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RPAC Meeting #4: Resource Adequacy & Portfolios

February 25, 2026

Agenda

1. Opening/Introductions
2. PRM & ELCC study
3. Break
4. Feedback Review & RPAC Portfolios
5. Wrap-Up

Introductions

- Your name
- Who you represent

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Planning Reserve Margin (PRM) & Effective Load Carrying Capability (ELCC) Study

Tucson Electric Power PRM and ELCC Study

Prepared for UNSE Resource Planning Advisory Council Meeting

Feb 25th, 2026

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Energy+Environmental Economics

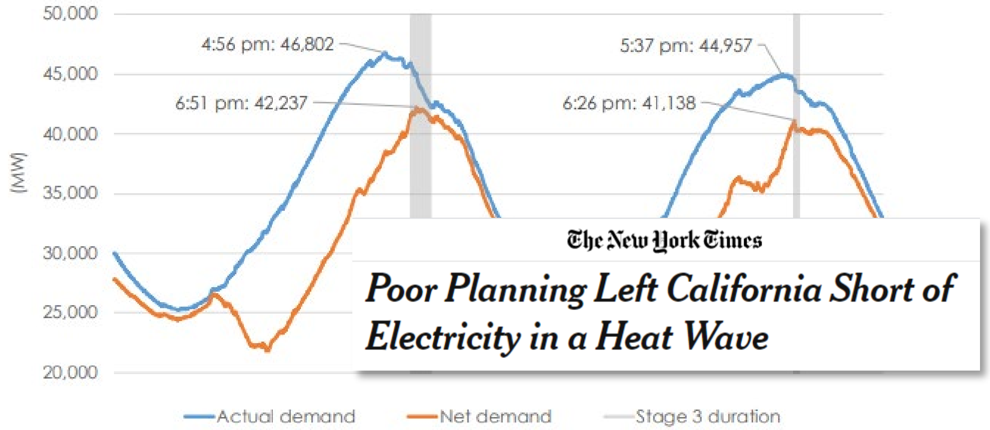
Agenda

- Introduction
- Resource Adequacy Best Practices
- Methods & Assumptions
- PRM and ELCC Results

Background

Resource adequacy is increasing in complexity – and importance

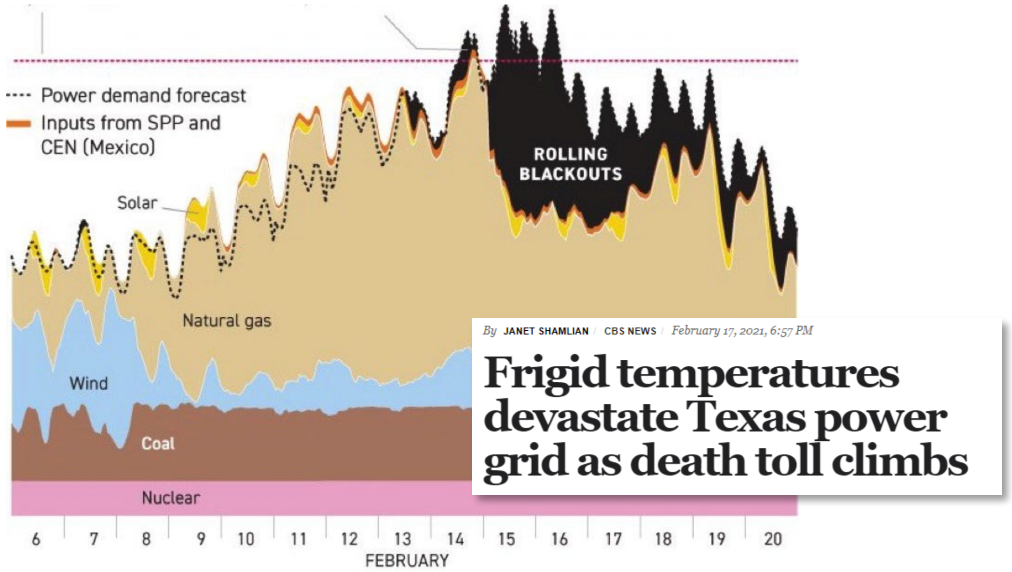
- **Transition towards renewables and storage introduces new sources of complexity in resource adequacy planning**
  - The concept of planning exclusively for “peak” demand is quickly becoming obsolete
  - Frameworks for resource adequacy must be modernized to consider conditions across all hours of the year – as underscored by California’s rotating outages during August 2020 “net peak” period
- **Reliable electricity supply is becoming increasingly important to society:**
  - Ability to supply cooling and heating electric demands in more frequent extreme weather events is increasingly a matter of life or death
  - Economy-wide decarbonization goals will drive electrification of transportation and buildings, making the electric industry the keystone of future energy economy



The New York Times

Poor Planning Left California Short of Electricity in a Heat Wave

Graph source: http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf



By JANET SHAMLIAN | CBS NEWS | February 17, 2021, 6:57 PM

Frigid temperatures devastate Texas power grid as death toll climbs

Graph source: https://twitter.com/bcshaffer/status/1364635609214586882

Study purpose

- **TEP retained E3 to conduct an RA study to establish PRM requirement and ELCC values for use in the development of TEP and UNSE's upcoming IRPs**
- **This study was built on E3's previous study for TEP as well as data sets developed as part of an ongoing effort to update E3's study "Resource Adequacy in the Desert southwest"**
- **Relatively to the last analysis in 2023, the major updates include:**
  1. Updates to TEP and UNSE's load forecasts (including updated outlook for new large customers) and existing resource portfolio (based on recent RFP outcomes)
  2. Additional granularity in quantification of ELCC values to better capture dynamic of saturation effects
  3. Independent technology ELCCs for TEP and UNSE systems separately

Resource Adequacy Best Practices

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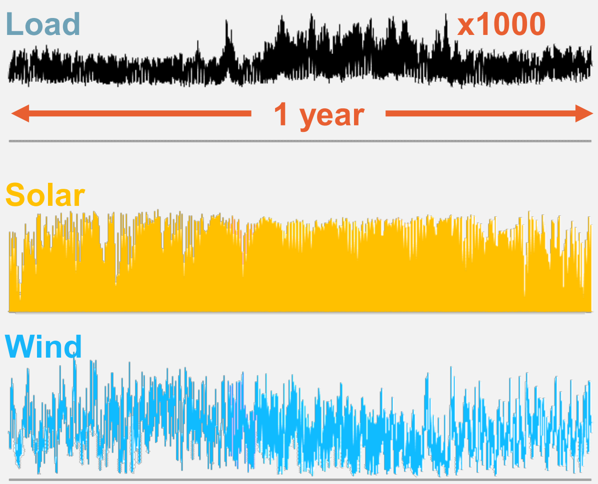
Planners are increasingly using LOLP models to support enhancements to resource adequacy

Part 1: Model + Data Development

Develop a robust dataset of the loads and resources, typically in a loss of load probability (LOLP) model

LOLP modeling evaluates resource adequacy across all hours of the year under a broad range of weather conditions

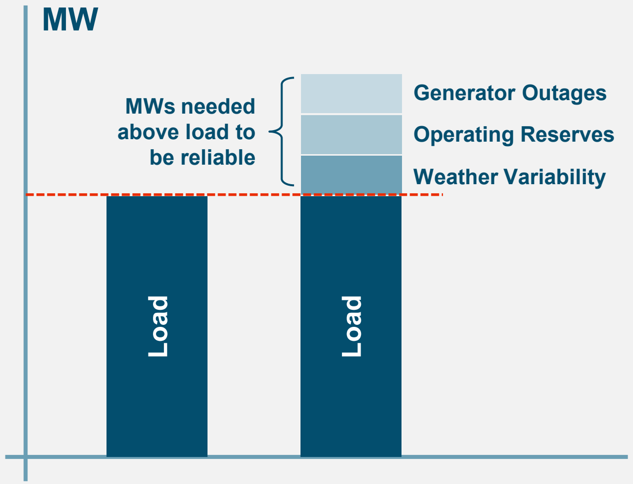


Robust probabilistic models + datasets are the foundation of any resource adequacy analysis

Part 2: Need Determination

Identify the Total Reliability Need to achieve the desired level of reliability

Factors that impact the amount of effective capacity needed include load & weather variability, operating reserve needs

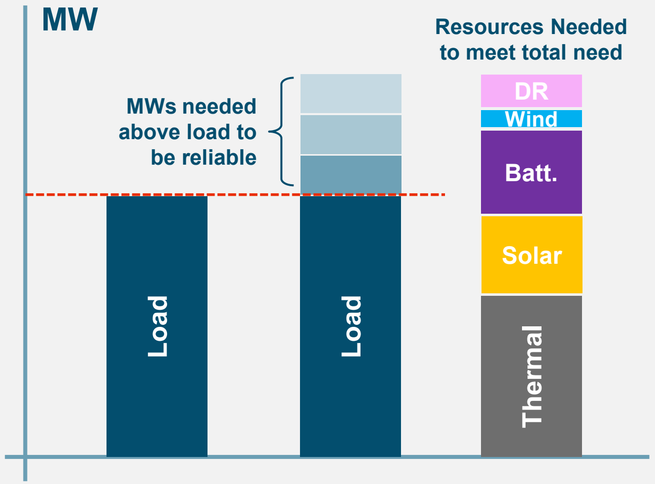


The total reliability need is calculated to meet a target reliability standard (e.g. 0.1 LOLE)

Part 3: Resource Accreditation

Calculate resource capacity contributions

Measures a resource's contribution to reliability needs relative to target reliability, accounting for performance across all hours



Resource accreditation determines how much each resource counts towards the total reliability need

Using ELCC to accredit resource contribution to system needs

- **Effective Load Carrying Capability (ELCC) represents the equivalent "perfect" capacity that a resource provides in meeting the target reliability metric (e.g., 0.1 day/year LOLE)**
- **ELCC is a <u>technology-agnostic</u> metric of capacity value and accounts for all factors that can limit availability:**
  - Energy availability
  - Hourly variability in output
  - Duration and/or use limitations
  - Temperature-related de-rates and outage rates
  - Correlated outage risk…
- **Calculation of ELCC requires iterative use of LOLP modeling:**

1 **Calculate existing system reliability and tune the system to the target**

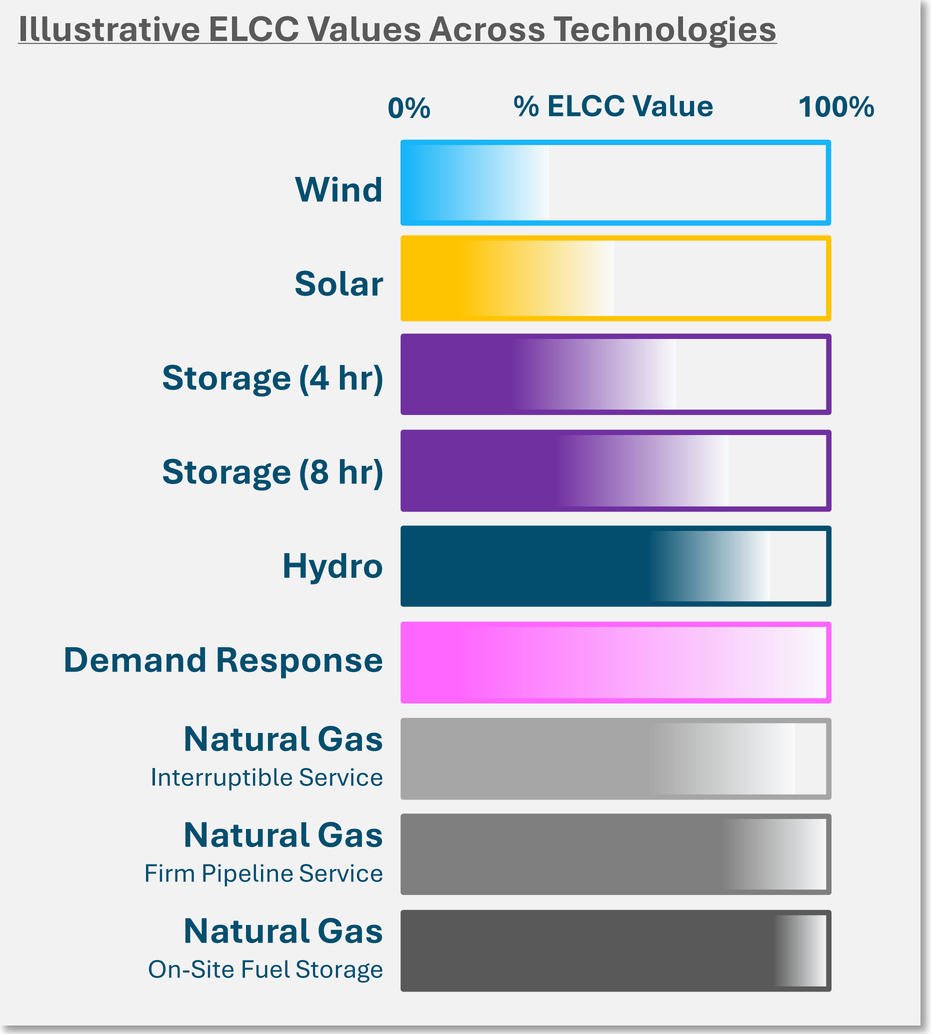
2 **Add desired resource to portfolio**

Addition of new source of generation will increase reliability relative to measurement in Step 1

3 **Remove perfect capacity until target reliability is restored**

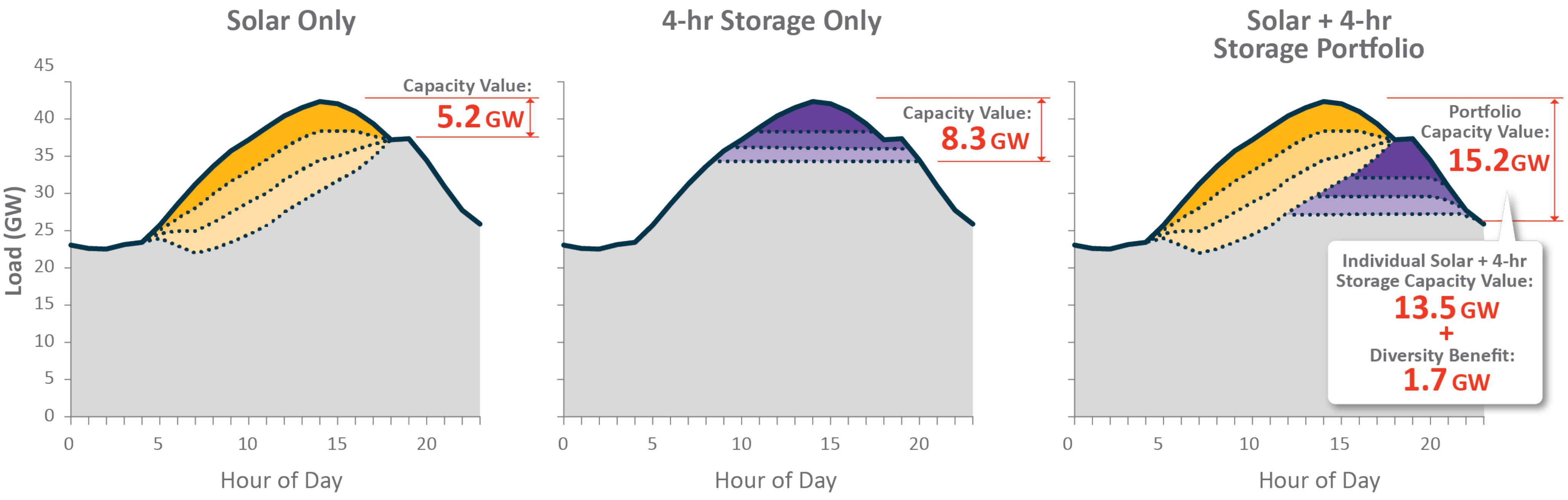
Removal of perfect capacity results in decrease in reliability until original target is met

A resource's ELCC is equal to the amount of perfect capacity removed from the system in Step 3



ELCC captures diversity benefits among technologies

- Resources with complementary characteristics produce the opposite effect, synergistic interactions (also described as a "diversity benefit")
- As penetrations of intermittent and energy-limited resource grow, the magnitude of these interactive effects will increase and become non-negligible



Methodology and Input Assumptions

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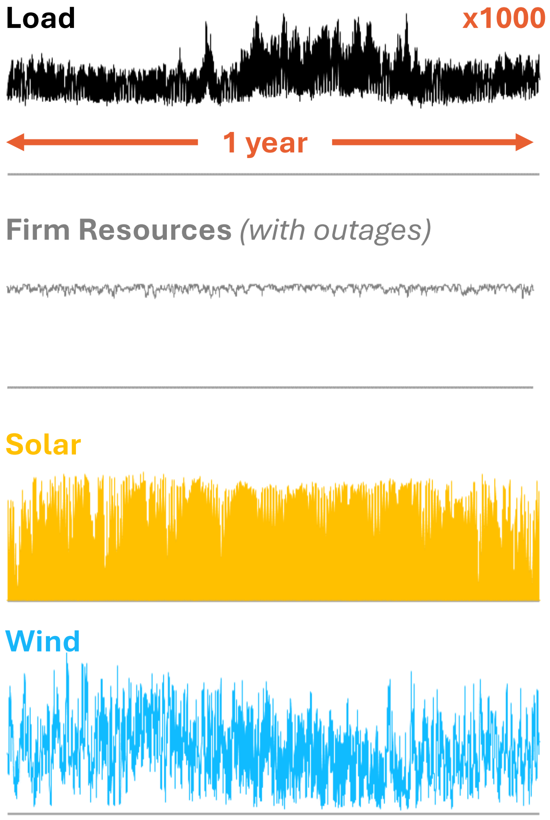
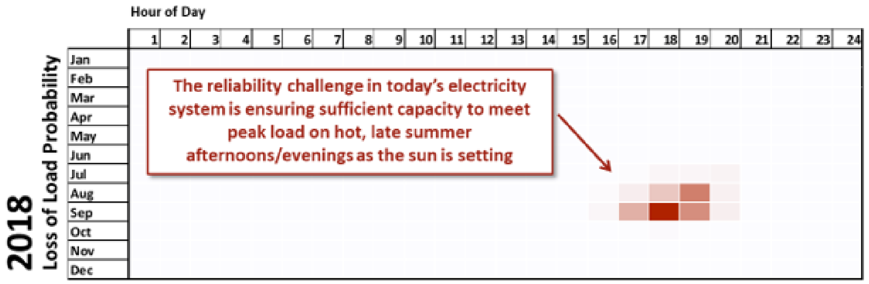
Setting up E3's RECAP model

- **E3's Renewable Energy Capacity Planning (RECAP) model is a probabilistic method to consider system reliability across a wide range of load and weather conditions**
- **Monte Carlo simulations consider system operations across a range of conditions**
  - Broad range of loads & renewables
  - Randomly simulated plant outages
  - Dispatch of use-limited resources
- **Model results include:**
  - Loss of load expectation (LOLE) and other reliability statistics
  - PRM requirements
  - ELCCs of different resources

Monte Carlo simulation of loads, renewable profiles, and generator outages used to simulate 1,000 years of plausible system conditions

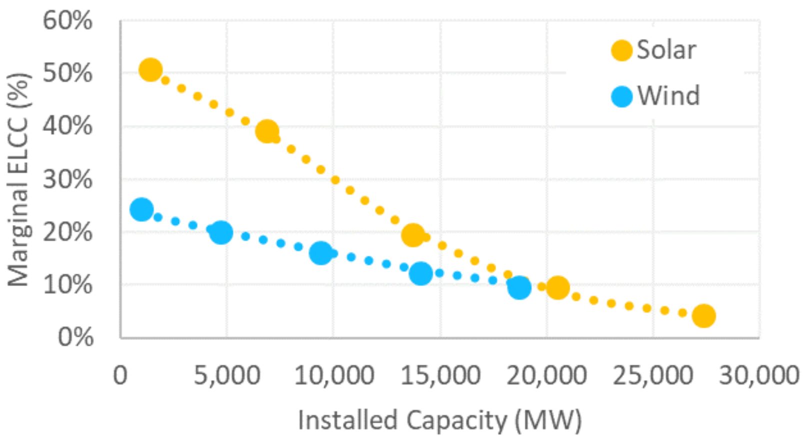


System reliability measured relative to "one day in ten year" standard; periods of high loss of load probability identified



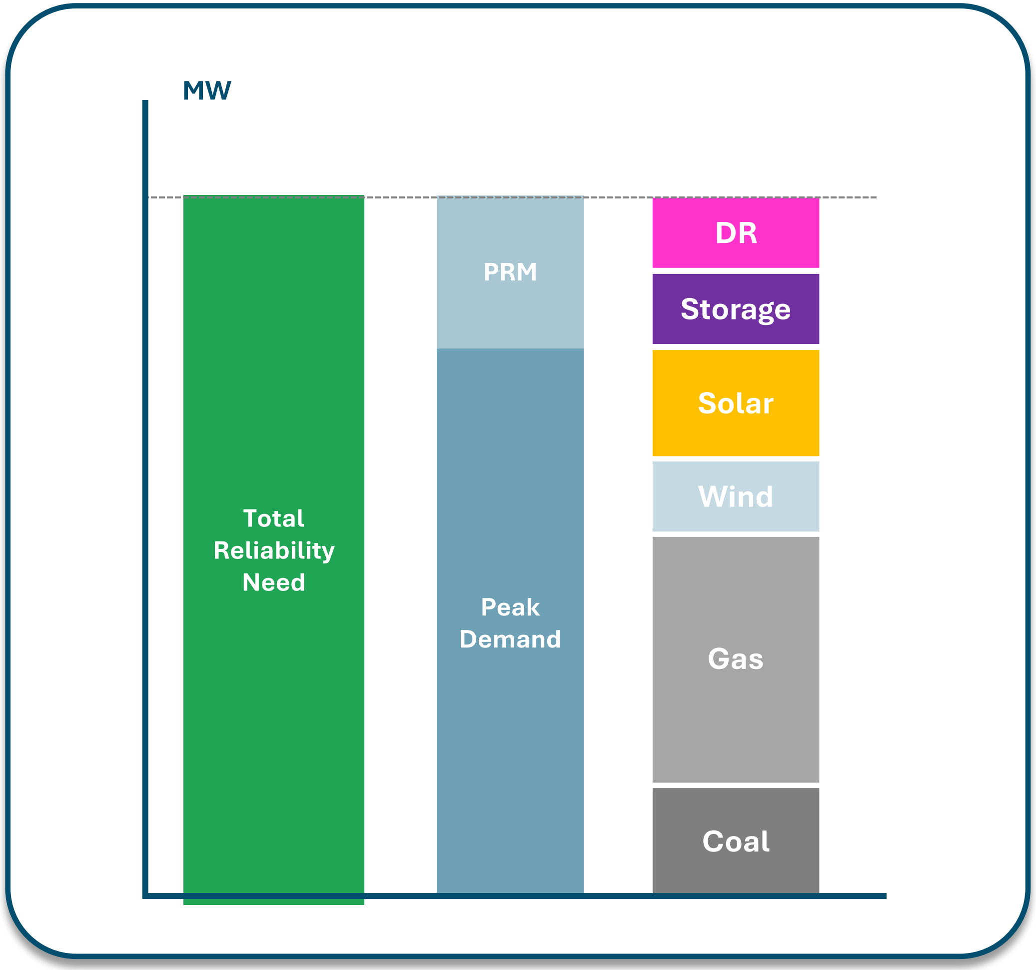
The reliability challenge in today's electricity system is ensuring sufficient capacity to meet peak load on hot, late summer afternoons/evenings as the sun is setting

Effective load carrying capability (ELCC) for a wide range of types of resources evaluated



Example RECAP result from *Long-Run Resource Adequacy under Deep Decarbonization Pathways for California* (Calpine, 2019)

Using RECAP for Need Determination and Resource Accreditation



Need Determination Deliverable:

Total Reliability Need measured in ICAP, converted to an ***PRM target*** for UNSE +TEP system

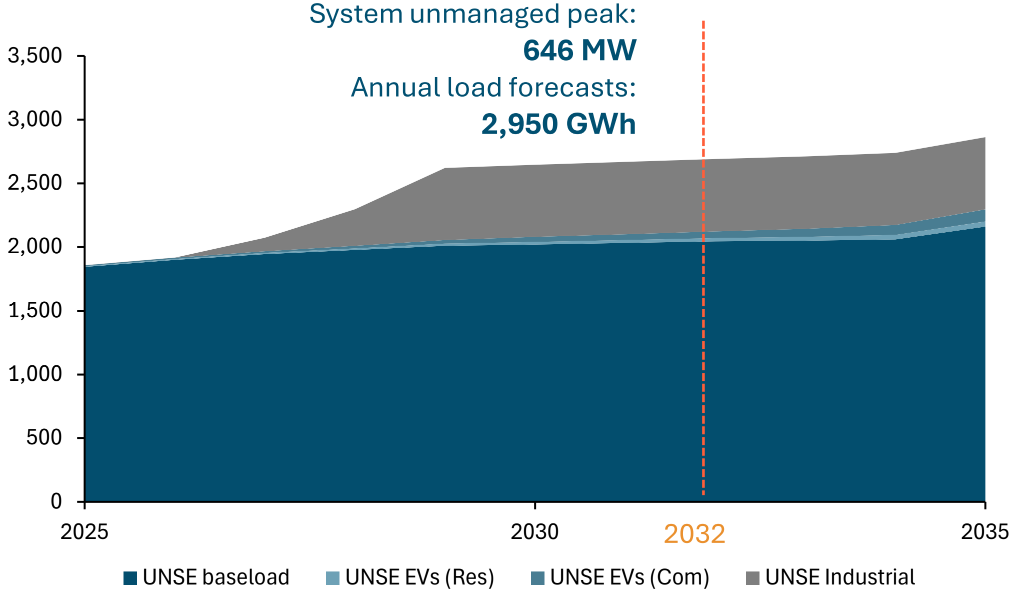
Resource Accreditation Deliverable:

1. **Static capacity value provided by *existing and committed resources* in the portfolio**
   - Summer net dependable capacity for thermal resources
   - ELCC for existing renewable and storage resources
2. **Dynamic capacity accreditation for *generic resources* evaluated in IRP analyses (changes with penetration)**
   - Incremental wind curves
   - Incremental Solar – Storage surfaces

UNSE Loads and Existing Resources

UNSE Energy Forecast

GWh



- Load among existing end uses projected to remain relatively flat (includes impacts of energy efficiency and behind-the-meter solar)
- Significant increases in load projected in 2027 as a result of new Hermosa mine coming online

UNSE Total Capacity by Type, 2025 & 2032 (MW)

	2025	2032	Change
Coal *(summer)*	-	-	-
Natural Gas *(summer)*	267	431	+164
Wind	10	0	-10
Utility-scale Solar	97	96	-1
Battery Storage	-	-	-
Demand Response	-	-	-
Total	**374**	**527**	**+153**

Key portfolio changes

- New natural gas resources
- Existing wind retirement (-10 MW Kingman Wind)

A Rich Temporal Library of Load & Renewable Profiles

Profile	Primary Source(s)	Weather Conditions Captured	Notes
Loads	**UNSE** Hourly Historical Load **ERA5 Land** Historical Weather Data	2020 2024 1970 2024	• Neural network regression used to back-cast hourly load patterns under broad range of weather conditions using recent historical load data (2017-2024 for TEP, 2020-2024 for UNSE) and long-term weather data (1970-2024) • Historical shape scaled to match future forecasts of regional energy demand • Shapes for load modifiers (e.g., transportation electrification) layered on top of neural network results
Wind	**NREL** WIND Toolkit	2007 2012	• Profiles for **existing wind resources** simulated based on plant locations, known characteristics (e.g., hub height & power curve) • Profiles for **additional wind resources** simulated based on generic locations chosen by E3 with input from TEP
Solar	**NREL** System Advisor Model	1998 2022	• Profiles for **existing utility-scale solar resources** simulated based on plant locations, known characteristics (tracking vs. tilt, inverter loading ratio) • Profiles for **additional utility-scale solar resources** simulated based on generic locations and technology characteristics chosen by E3 with input from TEP • Profiles for **behind-the-meter/distributed solar** simulated for TEP/UNSE service area

Planning Reserve Margin Requirement

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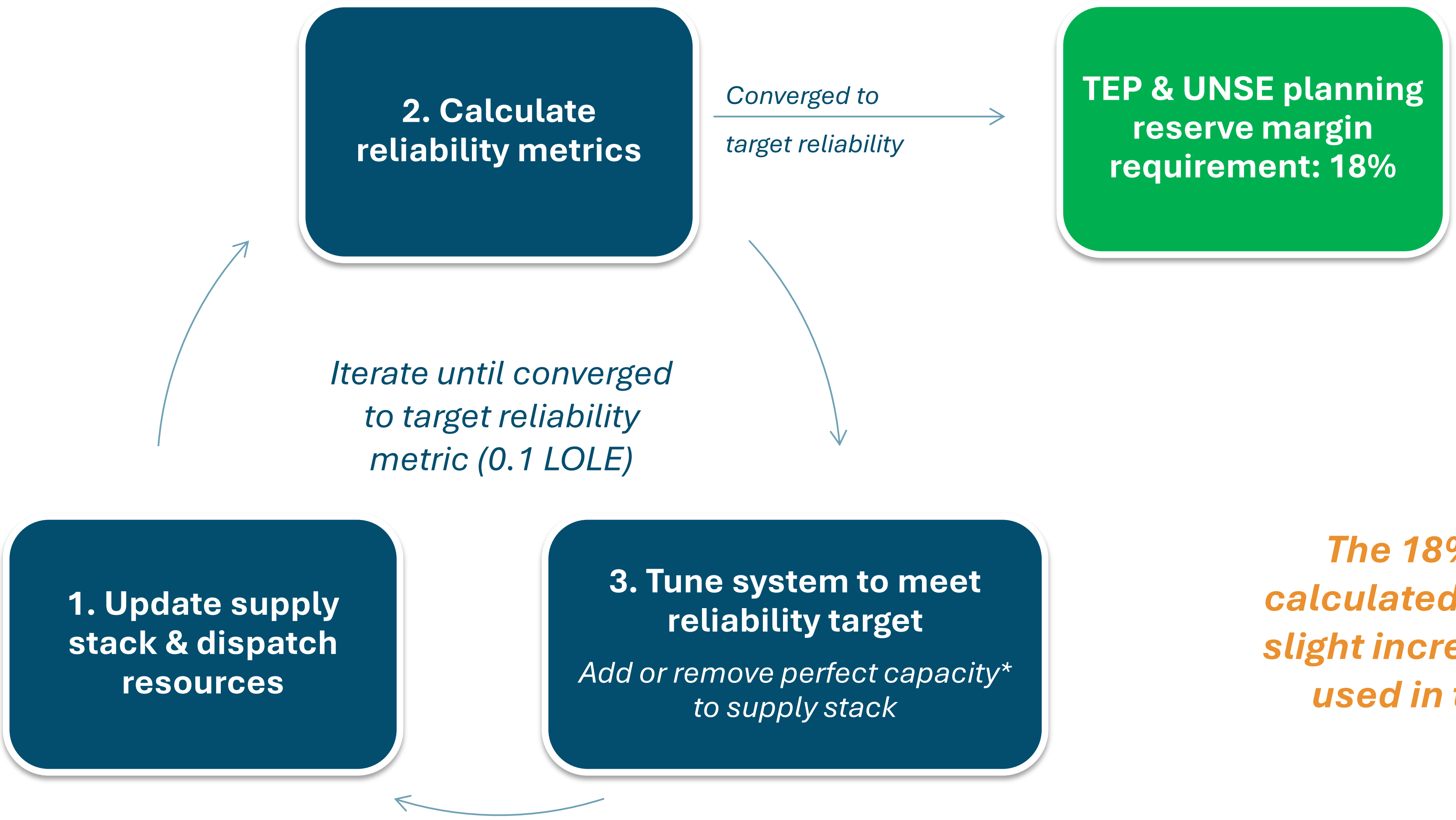
Calculating Target PRM using LOLP Modeling



2. Calculate reliability metrics

Converged to target reliability

TEP & UNSE planning reserve margin requirement: 18%

Iterate until converged to target reliability metric (0.1 LOLE)

1. Update supply stack & dispatch resources

3. Tune system to meet reliability target

Add or remove perfect capacity to supply stack*

The 18% PRM requirement calculated in this study reflects a slight increase to the assumption used in the 2023 IRP (16.5%)

Illustrative Example of Tuning to Calculate the PRM Requirement*

Without tuning adjustment (system "as specified")

	Installed Capacity (MW)	Accredited Capacity (MW)**
Coal	0	0
Natural Gas	2,918	2,918
Wind	628	1,287
Solar	1,298	
Storage	1,030	
DR	10	
Tuning Adjustment	0	0
Total Capacity (MW)		**4,205**
Median Peak Demand (MW)**		3,779
Achieved PRM (%)		**13%**
Loss of Load Expectation (days/yr)		**1** ☒

With tuning adjustment (calibrated to 0.1 days/yr)

	Installed Capacity (MW)	Accredited Capacity (MW)**
Coal	0	0
Natural Gas	2,918	2,918
Wind	628	1,287
Solar	1,298	
Storage	1,030	
DR	10	
Tuning Adjustment	+267	+267
Total Capacity (MW)		**4,472**
Median Peak Demand (MW)**		3,779
Achieved PRM (%)		**18%**
Loss of Load Expectation (days/yr)		**0.1** ☑

* Results shown for joint system (TEP & UNSE), capturing benefits of existing load and resource diversity between the two systems; illustrative resource portfolio includes existing & committed resources and generic renewable & storage additions from previous IRP

** Thermal resources are accredited at summer net dependable capacity; renewables, storage, and DR are accredited using ELCC

*** The median peak demand outputs from RECAP differ slightly (<2% difference) from sum of UNSE and TEP forecasts as RECAP captures the coincident peak from all load components in two systems

UNSE Current Load Resource Balance in 2032

UNSE Load-Resource Balance in 2032

Existing & Committed Resources

	Installed Capacity (MW)	Accredited Capacity (MW)
Median Peak Demand (MW)		646
PRM Requirement (%)		18%
PRM Requirement (MW)		**762**
Coal	0	0
Natural Gas	431	431
Wind	0	0
Solar	96	39
Storage	0	0
DR	0	0
Tuning Adjustment	0	0
Total Capacity (MW)		**470**
Capacity Shortfall (MW)		**292**

- **In 2032, UNSE's forecasted peak demand is 646 MW, resulting in a total requirement for accredited capacity of 762 MW at 18% PRM**
- **UNSE's existing portfolio of resources provides 470 MW of accredited capacity towards the PRM requirement**
  - Includes existing resources that will remain in UNSE's portfolio and resources under development with executed contracts
- **Maintaining a reliability standard of 0.1 days per year would require procurement of an additional 292 MW of accredited capacity**
  - This serves as the starting point for the ELCC analysis

Effective Load Carrying Capability Results

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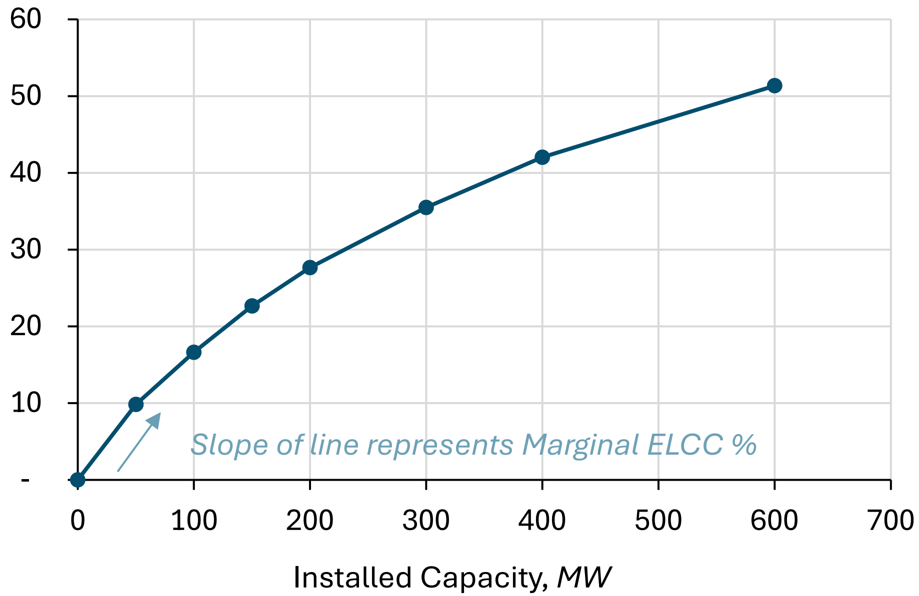
Capacity Value for Generic UNSE Wind Additions

Cumulative Wind ELCC

Perfect MW



Cumulative and Marginal Wind ELCC

Wind Capacity MW	Cumulative ELCC (MW)	Average ELCC(%)	Marginal ELCC(%)
-	-	-	-
50	10	20%	20%
100	17	17%	14%
150	23	15%	12%
200	28	14%	10%
300	35	12%	8%
400	42	11%	7%
600	51	9%	5%

Cumulative ELCC (MW) represents total capacity contribution of the incremental resources

Adding more resource capacity brings higher capacity value

Average ELCC (%) represents percentage ELCC of the total capacity contribution of the incremental resource

Adding more resource capacity brings higher capacity value

Marginal ELCC (%) for wind measures how effective the additional wind can increase the portfolio ELCC

*Adding the initial **50 MW** adds **10 MW** of incremental value, equivalent to a 20% marginal ELCC*

Marginal ELCC decline to single digit after 200 MW penetration – at higher penetrations, loss-of-load risks shift to periods of low wind

Note: Generic curve wind resources are evaluated based on existing thermal portfolio, without wind

Cumulative Portfolio Capacity Value provided by Generic Solar and Storage Addition in UNSE

Cumulative portfolio ELCC of Incremental Resource Additions

Perfect MW

Increasing Storage Capacity

Increasing Solar Capacity

		4-hour Battery Storage Capacity (MW)									
		-	50	100	150	200	250	300	400	500	600
Solar Capacity (MW)	-	-	48	92	137	175	192	202	212	219	227
	50	9	56	101	145	187	209	218	229	236	243
	100	13	60	105	150	194	221	231	243	250	258
	150	15	63	108	152	196	230	243	256	264	271
	200	17	64	110	154	198	235	252	267	276	283
	250	18	65	111	156	200	238	261	278	286	294
	300	19	66	112	157	201	240	268	288	296	305
	400	20	68	114	159	203	242	276	303	316	325
	500	22	69	115	160	204	244	280	311	325	336
	600	24	71	117	162	206	246	281	314	332	343

200 MW 4-hr Storage and 300 MW Solar can provide 201 MW perfect capacity toward reliability need

As the penetration of either resource increases, the total capacity contribution of the incremental resources also increases, reflecting their additional reliability contribution to the system

Note: Generic surface resources are evaluated beyond existing and committed solar *(96MW)* ***and zero storage***

Marginal ELCC for UNSE Solar

Marginal ELCC of Incremental Solar Additions

% ELCC of marginal storage additions

Increasing Storage Capacity

Increasing Solar Capacity

		4-hour Battery Storage Capacity (MW)									
		-	50	100	150	200	250	300	400	500	600
Solar Capacity (MW)	-	-	-	-	-	-	-	-	-	-	-
	50	18%	17%	18%	17%	23%	34%	32%	33%	33%	32%
	100	8%	8%	8%	7%	14%	25%	27%	28%	28%	30%
	150	5%	4%	5%	5%	5%	17%	23%	26%	29%	27%
	200	3%	3%	4%	5%	4%	10%	19%	23%	24%	24%
	250	3%	2%	2%	3%	3%	6%	17%	22%	21%	21%
	300	2%	3%	2%	2%	3%	5%	15%	20%	20%	23%
	400	2%	1%	2%	2%	2%	2%	8%	15%	19%	20%
	500	2%	2%	2%	1%	2%	2%	4%	8%	10%	11%
	600	2%	1%	2%	2%	2%	2%	2%	3%	7%	7%

Diminishing solar ELCCs at higher penetrations

Marginal solar ELCC is high in the first 50 MW addition but decline to single digit quickly afterwards ("diminishing returns")
As more solar is added to the system, periods of risk move to low-solar generation hours, reducing its ELCC

At higher penetration of storage, marginal ELCC of solar increases ("diversity benefit")
Storage can charge from excess solar in the mid day and discharge in sunset hours / late afternoons when solar output is low, creating a positive interactive benefit

Note: Generic surface resources are evaluated beyond existing and committed solar** (96MW) **and zero storage

Marginal ELCC for UNSE Storage

Marginal ELCC of Incremental Storage Additions

% ELCC of marginal storage additions

Increasing Storage Capacity

Increasing Solar Capacity

		4-hour Battery Storage Capacity (MW)									
		-	50	100	150	200	250	300	400	500	600
Solar Capacity (MW)	-	-	95%	90%	89%	77%	33%	20%	10%	7%	7%
	50	-	95%	90%	88%	84%	43%	18%	11%	7%	7%
	100	-	95%	90%	89%	89%	54%	20%	12%	7%	8%
	150	-	95%	91%	88%	88%	67%	26%	13%	9%	7%
	200	-	95%	92%	89%	87%	73%	35%	15%	9%	7%
	250	-	95%	91%	90%	87%	77%	46%	17%	8%	7%
	300	-	95%	91%	90%	89%	79%	56%	20%	8%	9%
	400	-	95%	92%	90%	87%	79%	68%	27%	12%	9%
	500	-	95%	92%	89%	89%	80%	72%	31%	15%	10%
	600	-	95%	91%	90%	87%	82%	70%	32%	18%	11%

Similar diminishing return is observed in storage marginal ELCC (84% to 43% after 200 MW addition)

As more of the same duration (4-hr) storage is added to the system, system increasingly need resources that can sustain output for longer duration

Similarly, at higher penetration of solar, marginal ELCC of storage diminishes more slowly

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Note: Generic surface resources are evaluated beyond existing and committed solar** (96MW) **and zero storage

Thank You

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Ruoshui Li, Ruoshui.li@ethree.com

Energy+Environmental Economics

Break - 10 minutes

Feedback Review & RPAC Portfolios

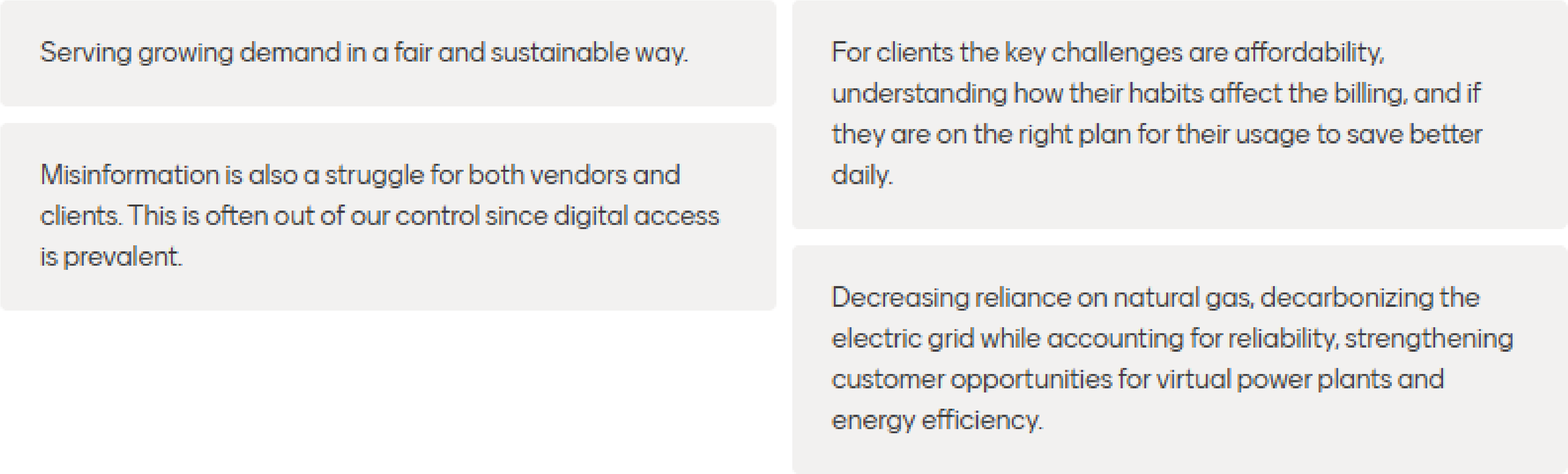
Planned Portfolio Refresher

Portfolio	Description
Technology Neutral	Least-cost analysis per Order 79589
Clean Energy Buildout	Includes only solar, wind, pumped hydro, geothermal, and nuclear as new resources
High Load Factor Customer Growth	Includes a load forecast that contains higher growth than the current forecast

RPAC Feedback on UNSE Portfolios

- UNSE shared an online survey requesting RPAC feedback
  - Only 2/3 responses
- Portfolio suggested by South32

What are the key challenges facing local electric utilities today?



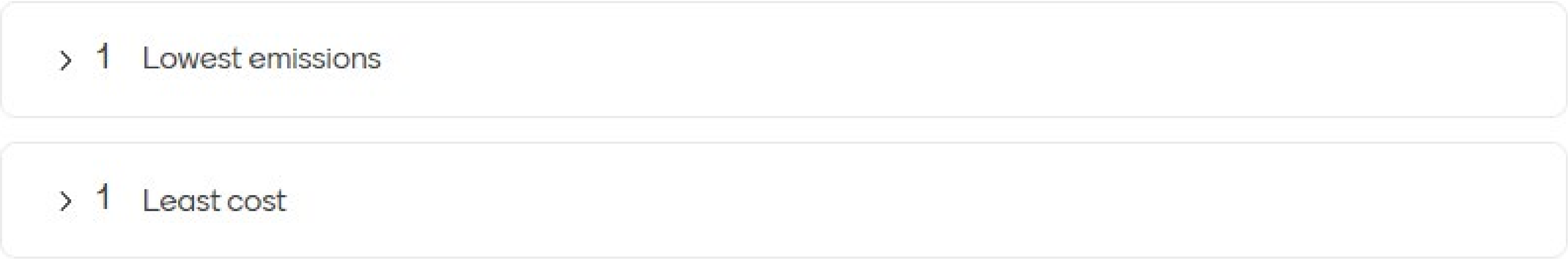
Serving growing demand in a fair and sustainable way.

Misinformation is also a struggle for both vendors and clients. This is often out of our control since digital access is prevalent.

For clients the key challenges are affordability, understanding how their habits affect the billing, and if they are on the right plan for their usage to save better daily.

Decreasing reliance on natural gas, decarbonizing the electric grid while accounting for reliability, strengthening customer opportunities for virtual power plants and energy efficiency.

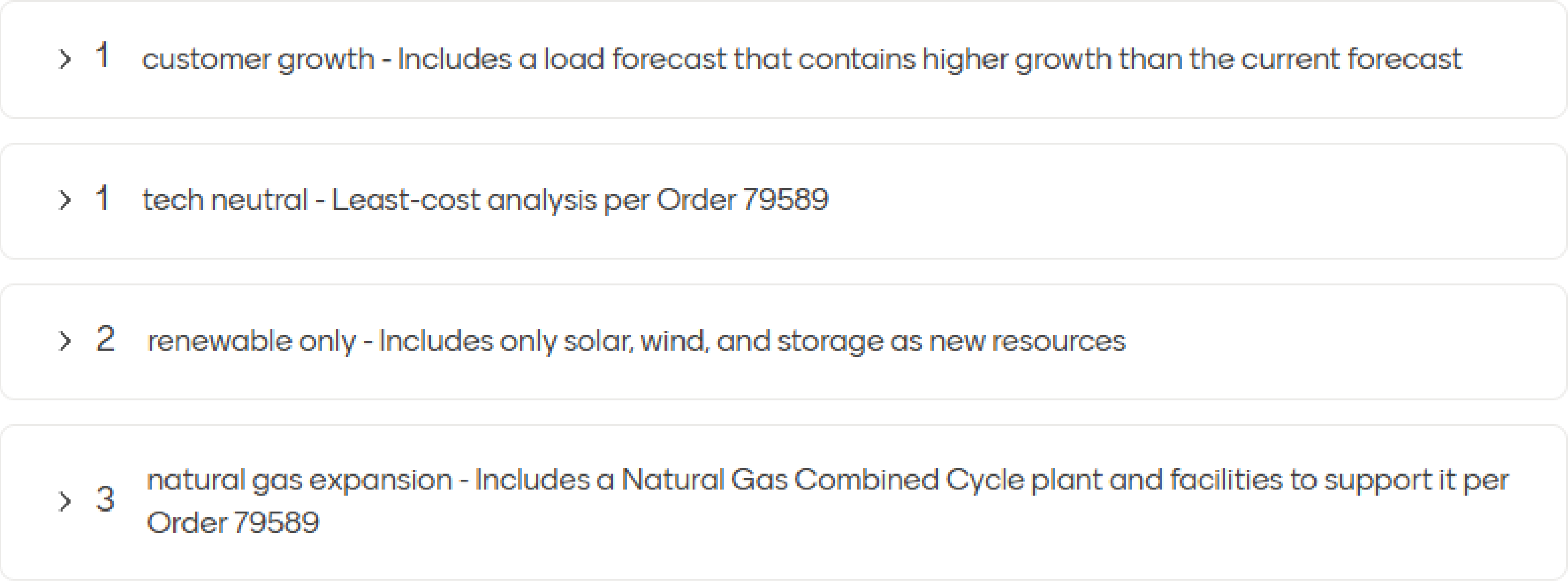
Priorities check – What is most important overall when it comes to resource planning?



› 1 Lowest emissions

› 1 Least cost

What is your initial prioritization of these potential portfolios?



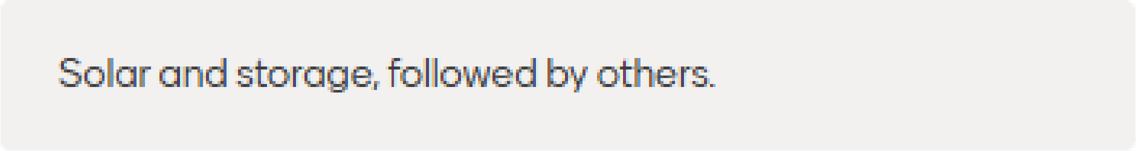
› 1 customer growth - Includes a load forecast that contains higher growth than the current forecast

› 1 tech neutral - Least-cost analysis per Order 79589

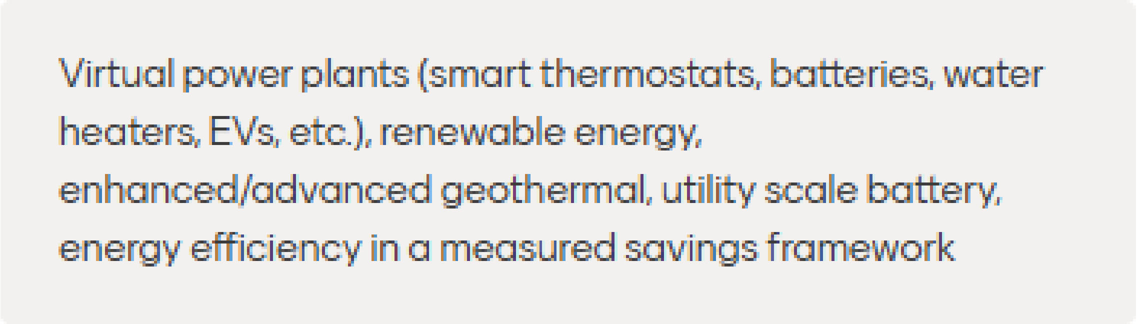
› 2 renewable only - Includes only solar, wind, and storage as new resources

› 3 natural gas expansion - Includes a Natural Gas Combined Cycle plant and facilities to support it per Order 79589

Focus on technology – Which technologies should UNSE prioritize?

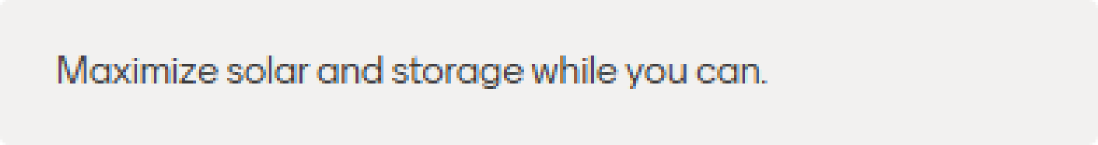


Solar and storage, followed by others.

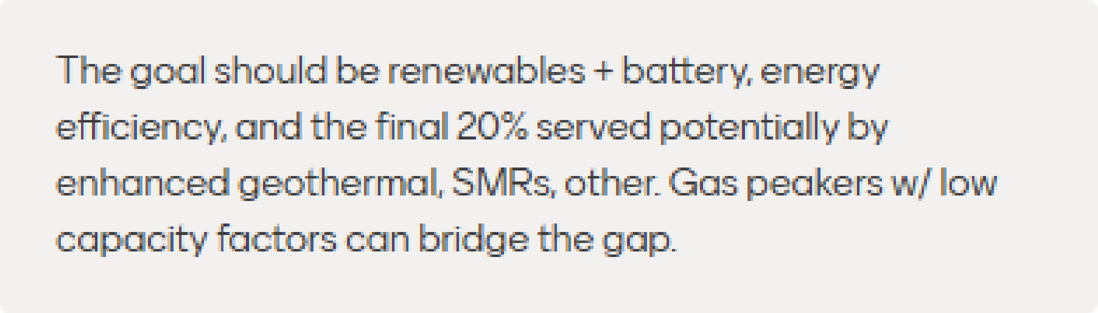


Virtual power plants (smart thermostats, batteries, water heaters, EVs, etc.), renewable energy, enhanced/advanced geothermal, utility scale battery, energy efficiency in a measured savings framework

Focus on energy mix – what’s a good approach?



Maximize solar and storage while you can.



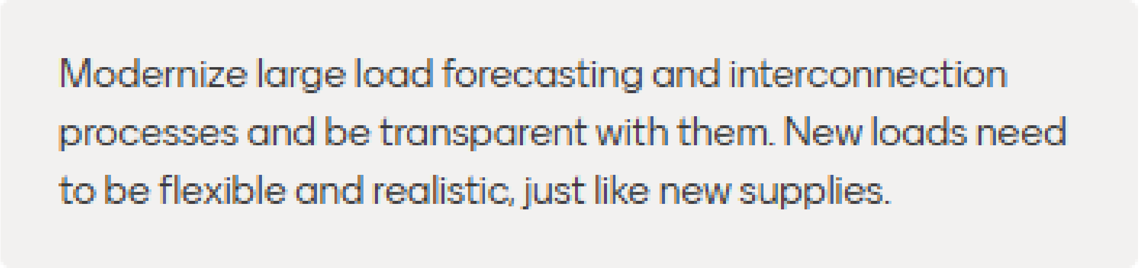
The goal should be renewables + battery, energy efficiency, and the final 20% served potentially by enhanced geothermal, SMRs, other. Gas peakers w/ low capacity factors can bridge the gap.

Focus on policy – What are you tracking?

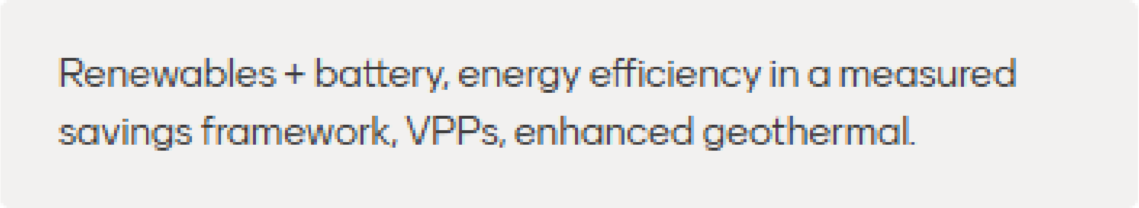
Load growth, renewable policies, cost allocation, rate design, gas pipelines.

ACC and SRP developments around energy efficiency, legislative bills on energy.

What is the best way to approach unprecedented demand?

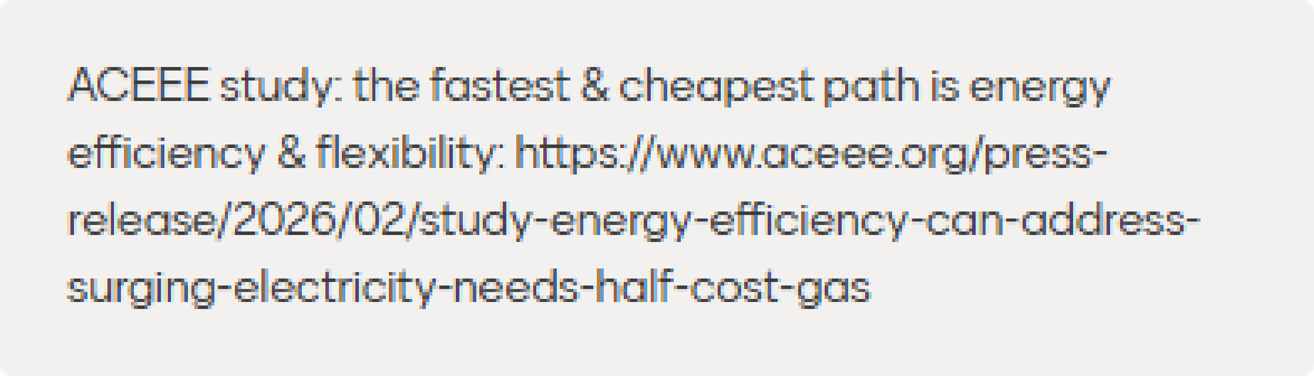


Modernize large load forecasting and interconnection processes and be transparent with them. New loads need to be flexible and realistic, just like new supplies.



Renewables + battery, energy efficiency in a measured savings framework, VPPs, enhanced geothermal.

What does UNSE need to know?



ACEEE study: the fastest & cheapest path is energy efficiency & flexibility: https://www.aceee.org/press-release/2026/02/study-energy-efficiency-can-address-surging-electricity-needs-half-cost-gas

RPAC Portfolio

- South32 has suggested a potential portfolio
- The Clean Energy/High Load portfolio would:
  - Model the same or similar load forecast to the High Load Factor Customer Growth portfolio
  - Include only solar, wind, storage, PSH, geothermal, and nuclear as new resources

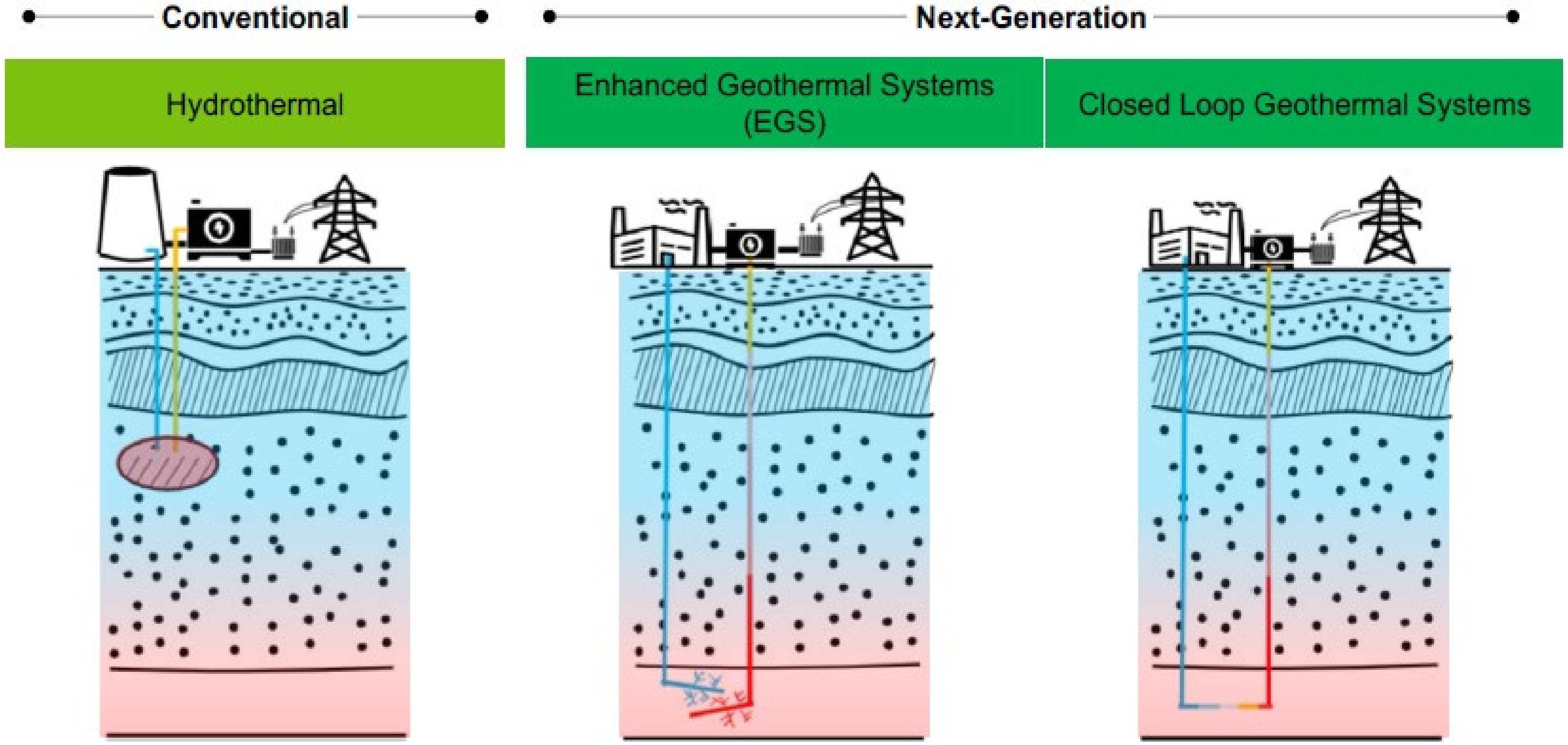
➢ Resource Deep Dives

Tucson Electric Power

- Advanced Geothermal Energy
- Advanced Nuclear Energy

Advanced Geothermal Energy

Promising Advancements But Many Unknowns



Conventional

Next-Generation

Hydrothermal

Enhanced Geothermal Systems (EGS)

Closed Loop Geothermal Systems

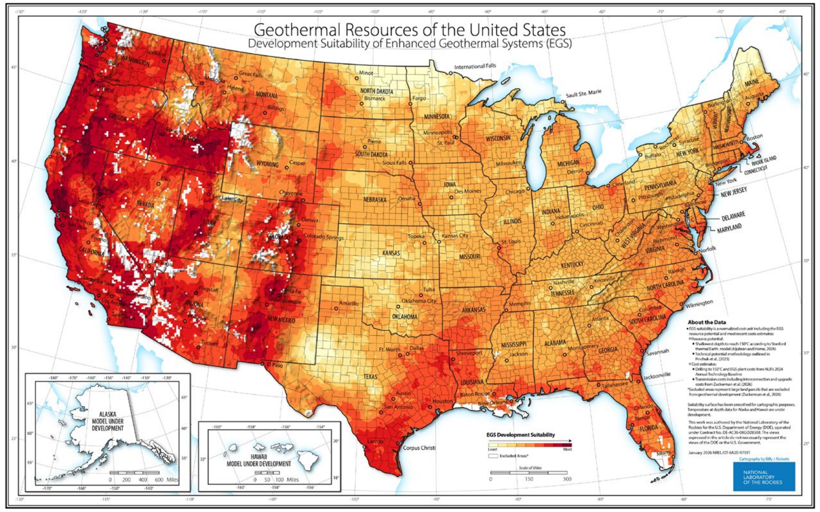
- Geothermal energy systems extract **heat from deep in earth's subsurface** and convert it to electricity by drawing a hot fluid from underground wells and processing it in a power plant.
- Recent advancements in "Enhanced" Geothermal Systems have made geothermal promising in **more areas.**

Advantages

- 24/7, fully dispatchable power
- Zero CO_2 emissions
- Short construction time
    - Uses technology and workforce adopted from oil & gas industry

Adoption Challenges

- High capital cost
- Not demonstrated in all geologies, including AZ
- Financial risk - Resource can degrade unpredictably once operational



Advanced Nuclear Energy

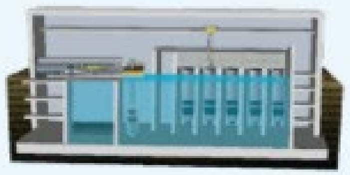
Decades of Progress in the Lab, Billion-Dollar Overruns in Reality

Advantages

- 24/7 power
- Zero CO_2 emissions
- Excellent safety record + improvements over legacy nuclear reactors

Adoption Challenges

- Long construction times
- High capital cost
- Siting & permitting
- Advanced reactors use a fuel (HALEU) that has no domestic supply chain
- US has lost nuclear know-how
  - Specialized workforce in short supply
  - Cost overruns and project delays

Microreactors *Range: 1 MW to 20 MW* Can fit on a flatbed truck, and are mobile and deployable.	*Small Modular Reactors* *Range: 20 MW to 300 MW* Can be scaled up or down by adding more units.	*Full-Size Reactors Range:* *300 MW to 1,000+MW* Can provide reliable, emissions-free baseload power.
		
• **Concept**	• Several companies are developing small reactors, but **none have been fully modularized** • First small reactor is under construction in Canada	• Three reactors built in the US in **25+ years**. • Two of these (Vogtle 3&4) were **7 years late** and **$17 billion over budget**

Next Meeting:

April 23rd

10am – 12pm