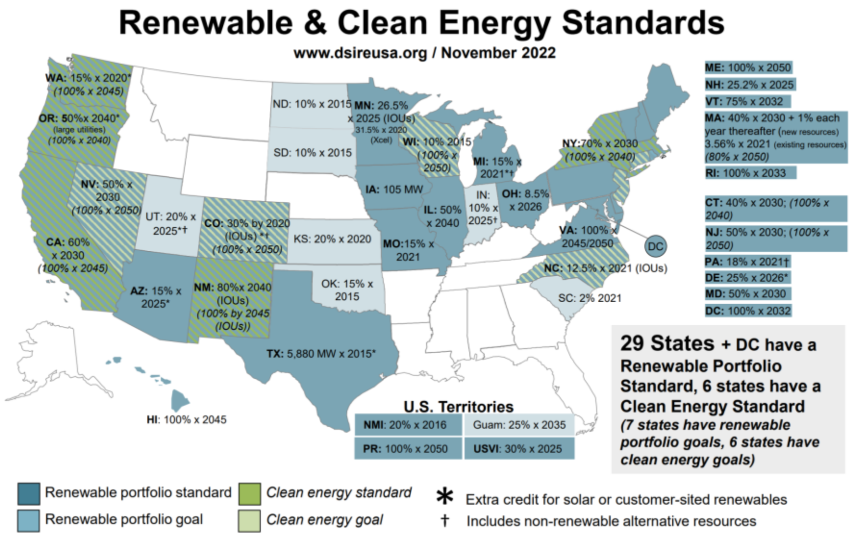
Overview

- Project Overview & Motivation
- Planning Framework
- Capacity Expansion Planning Model Overview
- Modeling complexities
- Key Drivers for Investments in Energy Storage technologies
- Preliminary modeling results
- Resource adequacy overview & Reliability-based Energy Storage Sizing
- Conclusions & Future considerations

Project Overview & Motivation

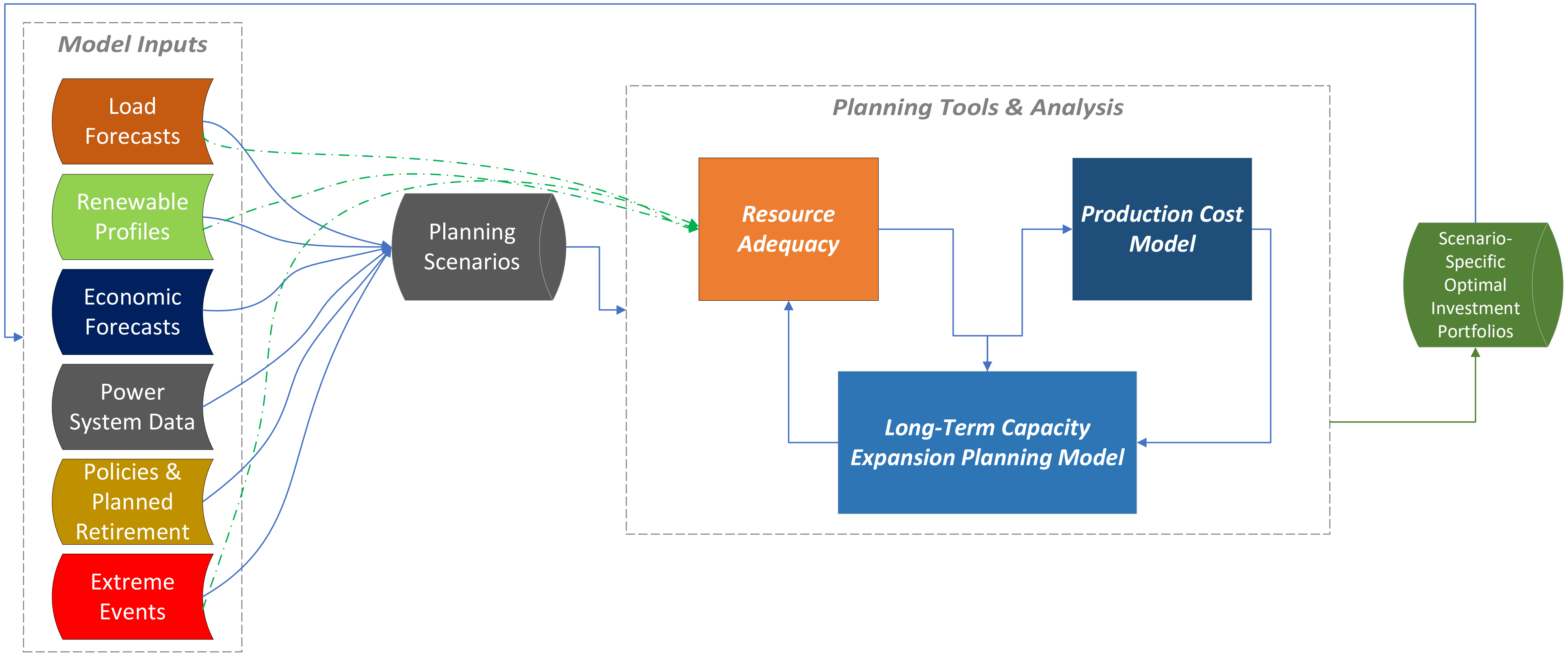
- ***PNM*** & ***Sandia National Laboratories*** are currently in a Collaborative Research & Development Agreement (CRADA) funded by Department of Energy Office of Electricity – Energy Storage Program
- ***Project Motivation***
  - Due to state legislation (e.g. New Mexico Energy Transitions Act (ETA)), 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 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 for planning for decarbonization and energy storage technologies at Sandia to support decision-makers on the siting and sizing of energy storage technologies
  - Published report on reserve requirements for future PNM system: https://www.osti.gov/servlets/purl/1868430

Sandia National Laboratories



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

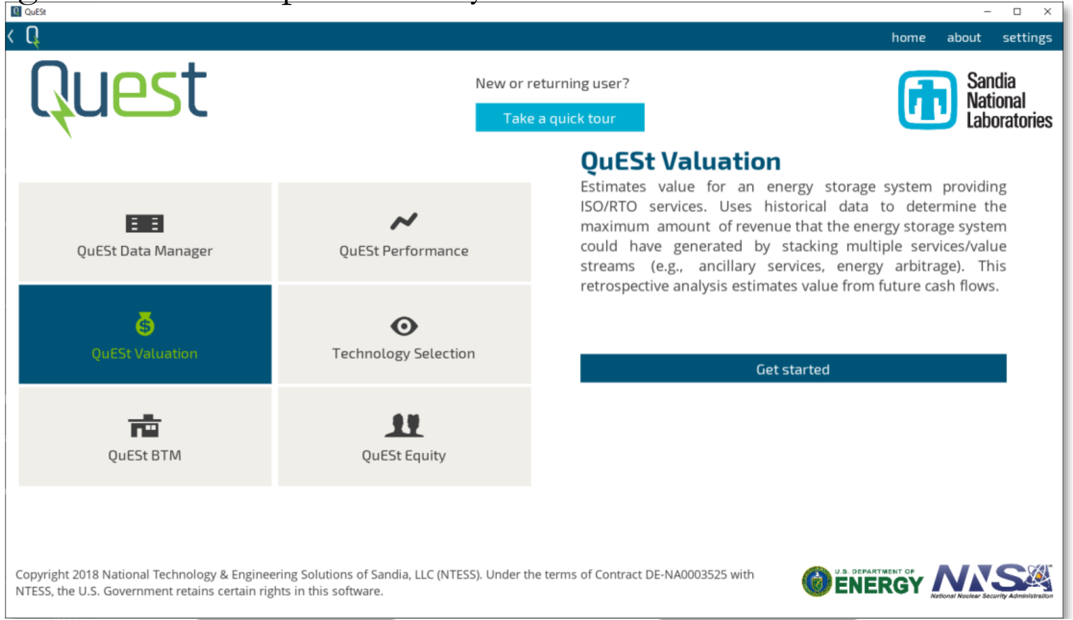
Key Model Outputs:

- 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

QuESt - Overview

QuESt is designed to give users access to models and analysis for energy storage used and developed by Sandia. It's designed to be transparent and easy to use without having to have knowledge of the mathematics behind the models or knowing how to develop code in Python.

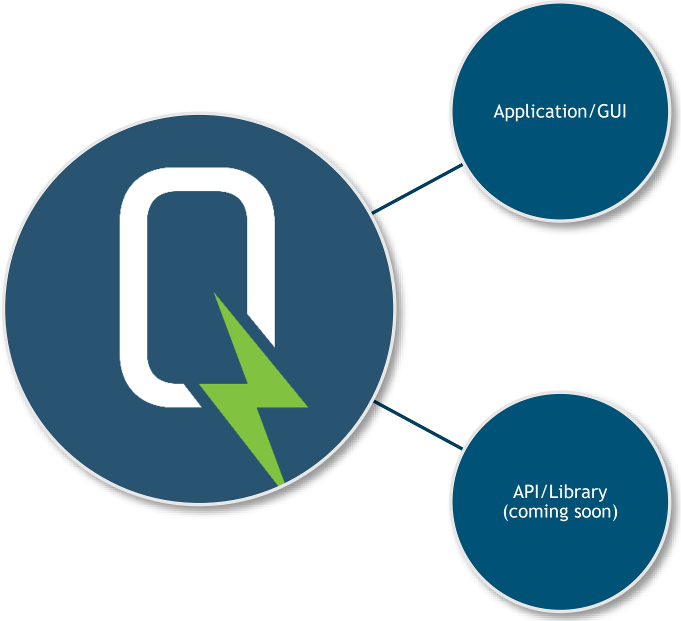


Decide what type of analysis to do.
- ISO/RTO value stacking => QuESt Valuation
- Behind-the-meter applications => QuESt BTM

Grab the appropriate data from QuESt Data Manager.
- ISO/RTO market data
- Utility rate structure
- PV profile
- Load profile

Select the appropriate application from the first step.
- Set up the analysis and run it
- View and process results

Version 1.6 available on GitHub: https://github.com/sandialabs/snl-quest
Slide developed by Tu Nguyen, Sandia National Laboratories



- Developed for user experience
- No hassle installation

- For power users
- Use for Python scripting
- More capabilities

Current:
- QuESt Data Manager
- QuESt Valuation
- QuESt BTM

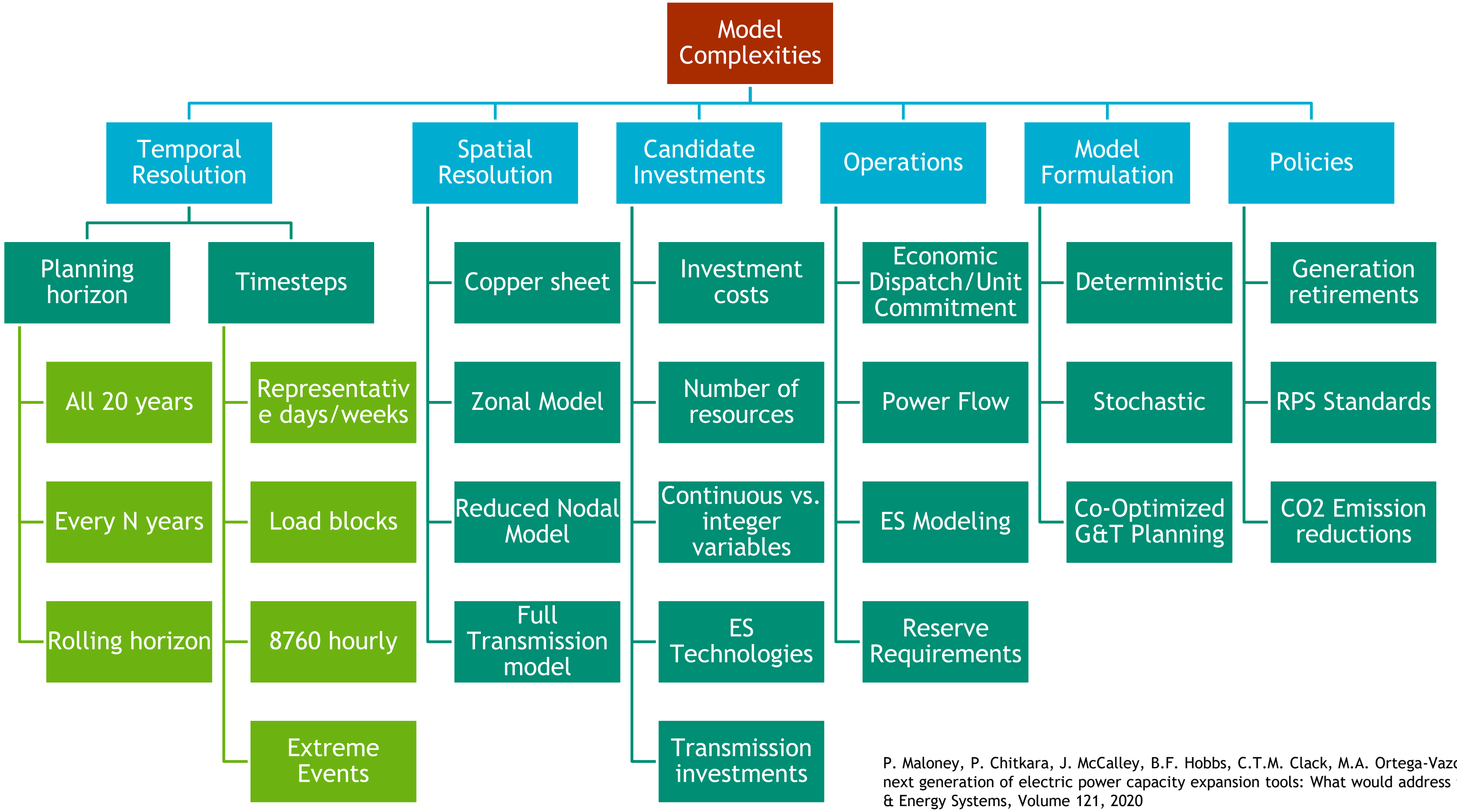
Beta Release:
- QuESt Tech Selection
- QuESt Performance

Alpha Release:
- QuESt Equity

Under Development:
- QuESt Microgrid
- **QuESt Planning**
- System Dynamics Tool for Energy Regulators

Complexities of the Capacity Expansion Planning Model

- Capacity expansion planning (CEP) models are complex and computationally expensive
- When constructing CEP models careful considerations need to be taken to maintain computational feasibility and to avoid unrealistic results



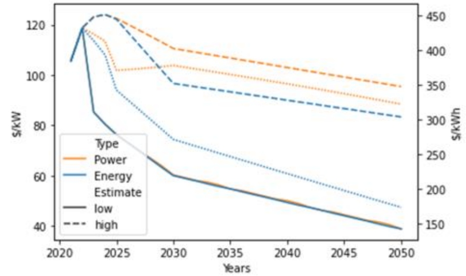
P. Maloney, P. Chitkara, J. McCalley, B.F. Hobbs, C.T.M. Clack, M.A. Ortega-Vazquez, A. Tuohy, A. Gaikwad, J. Roark, Research to develop the next generation of electric power capacity expansion tools: What would address the needs of planners?, International Journal of Electrical Power & Energy Systems, Volume 121, 2020

Key Drivers for Investments in Energy Storage Technologies

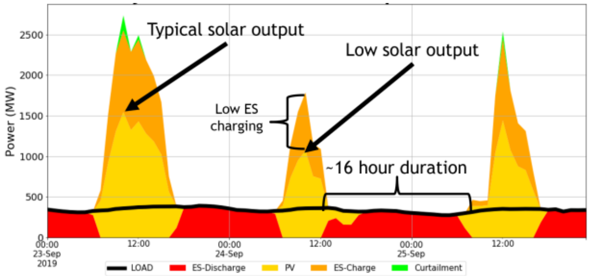
- Energy storage (ES) will play a key role in meeting the NM ETA renewable portfolio standard and carbon emission goals in the PNM system

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

Key Parameters & Modeling Considerations	Effect on ES Investments
ES duration	Optimizing power & energy capacities → Identifying system needs over time & technology selected
ES round-trip efficiency	Affects required installed capacities and operations
Investment Cost & Technology Maturation	Affects technologies selected & timing of investment
Renewable Penetration (Policies)	Sized to firm renewables & cover renewable energy lulls and extreme events
Technology Lifetime	Affects technology replacement costs
Temporal Resolution	Affects 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/



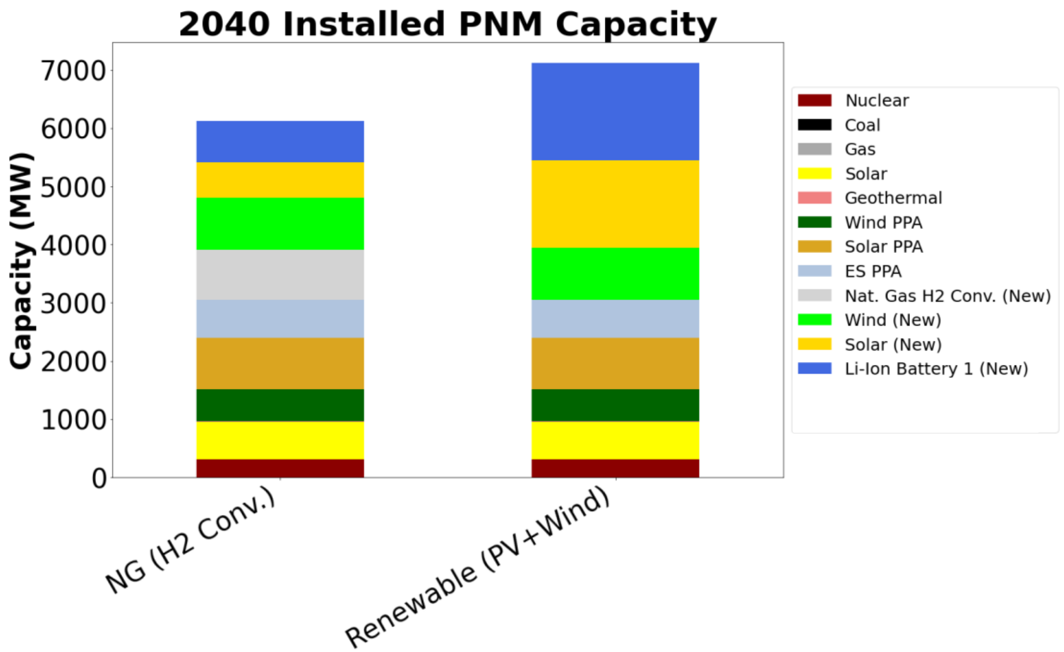
Example dispatch plot during low PV production

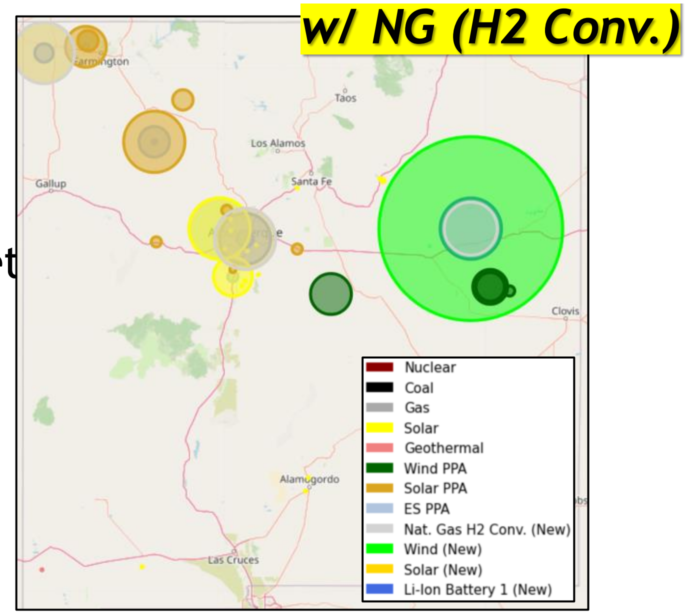
- Other factors such as *degradation*, *seasonal shifting*, and *capacity credits* should also be considered, but have not been closely investigated to date

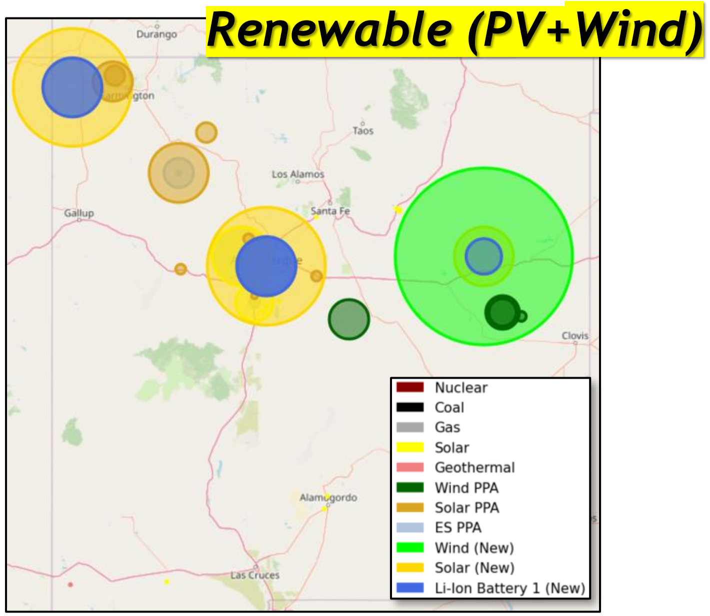
Preliminary Results

- ***Assumptions*:**
  - PNM Zonal Model (pipe & bubble) – capturing location-specific renewable profiles for existing and candidate resources
  - Reference load forecast
  - 2022-2040 – every 3 years
  - 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), NG (w/ Hydrogen (H2) conversion)
  - Temporal Resolution:
    - *Seasonal representative weeks + Peak Demand week* (5 weeks @ hourly timestep)
  - Investment & operational costs: NREL ATB [1], PNNL ES cost database [2], & PNM public dataset
  - Scenarios:
    - 1.) NG (H2 Conv.) expansion
    - 2.) Renewable (PV + Wind) expansion
    - Energy storage expansion in both scenarios

Note: Results are preliminary and further investigation needs to be completed before comparing with other models/results







Locations of candidate investments are approximate

2040 Generation Expansion

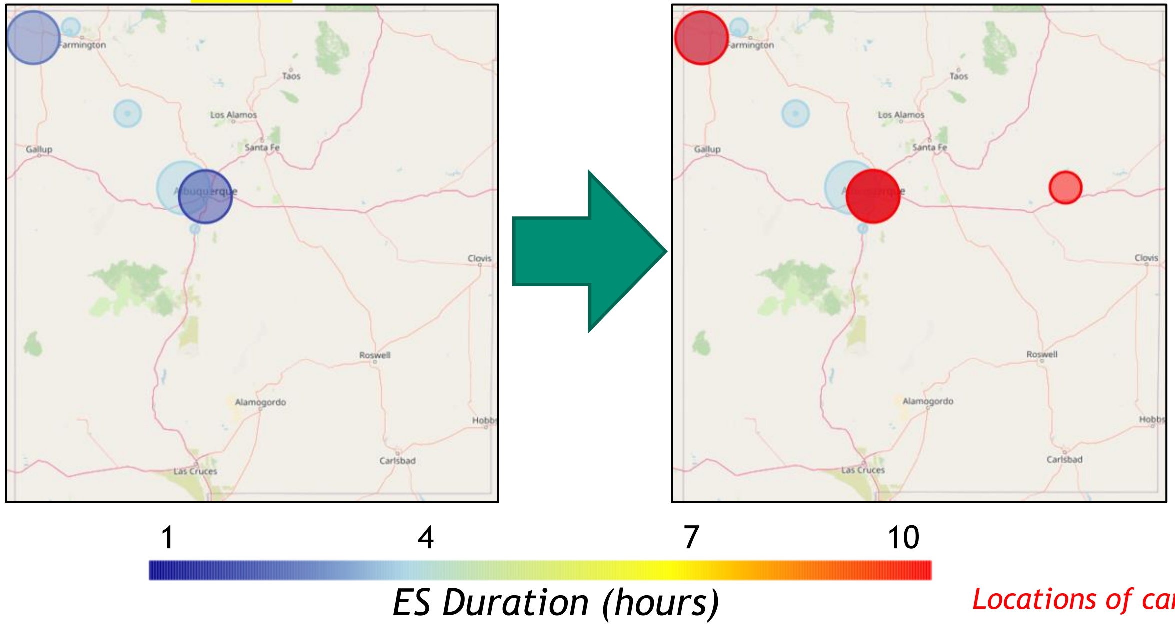
[1] https://atb.nrel.gov/
[2] https://www.pnnl.gov/ESGC-cost-performance

Expansion of Energy Storage Technologies – Preliminary Results

- Optimizing ES power and energy capacity provides insights into system's storage needs over time
- Planning tool can inform siting and sizing of ES technologies

Renewable (Wind + PV)-
Existing & Invested Energy Storage

2025 | 2040



	2040 Total ES Power Capacity (MW)	*2040 Total ES Energy Capacity (MWh)*
NG (H2 Conv.)	1367	7,366
Renewable (Wind + PV)	2327	14,790

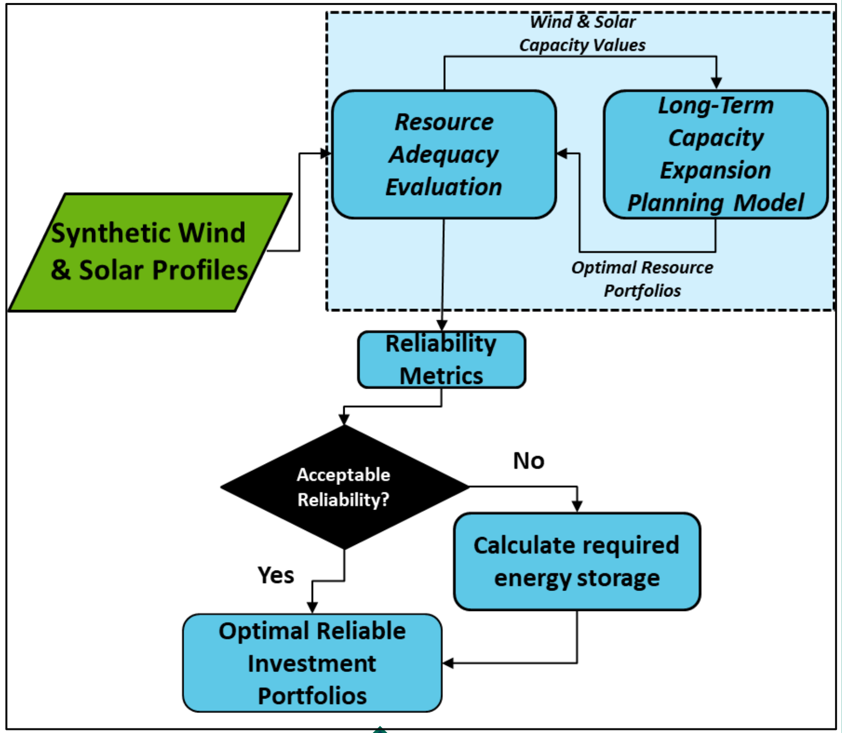
- Model chooses mix of ES durations throughout different points of time in planning horizon
- High renewable systems will require more energy storage power and energy capacity to maintain reliability and meet decarbonization goals – longer duration technologies are favored in high variable generation systems
- Certain technologies may be more favorable given the optimal power & energy capacity identified in the CEP

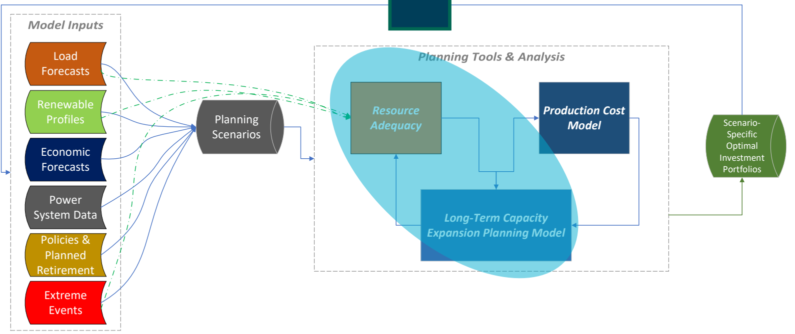
Locations of candidate investments are approximate

Note: Results are preliminary and further investigation needs to be completed before comparing with other models/results

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

High-Level Framework

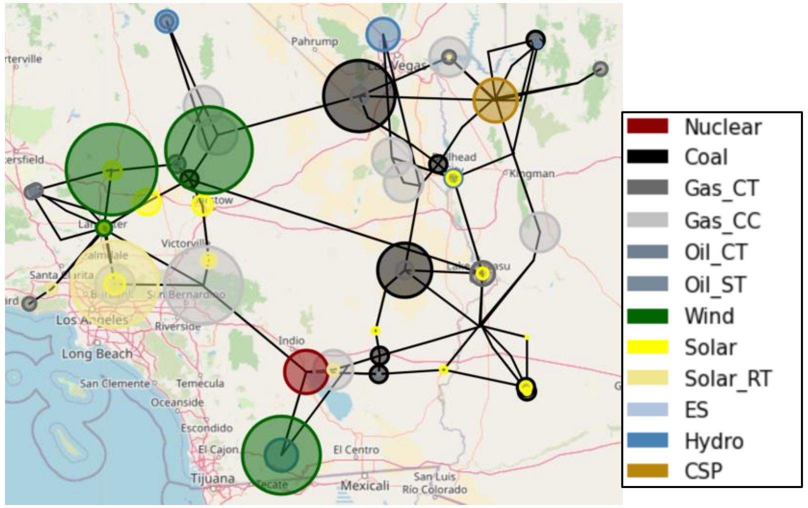




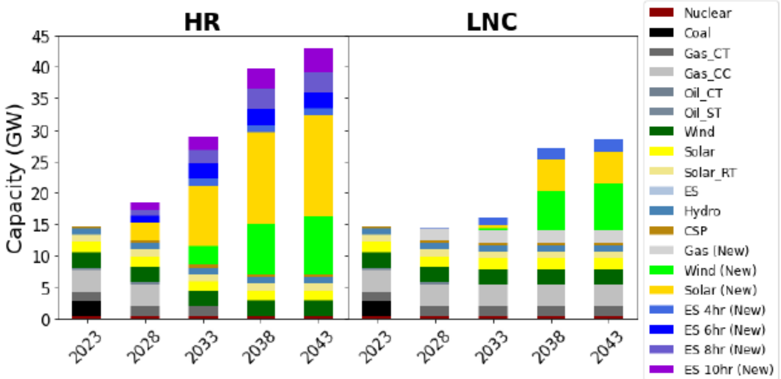
Scenarios

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.

Conclusions & Next Steps

- Coordination of planning tools will provide more insights into future investment solutions to achieve 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
  - Incorporate extreme events or tight margin time periods in the CEP model

Acknowledgements

We gratefully acknowledge:

- ***PNM Integrated Resource Planning Group***: Nick Phillips, Sarah Baxley, Shane Gutierrez
- ***Sandia National Laboratories***: Atri Bera, Walker Olis, Andres Lopez, Ray Byrne (Energy Storage Dept. Manager), Tu Nguyen (Energy Storage Analytics Lead)
- Funding from the ***DOE Office of Electricity - Energy Storage Program*** under the direction of Dr. Imre Gyuk
- Additional Collaborators: Andrew Benson (Now with Kairos Power), Joydeep Mitra (Michigan State University)

Questions?

Cody Newlun (cjnewlu@sandia.gov)