**ORIGINAL**

E000005523

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March 20, 2020

Commissioner Márquez Peterson
Arizona Corporation Commission
1200 W. Washington Street
Phoenix, AZ 85007

RE: Arizona Public Service Company (APS or Company)
In the Matter of Possible Modifications to the Arizona Corporation Commission's (Commission) Energy Rules
Docket No. RU-00000A-18-0284

Commissioner Márquez Peterson:

APS appreciates the opportunity to provide additional information in response to your March 12, 2020 letter in the above referenced docket. APS is providing two presentations to address your questions. The first presentation was delivered by Barbara Lockwood at the Energy Rules Workshop on March 11, 2020. The second presentation was prepared by E3 and shared with stakeholders during APS's IRP stakeholder process.

The analysis conducted by E3 outlines several scenarios that demonstrate the cost effectiveness of carbon-based clean energy goals compared to specific resource mandates. Several of these scenarios are illustrated on slides 44 through 53 of the presentation.

Please let me know if you have any questions.

Sincerely,

/s/ Rod Ross

Rodney J. Ross

RR/eml

c: Docket Control

**ACC - Docket Control - Received 3/23/2020 12:17 PM**
**ACC - Docket Control - Docketed 3/23/2020 1:11 PM**

**We're All In for Arizona:**

# Our Clean Energy Commitment

aps

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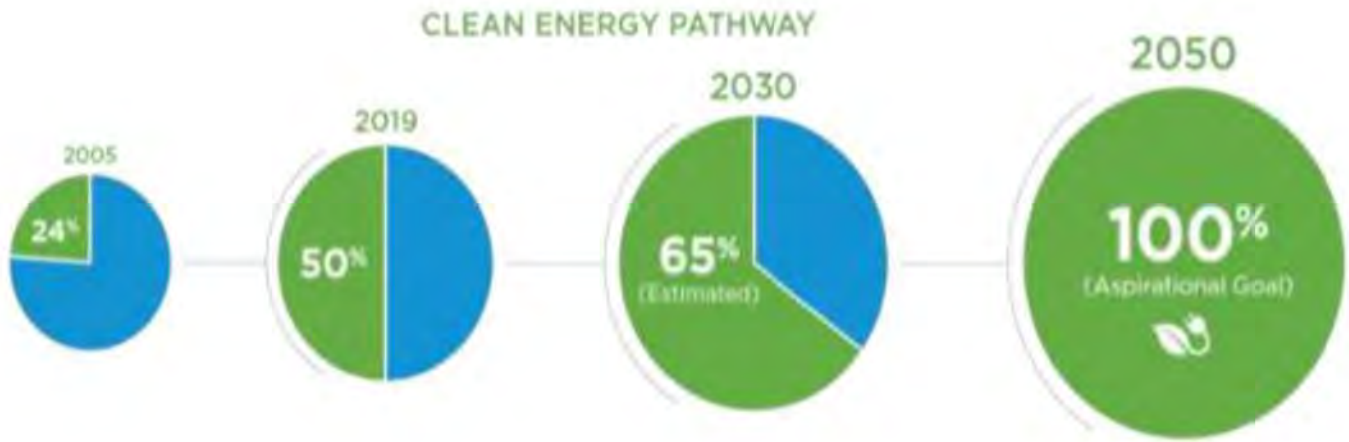
# Our Clean Energy Commitment




- A **2050 goal** to provide 100 percent clean, **carbon–free electricity**
- A **2030 target** of achieving a resource mix that is **65 percent clean energy**, with 45 percent of our generation portfolio coming from renewable energy
- A commitment to **end our use of coal–fired generation by 2031**

# Our Four Pillars

- ✓ Clean
- ✓ Reliable
- ✓ Affordable
- ✓ Customer-focused

# How We Will Get There

**Increasing Renewable and Clean Energy Resources**

300 – 500MW of additional renewable generation each year through 2030

**Counting on Palo Verde**

**Promoting Customer Technology and Energy Efficiency**

**Investing in Energy Storage**

**Managing Demand with a Modern Interactive Grid**

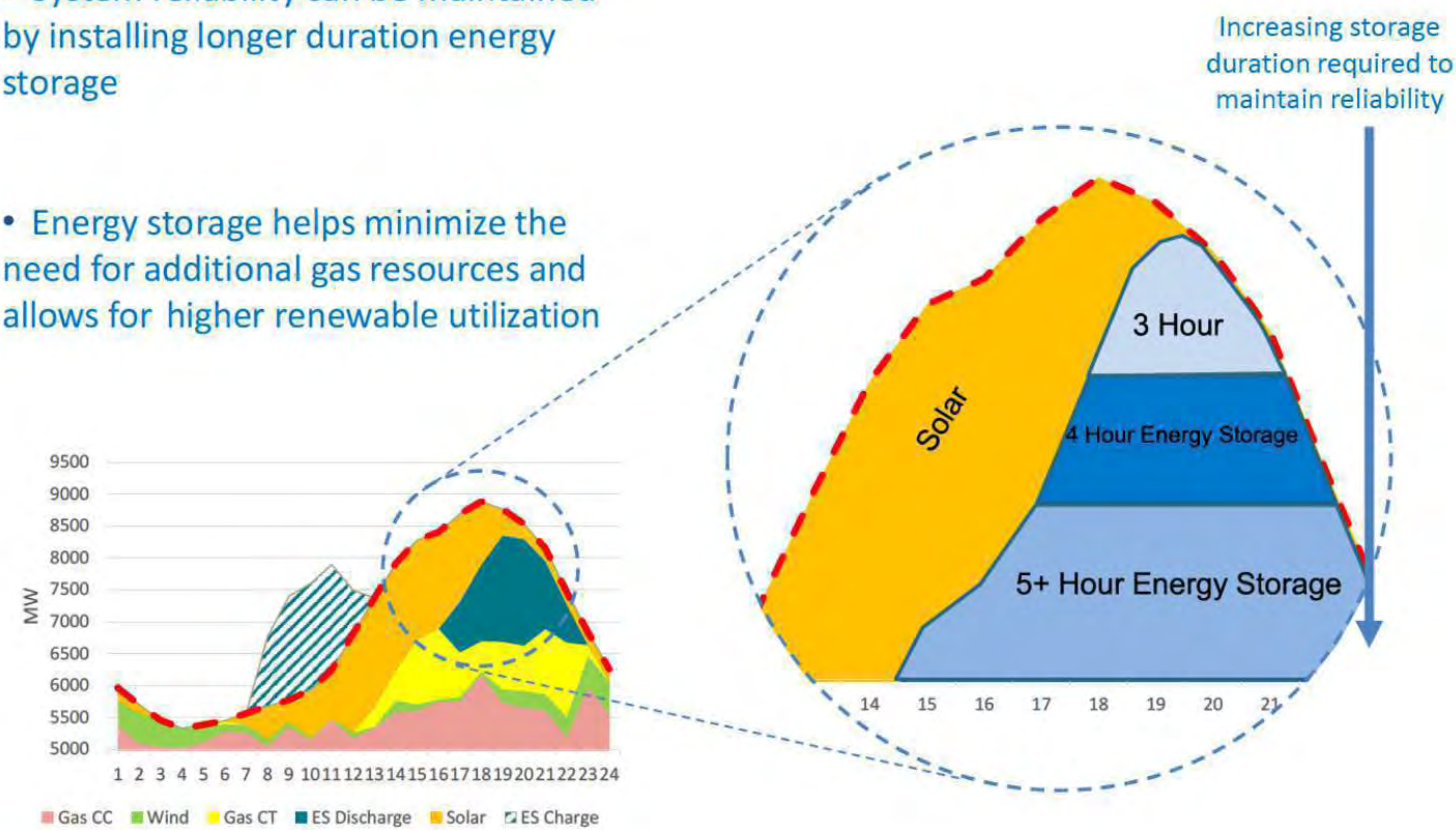
**Optimizing Regional Resources**

**Retiring Existing Coal Plants**

# Importance of Energy Storage

- System reliability can be maintained by installing longer duration energy storage

- Energy storage helps minimize the need for additional gas resources and allows for higher renewable utilization



# What it Will Take to Get There

## 1. Collaboration

Reaching 100 percent clean, carbon–free energy by 2050 will depend upon **critical input, support and partnership** with a variety of stakeholders, including customers, the Commission, state policymakers and other sectors of the Arizona economy

# What it Will Take to Get There

## 2. Innovation

APS will encourage policies that **enable market–based solutions,** and serve as a driving force behind energy research and development. We will continue to pursue the **advancement of new and emerging technologies**

# What it Will Take to Get There

## 3. A supportive policy environment

A regulatory environment that **encourages clean, affordable technologies, innovation and investment** is beneficial for customers, the communities we serve and our shareholders

Our plan is predicated on the **continuation of the current Arizona regulatory structure,** which represents the best opportunity to achieve a clean energy future without compromising reliability or affordability

**We believe robust public discussion promotes transparency and encourages sound public policy outcomes.**

**We also believe constructive outcomes on energy, cost recovery and utility investment opportunities are essential to achieving a clean energy future for Arizona.**

# Next Steps

- **Publish a report** that provides our perspective and further describes our commitment to clean energy
- Continue engagement with all stakeholders including advocates for low income customers, energy efficiency, and distributed generation, in support of our **2020 Integrated Resource Plan**
- Continue to **expand partnerships** with community organizations and research institutions
- Conduct **public discussions** about the **benefits of our commitment** to the broader Arizona economy
- **Engage with customers**, technology companies, and policy organizations, such as Advanced Energy Economy, to develop unique programs and solutions

# APS Response to Draft Rules

APS commends Commission staff for their efforts to develop these draft rules and looks forward to working with the Commission to ensure a reliable and affordable energy future for Arizona.

**APS Supports:**

- Consolidation of energy policies (IRP, RES, DSM) into a single comprehensive rule allows for better coordination
- Customer engagement and focus on utility and community impacts
- Frequency of interaction between Commission, stakeholders, and utility to ensure regular feedback
- Focus on near-term actions in a rapidly changing energy environment

# APS Response to Draft Rules

## Foundational Principle: Flexibility = Affordability

- Rapid pace of innovation demands a **flexible regulatory environment** that allows utilities to adopt technologies **based on customer need and affordability**, rather than a static and dated prescriptive mandates or standards
- Updates to Rules should consider the following:
  - Energy rules should recognize one-size-fits-all or standard-based policies may be inflexible to reliability and affordability needs of customers
    - Renewable energy and clean peak standards should be extremely flexible to reflect rapidly changing industry conditions (both customer usage and resource developments)
  - Clean resources and carbon reductions must be the focus of energy rules to allow for a broad set of energy solutions
  - Procurement process should be flexible and allow utilities to respond to changing technologies and markets
  - Consideration of tradeoffs such as affordability and potential for cost shifts must be evaluated prior to determining targeted goals

# Our Commitment

Here's what Arizona can expect from us:

- **We are putting our customers first**
- **We are working with our customers and other stakeholders to deliver a 100 percent clean energy future**
- **We are delivering affordable electricity Arizona can depend on**
- **We're all in for Arizona**

Energy+Environmental Economics

# APS IRP Stakeholder Screening Tool

## Final Analysis Results

**August 16, 2019**


Ren Orans, Managing Partner
Nick Schlag, Director
Lakshmi Alagappan, Director
Joe Hooker, Consultant
Xiaoxuan Hou, Consultant

# Table of Contents

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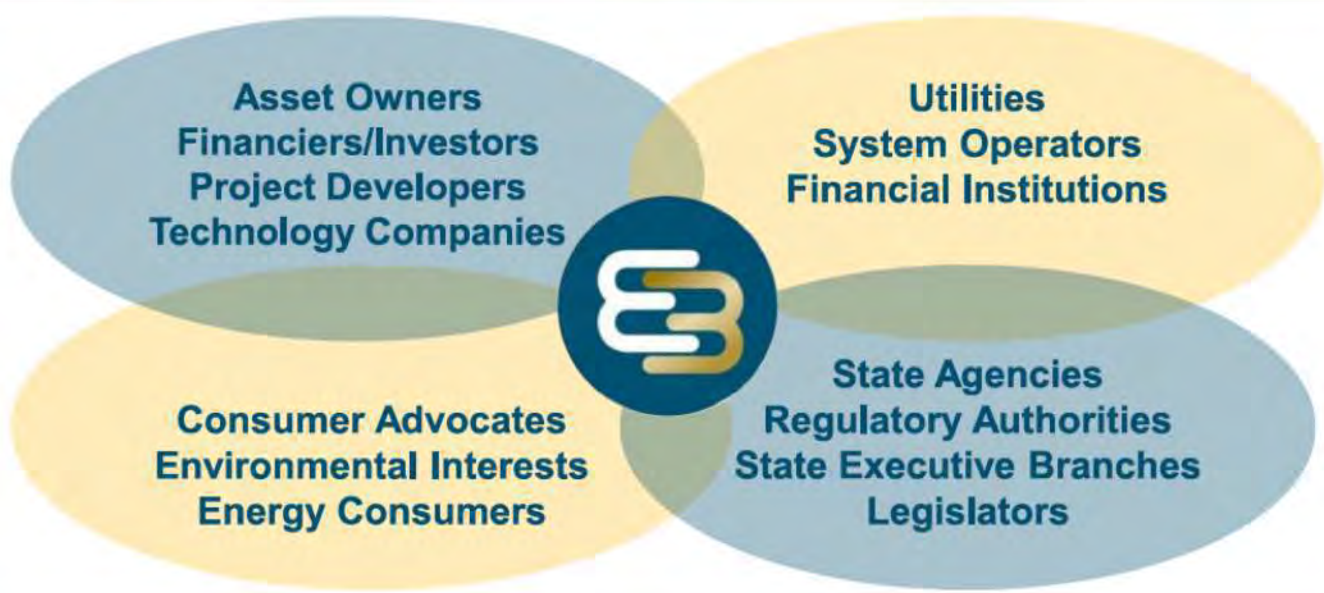
# Introduction

# About E3

- Founded in 1989, E3 is a leading energy consultancy with a unique 360-degree view of the industry
- E3 operates at the nexus of energy, environment, and economics
- Our team employs a unique combination of economic analysis, modeling acumen, and deep strategic insight to solve complex problems for a diverse client base



# Purpose of stakeholder engagement initiative

**E3 has worked with APS to engage stakeholders in a transparent scenario analysis exercise based on detailed analytics, with the objective of enabling stakeholders to test the impacts of various resource portfolios and policies before APS files its preliminary 2019 IRP**

**This initiative broadly encompassed three goals:**

1. Develop an Excel-based tool that balances complexities of electric system modeling with time limitations and is directionally consistent with industry standard optimization models
2. Provide stakeholders with a more active means to participate in the portfolio planning process
3. Allow stakeholders to put forth a set of scenarios to study and directionally inform APS' development of its IRP

# Guiding principles for the initiative

+ **Transparency:** stakeholders can review IRP inputs and propose alternative future views to see how they affect key output metrics

+ **Alignment:** analytics used to inform stakeholder discussion give results that are directionally consistent with more detailed planning models

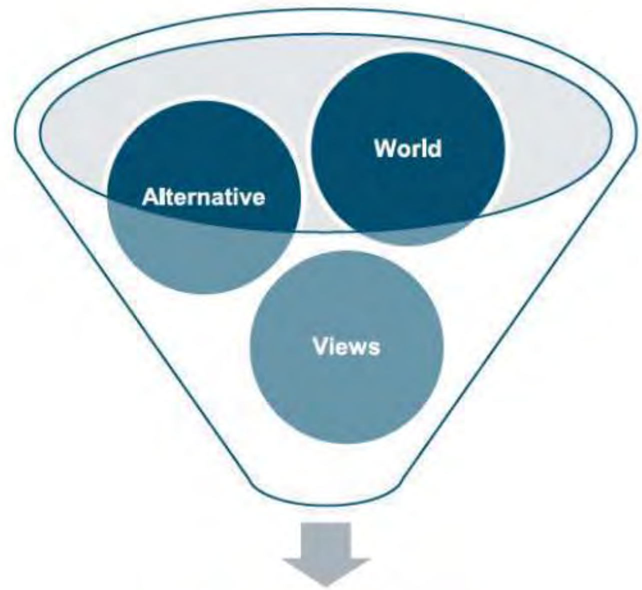
+ **Flexibility:** stakeholders can suggest alternative inputs (e.g., capacity additions or policy targets) to develop different scenarios

+ **Accessibility:** stakeholders will have input into the scenarios modeled in the preliminary 2019 IRP

# Overview of stakeholder screening tool

+ **E3's stakeholder screening tool is an Excel-based model capable of designing and evaluating portfolios based on:**
  - Assumptions used in APS' IRP
  - Alternatives proposed by stakeholders
+ **The tool provides useful directional results generally consistent with more rigorous planning models, enabling stakeholders to test a wide range of possibilities and build intuition**
+ **By using the tool to explore a wide range of alternative scenarios stakeholders will have the opportunity to develop more focused input into IRP process**

**Screening tool will allow stakeholders to prioritize input into scenario design**




**Reduced Set of Stakeholder Scenarios for Detailed IRP Modeling**

Energy+Environmental Economics

# Scenarios Analyzed

# Building blocks for clean energy

+ **A technology-neutral approach to establishing future goals will provide optionality as opportunities for carbon reductions evolve, enabling utilities to choose the most affordable "building blocks"**

| Building Block | Description |
|---|---|
| Nuclear | Maintain existing carbon-free generation |
| Renewables | Increase and diversify carbon-free generation |
| Fuel switching | Conversion from coal to gas (or other) generation |
| Clean imports | Utilize excess low-carbon electricity |
| Electrification | Electrify transportation sector and select building end uses |
| Energy storage | Load shifting/absorbing excess solar via energy storage |
| Demand management | Efficiency, demand response, & other demand-side measures |

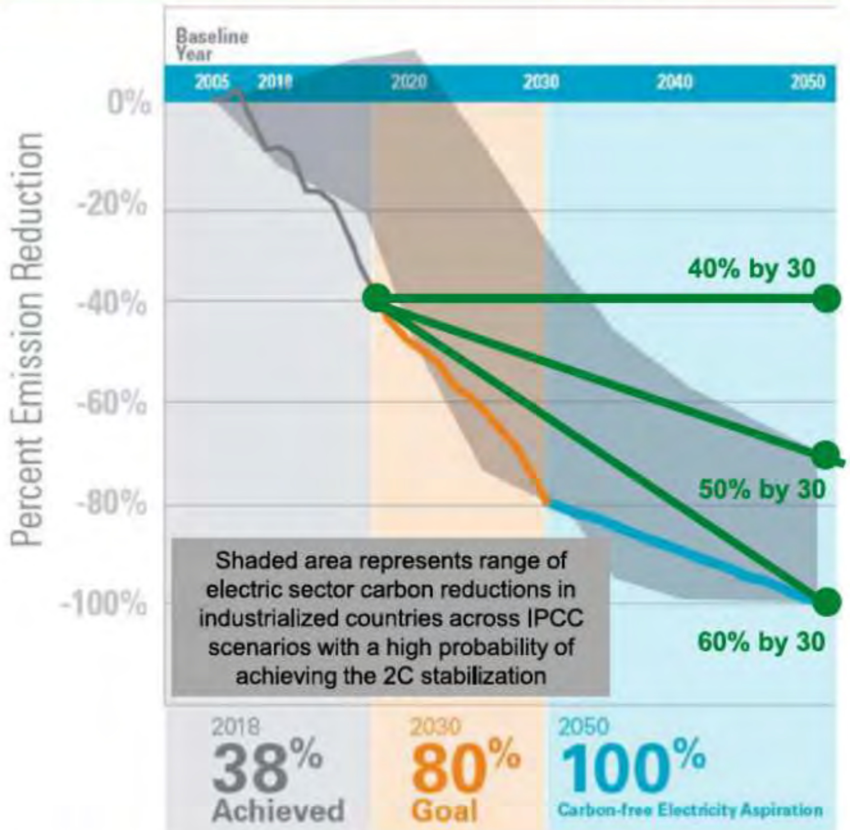
# Four groups of scenarios explore different policy options

- **Scenarios modeled generally fall into four broad categories that affect the types of investments needed in each:**
  1. **Renewable Portfolio Standard (RPS):** portfolios designed to meet a kWh production quota for renewables, expressed as a percent of retail sales (30-50% RPS by 2030)
  2. **Clean Energy Standard:** portfolios designed to meet a kWh production quota for carbon-free resources (including nuclear & clean imports), expressed as a percent of retail sales (60-80% clean by 2030)
  3. **Carbon Target:** portfolios designed to meet a specific carbon goal (40-60% reductions by 2030)
  4. **Natural Gas Prohibition:** portfolios that prohibit investment in new natural gas infrastructure to meet future reliability needs
- **Stakeholders also designed a wide range of sensitivities to test assumptions on load growth, technology costs, and other key assumptions**

# Science-based carbon targets
## (Informed by Xcel Energy's analysis of science-based targets)

- Global climate modeling efforts have established a range of emissions reductions trajectories consistent with 2C climate stabilization
- Downscaling these estimates to specific geographies, sectors, and companies is a challenging exercise with no one-size-fits-all solution
- Reduction goals based on IPCC modeling that informed Xcel Energy's targets include a wide range that encompasses both Carbon-50 and Carbon-60 scenarios
- Notwithstanding uncertainty, modeling suggests considerable reductions are needed to achieve global climate stabilization

### Science-based targets that informed Xcel Energy's future climate goals




**Background figure source:** Grounding Xcel Energy's Goals in Climate Science

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# Methods & Assumptions

# Model inputs and outputs

## Inputs

- Demand forecast
- Clean energy goals
- Existing resources
- Customer resources
- New resource options
- Fuel prices
- Hourly profiles
- Market prices

## Model

- Cost minimization
- Determine costs via hourly economic dispatch
- Identify new build resources
- Satisfy planning reserve margin
- Satisfy hourly energy needs
- Satisfy clean energy goal(s)

## Outputs

- Installed capacity
- Annual generation
- Imports
- Renewable curtailment
- Carbon emissions
- Generation cost

***Analysis conducted in five-year increments***

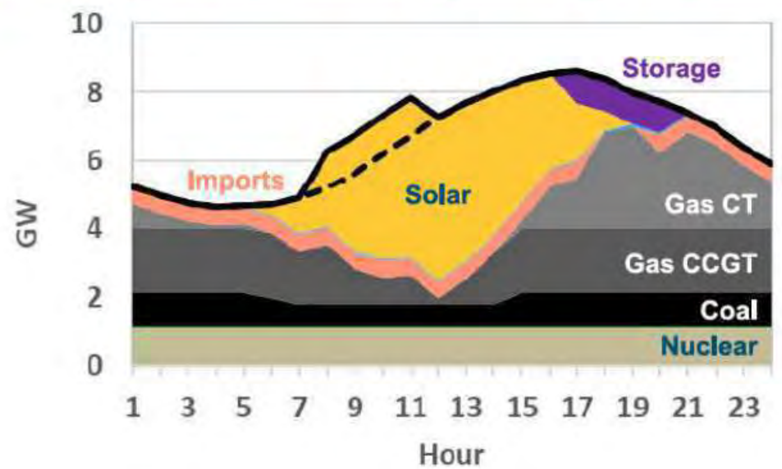
***Model outputs reported in nominal dollars***

# Overview of model functionality

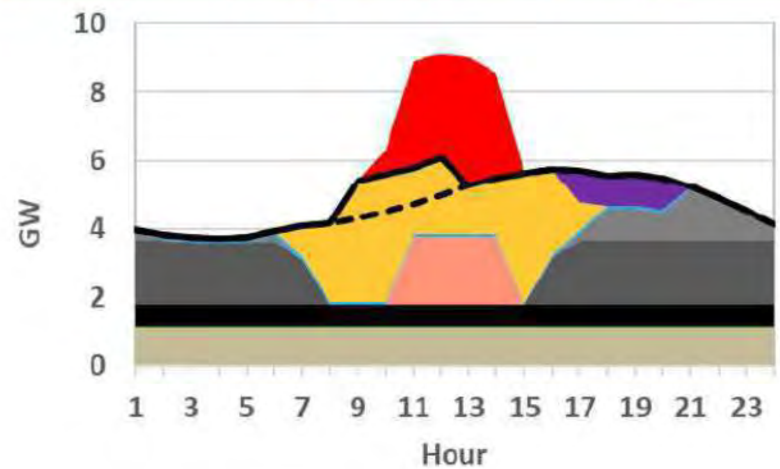
**The screening tool constructs portfolios from a menu of resource options to meet specified clean energy and carbon goals while maintaining reliability:**

- Renewables selected to provide carbon-free energy to meet user-specified goals
- Customer resources included in portfolio based on user forecast
- Energy storage is added on an economic basis to balance renewables & meet reliability needs
- Tracks energy imports and associated implied emissions based on imputed market heat rates
- Additional gas resources added to meet reliability when economic to maintain affordability

## Example Summer Dispatch (2030)



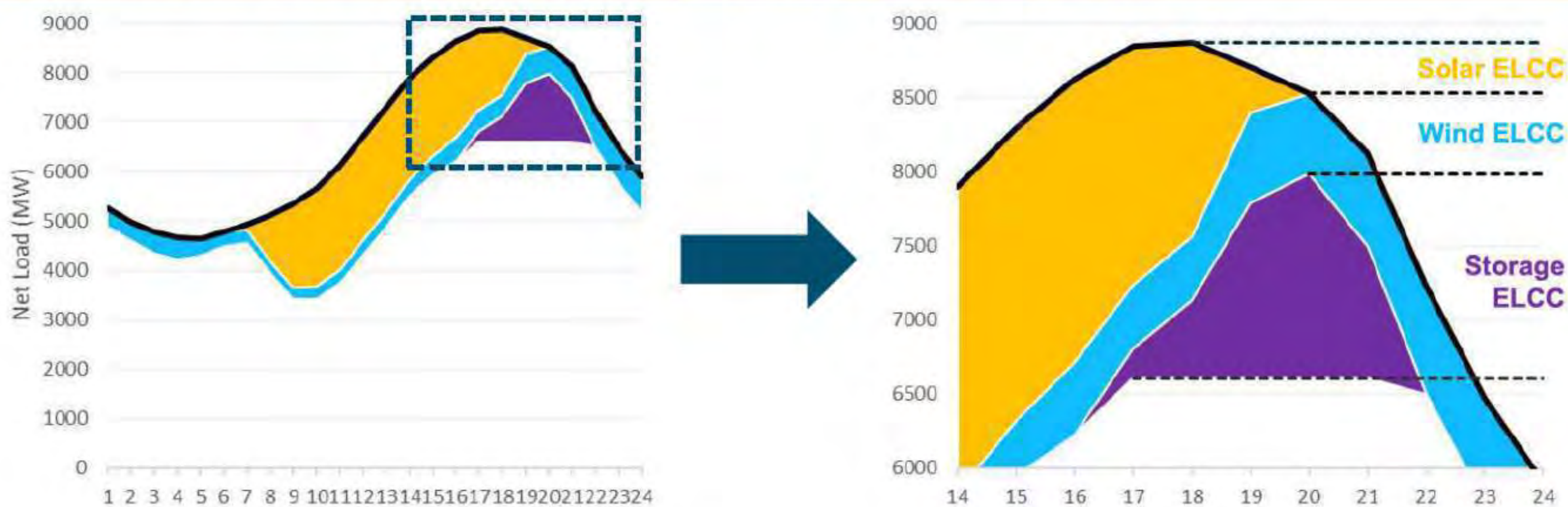

## Example Spring Dispatch (2030)



# Approximation of renewable & storage ELCC

+ **Planning reserve margin (PRM) requirement of 15% maintained to ensure reliability**
+ **Capacity accreditation for variable and use-limited resources under a PRM framework requires estimate of "effective load carrying capability," which captures limitations of each resource to meet reliability needs**
    - Typically determined through detailed loss-of-load-probability modeling
+ **In this model, ELCCs for renewables & storage are estimated based on their respective impacts on the net peak demand across the top 60 hours of the year (1% of hours)***

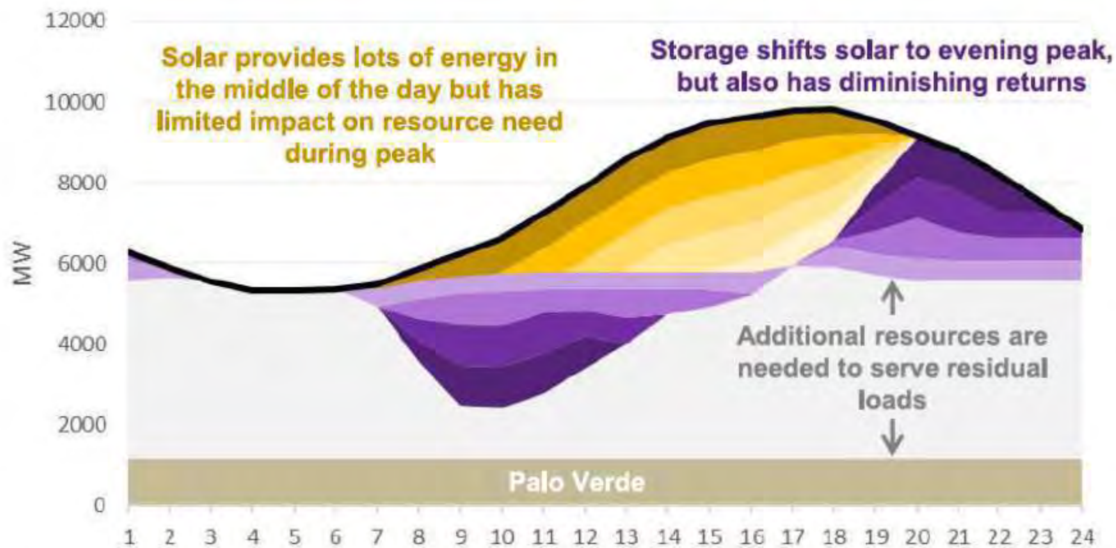
## Approximation of ELCC Based on Impact on Net Peak Demand




** APS uses top 90 hours in its modeling; E3's assumptions and methodology based on benchmarking against APS analysis and other prior work*

# Meeting reliability needs during peak periods

- **Resources needed to ensure reliability are based on expected peak demand plus a planning reserve margin**
  - Example of 2030 need: 10,000 MW peak + 15% reserve margin = **11,500 MW**
- **Contribution of different resources varies according to availability:**
  - **Nuclear, coal, and gas ("firm" resources)** that are available on demand contribute full capacity
  - **Solar, wind, and storage** contribute less than full capacity due to limits on availability



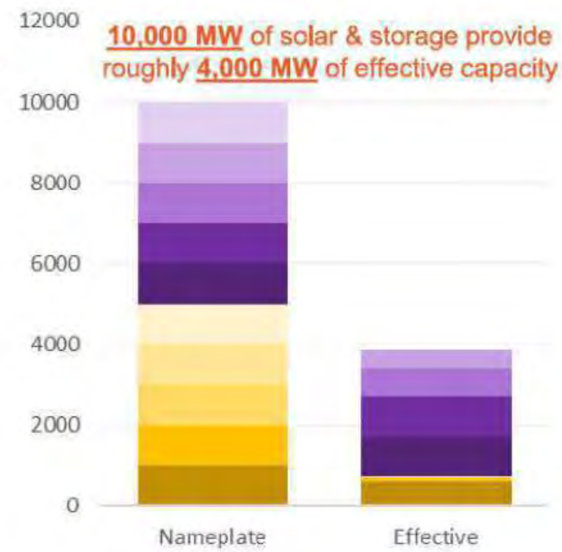




*Figure is illustrative of model dynamics and not a model result*

# Key model inputs & assumptions

## + Inputs and assumptions used in this study provided by APS

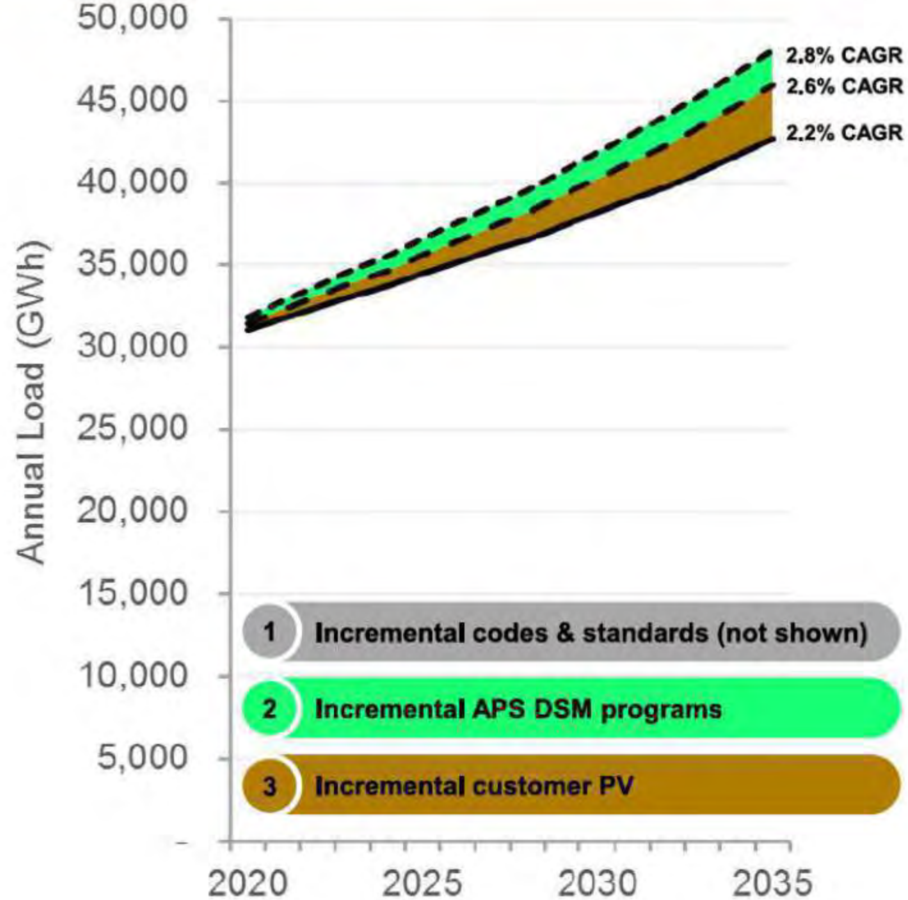
| Category | Assumption |
|---|---|
| **Load Forecast** | • Energy demand (prior to impacts of APS programs) grows at a rate of 2.8%/yr |
| **Energy Efficiency** | • Energy efficiency program assumptions vary across scenarios<br>• APS current DSM plan (~116 GWh/yr) reduces growth rate to 2.6%/yr<br>• "High EE" scenario (239 GWh/yr) reduces growth rate to 2.3%/yr |
| **Demand Response** | • Demand response programs continue to grow at a rate of 25 MW per year |
| **BTM Solar** | • BTM solar increases from 1,269 MW in 2020 to 2,819 MW in 2035 |
| **Nuclear** | • Palo Verde (1,146 MW) remains in service throughout analysis period |
| **Coal** | • Navajo Generating Station retired by 2019<br>• Cholla retired in 2025 for modeling purposes[a]<br>• Timing of Four Corners retirement varies across scenario (2031 or 2038)<br>• Take-or-pay fuel supply agreement results in low marginal cost of generation up to ~60% capacity factor through 2031<br>• Beyond 2031, minimum take-or-pay requirement removed and plant operated based on economics |
| **Gas** | • Existing APS-owned gas plants remain in service throughout analysis<br>• CCGT tolling agreements totaling 1,600 MW expire in mid-2020s; 1,135 MW extended based on economics[b]<br>• New gas CCGT and CT resources selected by the model based on costs in Appendix |
| **Utility-Scale Solar** | • Existing APS resources (~500 MW) remain in service; new First Solar project (65 MW) added in 2021<br>• New solar resources selected by the model based on costs (including integration cost of $2.50/MWh) |
| **Wind** | • Existing APS resources (~300 MW) remain in service<br>• New wind resources selected by the model based on costs (including integration cost of $2.50/MWh) |
| **Storage** | • Planned 850 MW of utility-scale storage deployed by 2025<br>• Additional storage selected by the model based on costs |
| **Fuel prices** | • Uranium, coal, and gas prices aligned with APS 2019 IRP assumptions (see Appendix)<br>• Carbon price begins in 2025 |
| **External market prices** | • Hourly price forecast for California reflects aggressive policy goals & associated negative prices at a floor of -$30/MWh (escalating at inflation) |

[a] APS is considering a biomass conversion of a Cholla unit; however, given that this is not final, we assume that the plant is retired for modeling purposes
[b] The extension of CCGT tolls is a simplifying assumption made for the purposes of E3's analysis and does not reflect a commitment by APS

# Demand forecast (energy)

- **Robust growth in population and economic activity are expected to drive increased energy demand over time**
- **Efficiency assumptions reflect APS' current DSM plan**
- **Forecast load growth is partially offset by incremental DSM and DG PV**
  - Effects DSM and customer PV reduce expected growth rate by >1%/yr

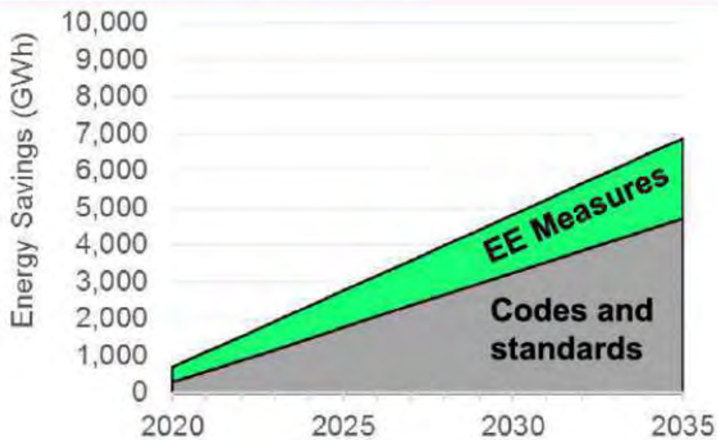
**APS Demand Forecast**



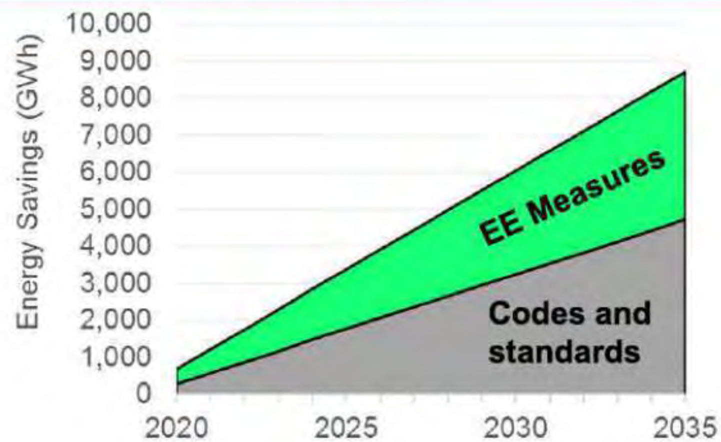
# Energy efficiency levels

- Two energy efficiency levels were modeled: APS' current DSM program level and a higher EE level
- APS current DSM plan focuses on peak reductions & results in 116 GWh of incremental EE programs per year
  - 412 GWh of incremental EE per year when including codes and standards
  - Based on DSM measures in the APS 2019 DSM Plan (filed 12/31/18)
- Higher DSM level results in 239 GWh of incremental EE programs per year
  - 534 GWh of incremental EE per year when including codes and standards

## APS Current DSM Plan




## High DSM Sensitivity

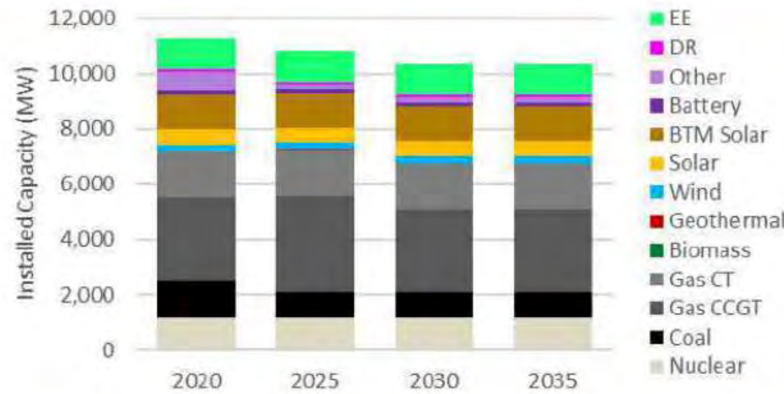



***Additional analysis needed to characterize the cost impacts of achieving the High DSM scenario***

# Existing and planned resources

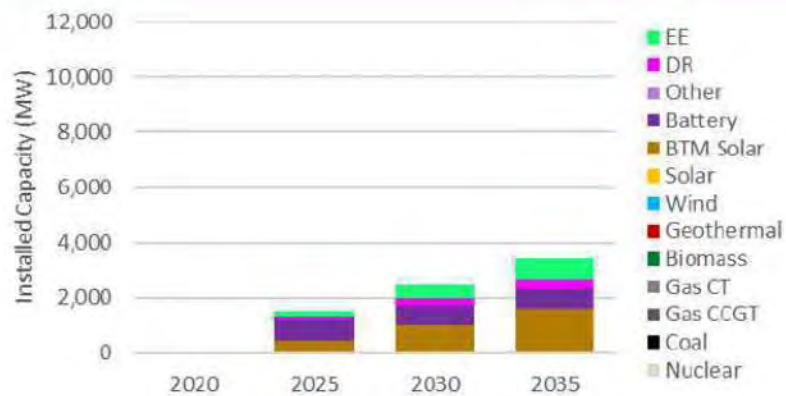
## Existing Resources *(through 2020)*

- **Resource retirements and expiring contracts, combined with load growth, drive capacity needs through 2035:**
  - PacifiCorp seasonal exchange (480 MW) expires in 2020
  - Cholla (387 MW) retires after 2024
  - 1,598 MW of CCGT tolls expire between 2025 & 2030; this analysis assumes that 1,135 MW of CCGTs are renewed through the analysis horizon (assumption informed by preliminary analysis & sensitivities)




## Planned Additions *(beyond 2020)*

- **APS DSM programs reduce 2035 peak by an additional 700 MW**
- **New DR deployed at a rate of 25 MW per year**
- **Battery storage added to meet APS' 850 MW goal by 2025**
- **Customer adoption of BTM solar results in additional 1,500 MW by 2035**



# New resource options

+ **In each five years, the model selects which new investments to add to the portfolio on a least-cost basis while considering that (1) sufficient effective capacity must be available to meet reliability needs (i.e. PRM needs); and (2) sufficient "clean" energy is available to meet the corresponding policy goal**

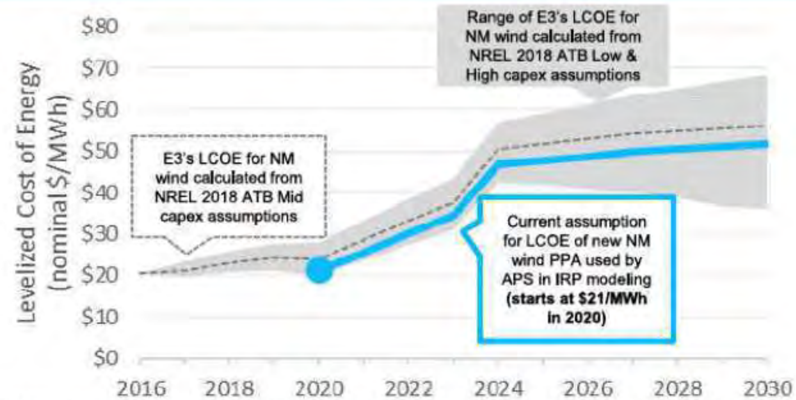
| Resource* | Option(s) | Capabilities |
|---|---|---|
| **Utility-Scale Solar** | • Single-axis tracking utility-scale solar with 33%+ capacity factor (pre-curtailment) | • Low cost source of intermittent generation<br>• Limited capacity value beyond levels in existing portfolio |
| **Wind** | • New Mexico wind (49% capacity factor pre-curtailment)<br>• Arizona wind (32% capacity factor pre-curtailment) | • Low cost source of intermittent generation<br>• Small to medium additional capacity value |
| **Energy Storage** | • 4-hour lithium ion battery storage | • Source of flexibility to balance intermittency of renewables (esp. solar) and wholesale purchases from California<br>• Initially large capacity value but declining impact with scale |
| **Gas CT** | • Frame combustion turbines | • Low-cost source of new capacity to meet reliability needs<br>• Infrequent operations due to high heat rate |
| **Gas CCGT** | • Combined cycle gas turbines | • High-cost source of new capacity to meet reliability needs<br>• Lower heat rate translates to more frequent operations |

** Customer solar, demand response, and energy efficiency are treated as fixed resources and are not optimized in this study; see Slide 20 for a summary of assumptions. Future efforts may consider incorporating these options into optimization if data is available.*

# New Mexico wind cost assumptions

- **Cost assumptions for wind resources refreshed following APS' discussions with stakeholders**
  - Near-term price ($21/MWh LCOE for PPA in 2020) informed by market
  - Long-term increase driven primarily by sunset of PTC
- **LCOEs across analysis horizon reduced by approximately $10/MWh relative to assumptions used in May 15 analysis**
- **Updated cost projections for wind generally align with E3's range of benchmarks for "typical" NM wind resources**
  - Developed based on forecasted cost & performance assumptions from NREL's 2018 Annual Technologies Baseline
  - Calculated using E3's PPA pro-forma financing model

## New Mexico wind LCOE comparisons




*LCOE comparisons reflect only the levelized cost of energy and do not include adjustments for transmission, integration, or imputed debt

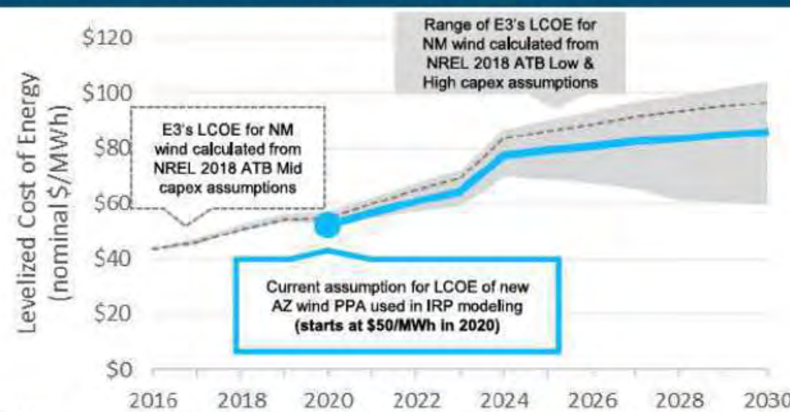
## New Mexico wind all-in cost


*Assumes resource is delivered to APS system on existing transmission via PNM wheel; the quantity of wind that can be delivered over existing transmission in this manner is capped at 323 MW + an additional 848 MW upon Four Corners' retirement

# Arizona wind cost assumptions

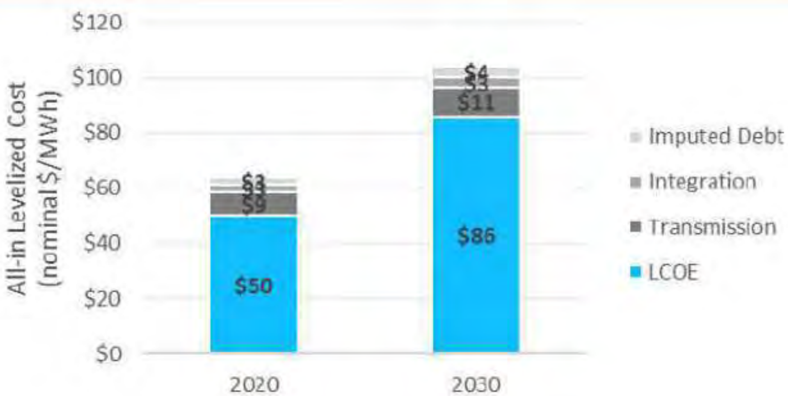
- **Cost assumptions for AZ wind resources are consistent with NM wind but reflect a lower expected capacity factor**
  - Low 30s for AZ wind vs. high 40s for NM wind
- **Cost assumptions for AZ wind resources remain relatively consistent with assumptions used in analysis presented May 15**

## Arizona wind LCOE comparisons




*LCOE comparisons reflect only the levelized cost of energy and do not include adjustments for transmission, integration, or imputed debt

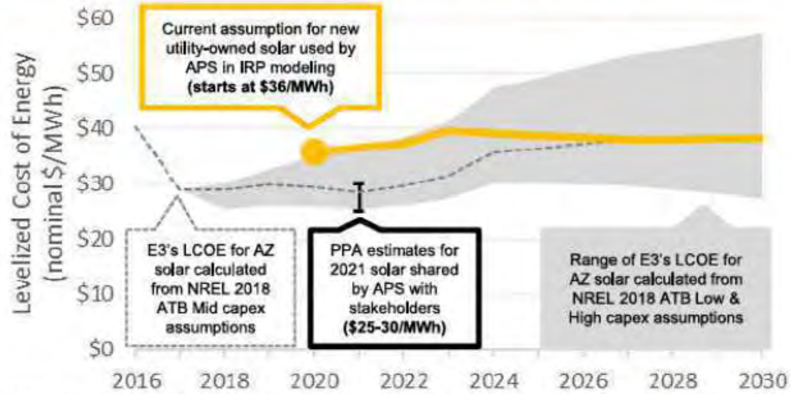
## Arizona wind all-in cost



# Arizona solar cost assumptions

- **Future projection of solar costs updated based on assumptions provided by APS' resource planning team**
  - No change to near-term costs
  - Long-term projection reduced (2030 costs reduced by 20%)
- **APS' projected solar costs benchmarked against E3's range of internal projections for a "typical" future AZ tracking solar plant**
  - Developed based on forecasted cost & performance assumptions from NREL's 2018 Annual Technologies Baseline
  - Calculated using E3's PPA pro-forma financing model
- **While APS' near-term solar cost assumptions are higher than public benchmarks, aggressive assumed cost reductions result in a long-term trajectory that is generally in line with industry expectation**

## Arizona solar PV LCOE assumptions



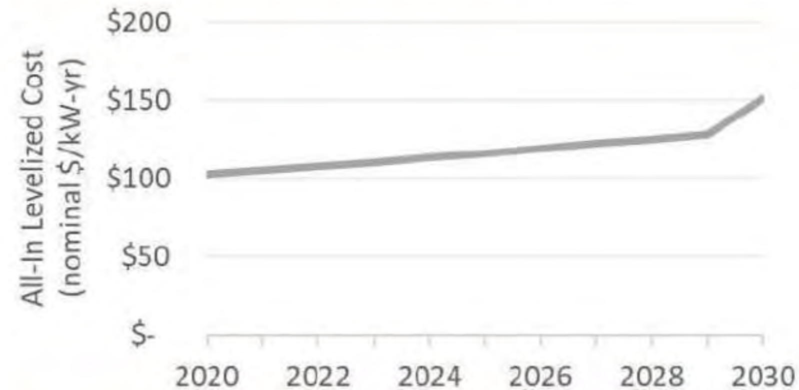

*LCOE comparisons reflect only the levelized cost of energy and do not include adjustments for transmission, integration, or imputed debt

## Arizona solar PV all-in cost

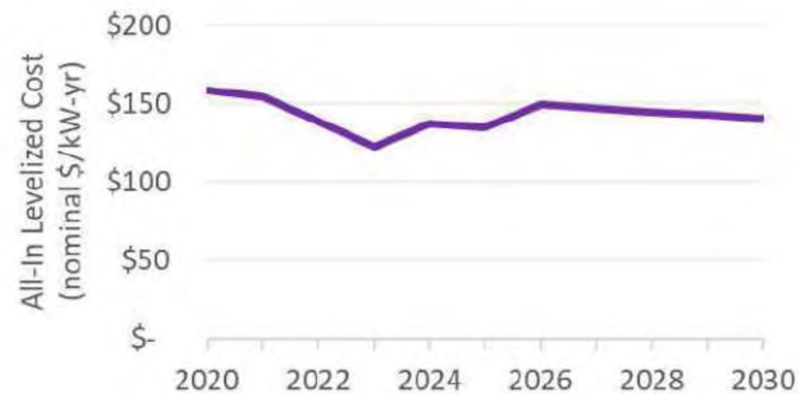
# Capacity resource cost assumptions

- **The cost of a gas combustion turbine (CT) rises gradually with inflation through 2030**
- **APS forecasts having adequate gas pipeline capacity to accommodate new gas capacity until 2030**
  - At this point, investment in new gas pipelines is needed, resulting in a bump up in all-in CT costs in 2030
- **Battery storage costs are forecasted to decline significantly in real terms through 2030**
  - The cost of battery storage can be reduced further by combining battery storage with solar to receive the federal investment tax credit. This is not considered in this analysis

## Gas CT All-In Levelized Cost




## 4-hr Battery All-In Levelized Cost



# Wholesale market interactions

- **Wholesale market price forecast reflects California's increasing reliance on renewables to meet policy goals**
  - Increasing frequency of negative pricing in the middle of the day, particularly during springtime
- **Emissions accounting convention for market purchases reflects the underlying physical carbon content of imported power:**
  - At prices above $0/MWh, assumed emissions rate reflects gas on the margin
  - At prices below $0/MWh, purchases are treated as carbon-free, reflecting likelihood that solar is the marginal resource

## 2020 Market Prices

| Month | Hour of Day | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Jan | 25 | 25 | 25 | 25 | 25 | 28 | 30 | 31 | 29 | 27 | 23 | 21 | 21 | 23 | 25 | 28 | 33 | 37 | 38 | 38 | 36 | 32 | 28 | 26 |
| Feb | 25 | 24 | 24 | 24 | 25 | 28 | 30 | 30 | 25 | 20 | 15 | 13 | 14 | 17 | 21 | 26 | 31 | 36 | 39 | 39 | 37 | 33 | 29 | 25 |
| Mar | 23 | 23 | 23 | 24 | 25 | 28 | 29 | 26 | 18 | 7 | 2 | -1 | 0 | 3 | 8 | 15 | 25 | 32 | 38 | 38 | 36 | 31 | 27 | 24 |
| Apr | 23 | 23 | 23 | 23 | 24 | 27 | 25 | 20 | 7 | 0 | -2 | -4 | -5 | -3 | 4 | 14 | 24 | 32 | 38 | 40 | 38 | 33 | 28 | 24 |
| May | 23 | 22 | 22 | 23 | 23 | 22 | 20 | 16 | 12 | 4 | 4 | 3 | 4 | 7 | 17 | 26 | 33 | 38 | 41 | 42 | 40 | 34 | 28 | 23 |
| Jun | 21 | 21 | 21 | 22 | 22 | 21 | 19 | 16 | 16 | 17 | 19 | 21 | 23 | 26 | 29 | 32 | 37 | 41 | 44 | 44 | 42 | 35 | 28 | 22 |
| Jul | 25 | 25 | 25 | 26 | 24 | 23 | 21 | 20 | 20 | 20 | 23 | 29 | 34 | 39 | 43 | 48 | 51 | 53 | 53 | 52 | 49 | 40 | 32 | 26 |
| Aug | 25 | 25 | 25 | 25 | 26 | 28 | 28 | 27 | 24 | 28 | 32 | 37 | 41 | 45 | 48 | 50 | 50 | 51 | 51 | 50 | 46 | 38 | 31 | 25 |
| Sep | 24 | 24 | 24 | 24 | 25 | 28 | 28 | 27 | 24 | 25 | 29 | 33 | 37 | 42 | 46 | 49 | 52 | 53 | 53 | 51 | 46 | 37 | 29 | 24 |
| Oct | 24 | 24 | 24 | 25 | 26 | 29 | 30 | 28 | 23 | 21 | 22 | 24 | 27 | 31 | 35 | 39 | 43 | 46 | 47 | 45 | 42 | 35 | 29 | 25 |
| Nov | 25 | 25 | 24 | 24 | 25 | 29 | 31 | 30 | 25 | 21 | 20 | 21 | 21 | 23 | 27 | 32 | 38 | 42 | 43 | 42 | 40 | 35 | 30 | 26 |
| Dec | 28 | 27 | 27 | 27 | 28 | 30 | 32 | 32 | 29 | 25 | 23 | 21 | 21 | 22 | 26 | 31 | 37 | 41 | 42 | 41 | 40 | 36 | 32 | 29 |

## 2030 Market Prices

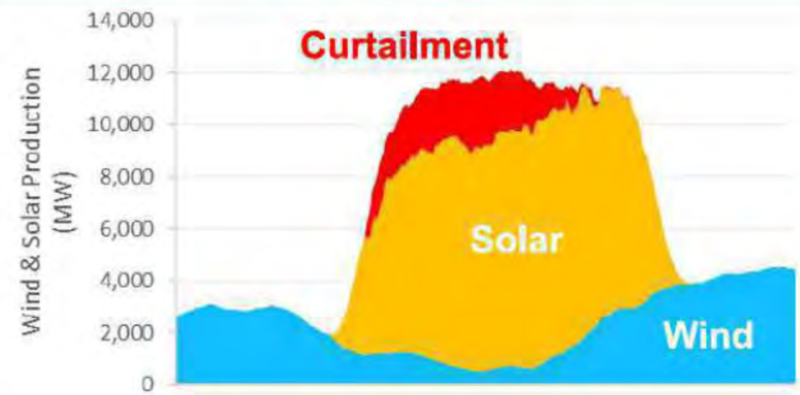
| Month | Hour of Day | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Jan | 32 | 32 | 32 | 32 | 33 | 38 | 42 | 42 | 23 | 6 | -5 | -11 | -12 | -7 | 8 | 14 | 40 | 51 | 55 | 54 | 50 | 44 | 37 | 33 |
| Feb | 32 | 31 | 31 | 31 | 32 | 37 | 40 | 27 | -13 | -17 | -22 | -28 | -28 | -25 | -7 | 11 | 27 | 48 | 55 | 54 | 51 | 44 | 38 | 33 |
| Mar | 31 | 32 | 32 | 33 | 34 | 39 | 39 | -8 | -39 | -42 | -42 | -42 | -42 | -42 | -31 | -28 | -13 | 39 | 53 | 54 | 50 | 43 | 37 | 32 |
| Apr | 31 | 31 | 31 | 31 | 33 | 36 | 28 | -32 | -39 | -42 | -33 | -33 | -33 | -42 | -39 | -37 | -25 | 32 | 54 | 58 | 55 | 47 | 38 | 32 |
| May | 32 | 31 | 31 | 33 | 34 | 27 | 6 | -26 | -28 | -33 | -34 | -37 | -35 | -33 | -26 | -12 | 12 | 50 | 60 | 63 | 60 | 50 | 40 | 33 |
| Jun | 31 | 31 | 31 | 32 | 33 | 26 | 17 | -23 | -24 | -27 | -27 | -23 | -22 | -10 | -8 | 10 | 22 | 53 | 62 | 66 | 64 | 53 | 41 | 31 |
| Jul | 34 | 34 | 34 | 36 | 33 | 27 | 13 | 4 | -8 | -6 | -1 | 2 | 5 | 11 | 21 | 35 | 53 | 69 | 76 | 78 | 73 | 59 | 46 | 35 |
| Aug | 34 | 34 | 34 | 35 | 36 | 39 | 33 | 17 | 1 | 4 | 9 | 24 | 32 | 40 | 44 | 53 | 59 | 68 | 73 | 74 | 68 | 55 | 43 | 35 |
| Sep | 32 | 32 | 32 | 33 | 35 | 39 | 35 | 17 | -1 | -2 | -1 | 7 | 17 | 26 | 34 | 49 | 63 | 72 | 79 | 77 | 68 | 52 | 40 | 32 |
| Oct | 31 | 30 | 31 | 31 | 33 | 39 | 37 | 4 | -21 | -32 | -33 | -24 | -14 | 0 | 15 | 36 | 54 | 65 | 69 | 66 | 60 | 48 | 39 | 32 |
| Nov | 32 | 31 | 30 | 31 | 32 | 38 | 41 | 10 | -16 | -21 | -23 | -24 | -24 | -24 | -6 | 17 | 48 | 58 | 59 | 56 | 53 | 46 | 39 | 33 |
| Dec | 37 | 37 | 37 | 37 | 38 | 42 | 46 | 44 | 31 | 5 | 1 | -11 | -9 | -8 | 6 | 34 | 52 | 61 | 63 | 60 | 58 | 51 | 44 | 38 |

# California market dynamics at higher renewable penetrations

- **Rapid deployment of solar to meet California's policy goals is expected to lead to increasing levels of renewable curtailment**
  - Expectation is that this dynamic will become increasingly prevalent as California pursues aggressive decarbonization goals and continues to develop solar
- **When California system is in a state of "overgeneration" (i.e. surplus renewable resources), market prices will drop below zero**
  - Utilities pay to generate in order to generate RECs for RPS compliance
  - Creates an opportunity for entities outside California to purchase surplus energy at negative prices to the mutual benefit of both parties

## Example daily price shape


## Corresponding wind & solar production



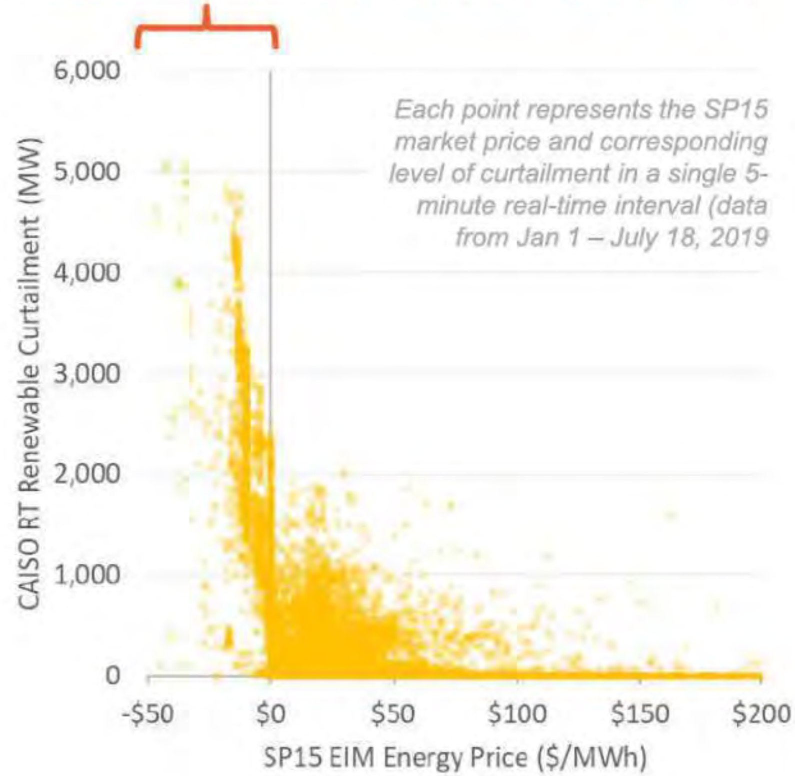

*Actual CAISO historical data from May 12, 2019*

# Are negative prices a reliable indicator of renewable curtailment?

- **Historical market data indicates that periods of negative pricing provide a reliable indication of renewable curtailment**
- **With an expectation that curtailment will increase as California develops additional solar**
  - 2019 curtailment YTD: 2% of available renewable generation
  - Expected levels in 2030 time frame: 4-10% of renewable generation

## Market prices & renewable curtailment

Renewable curtailment is observed in CAISO in **98% of all EIM intervals** when prices drop below zero



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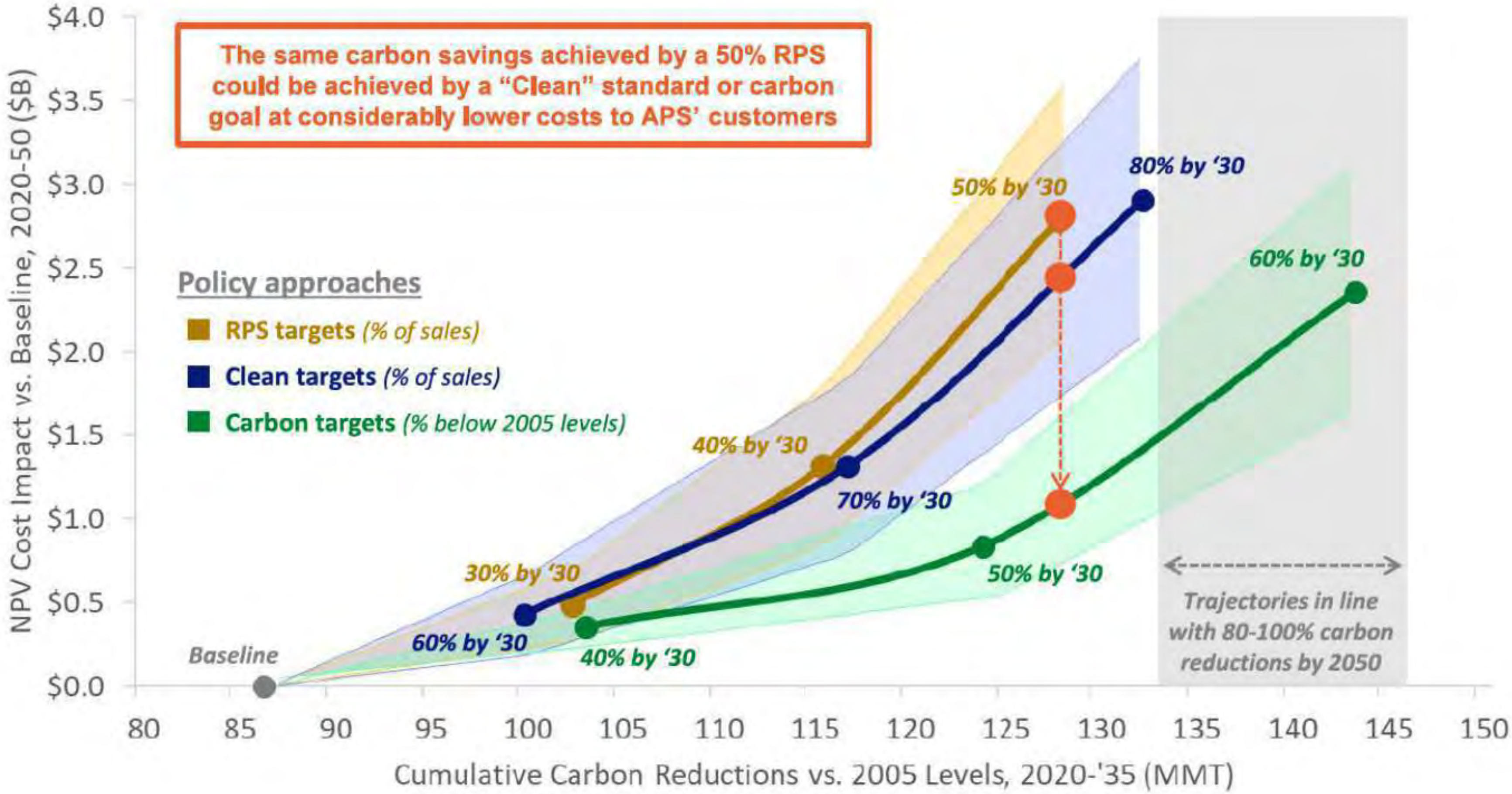
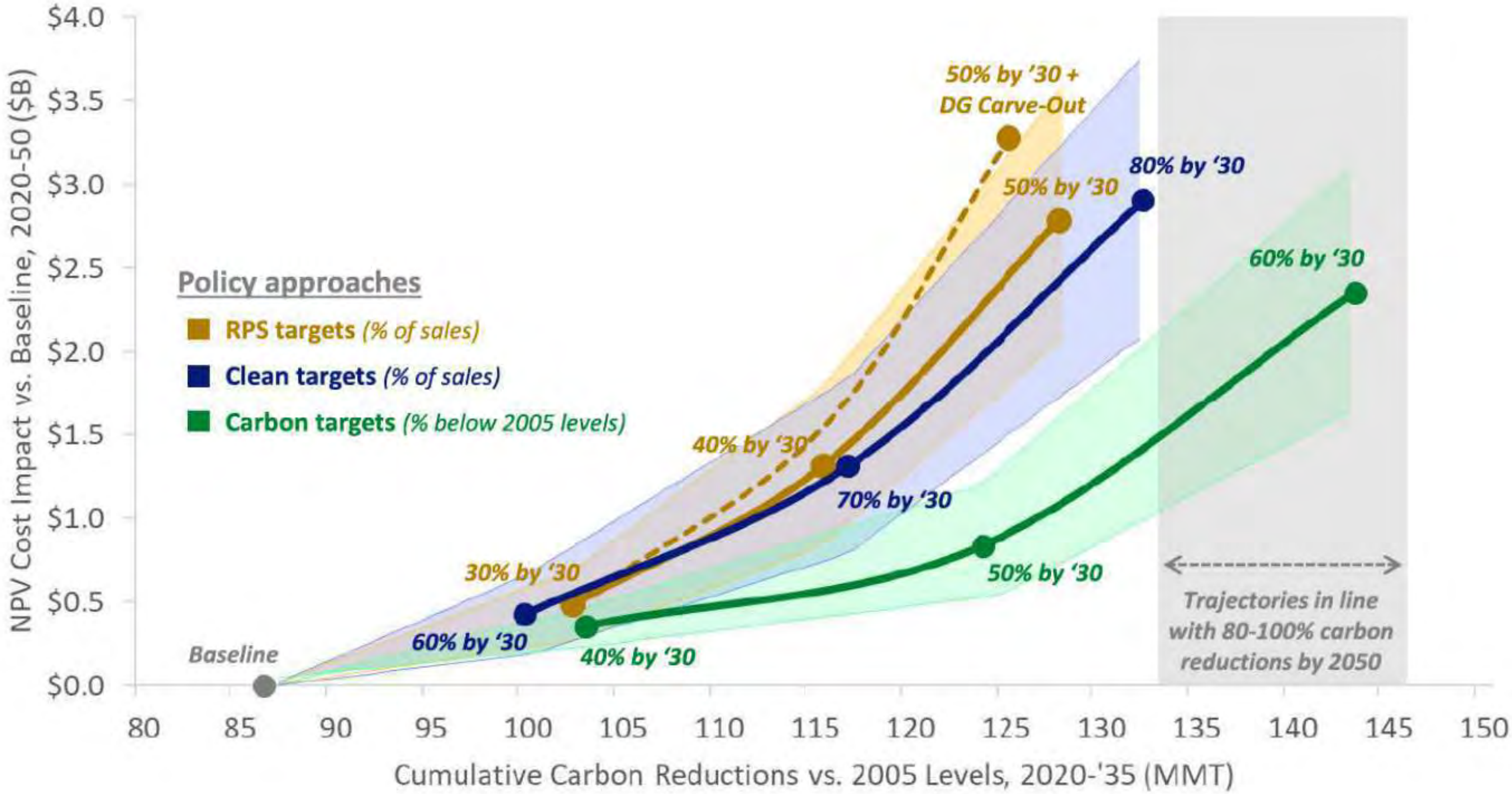
# Analysis Results

# Estimating a range of cost & carbon impacts for APS




**The expected cost impacts of a long-term prohibition on investment in new natural gas resources would result in significantly higher costs than any other scenario investigated, with an estimated NPV cost of $20-30 billion**

# Estimating a range of cost & carbon impacts for APS (including DG carve-out)

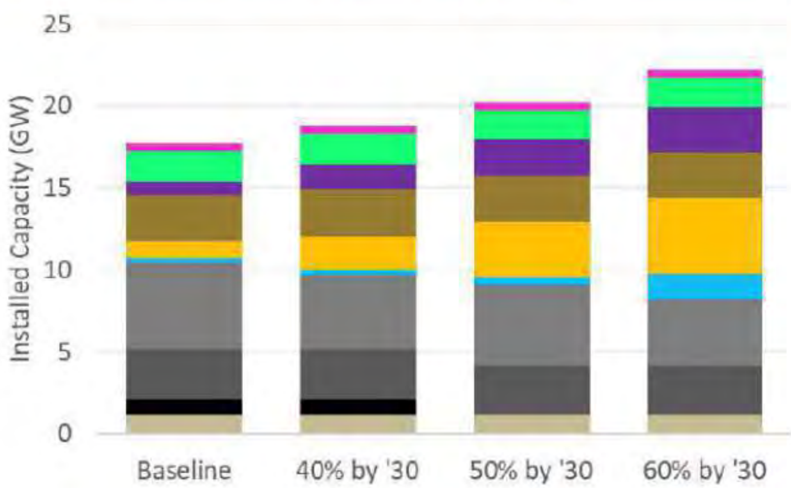


# Comparison of 2035 portfolios
## Carbon Target scenarios

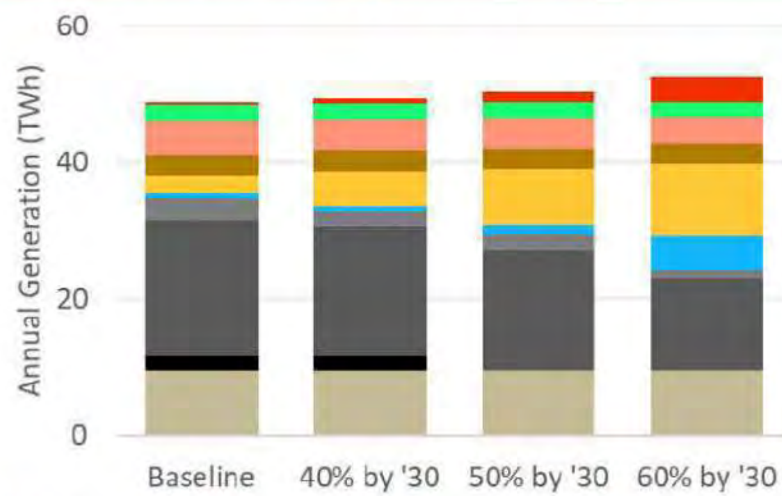
- Targeted policy goals focused on carbon enables least-cost achievement of carbon reductions
- Carbon reductions achieved through (1) displacement of existing coal, (2) investment in renewables, and (3) imports of "clean" resources from wholesale markets

| Scenario | NPV Cost, 2020-'50 ($B) | Total Carbon Reductions, 2020-'35 (MMT) |
|---|---|---|
| Baseline | — | 86 |
| 40% by '30 | $355 | 103 |
| 50% by '30 | $838 | 123 |
| 60% by '30 | $2,357 | 143 |

## 2035 Installed Capacity (MW)



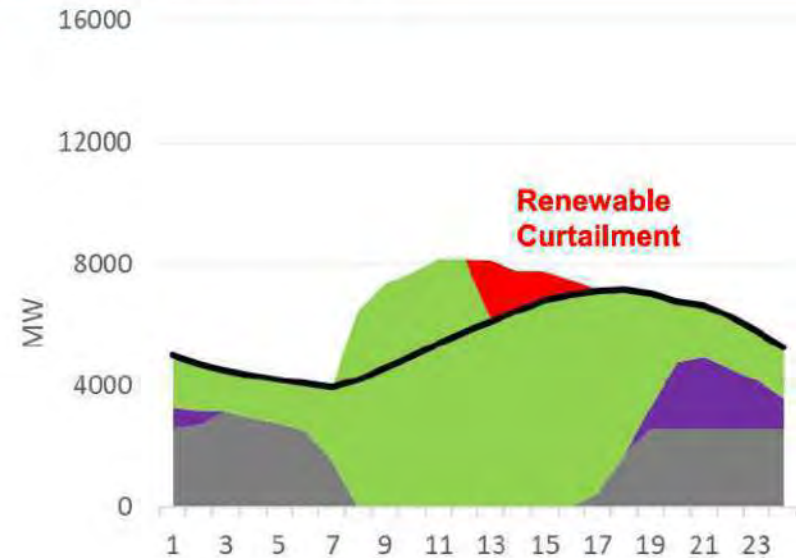

## 2035 Annual Energy Mix (GWh)



# System operations in carbon reduction scenarios

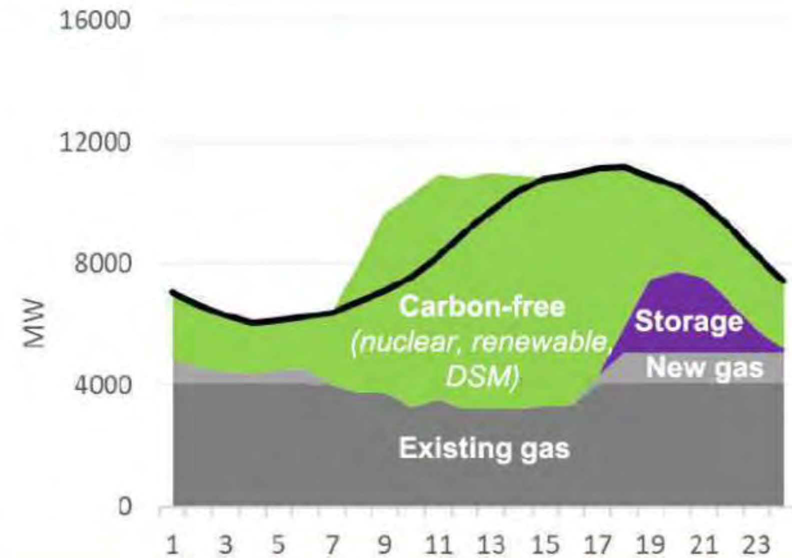
+ **Under typical conditions, system relies on a mix of renewables, storage, and existing gas—but some form of firm resource or long-duration storage will be crucial to meeting future summer peaking needs**
  - Based on current technologies, new gas investments are most likely the least cost approach to meet reliability needs

## Average Day in 2035




***System snapshots based on "60% Carbon Reduction by 2030" scenario, which achieves 70% carbon reductions by 2035***

## Peak Day in 2035

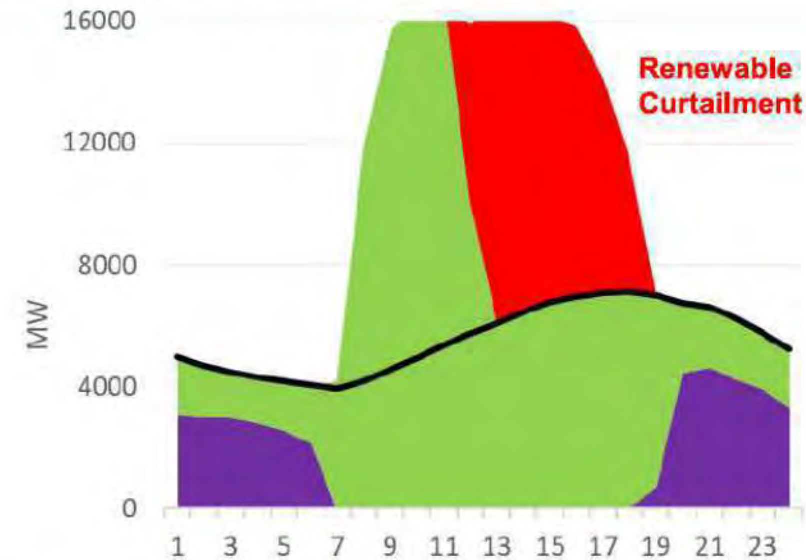



| Total New | Capacity (MW) | Capital ($B) |
|---|---|---|
| **Renewables** | 5,500 | $7 |
| **Storage** | 2,750 | $3 |
| **Gas** | 2,500 | $2 |

# Meeting future reliability needs without new gas resources

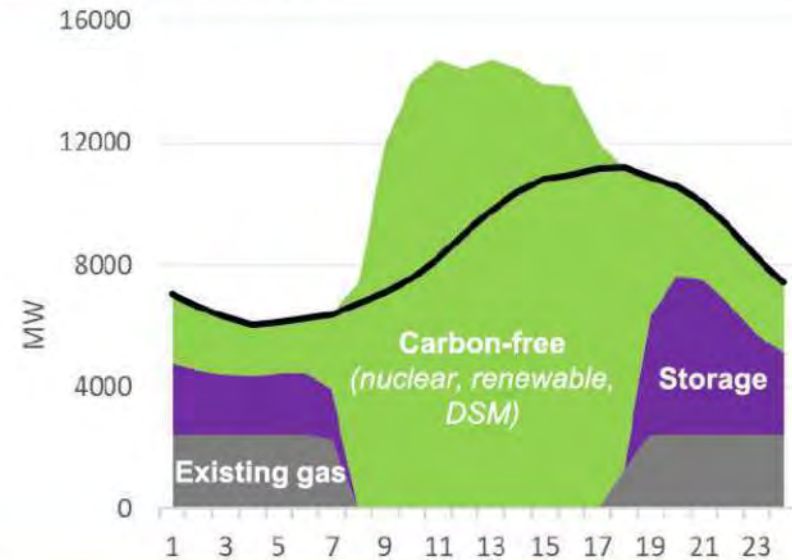
+ **Significant investment in solar & storage needed to meet long-term summer needs without new gas—resulting in significant curtailment in typical conditions**

## Average Day in 2035




***System snapshots based on modified version of "60% Carbon Reduction by 2030" scenario with additional renewable & storage resources to replace new gas resources***

## Peak Day in 2035



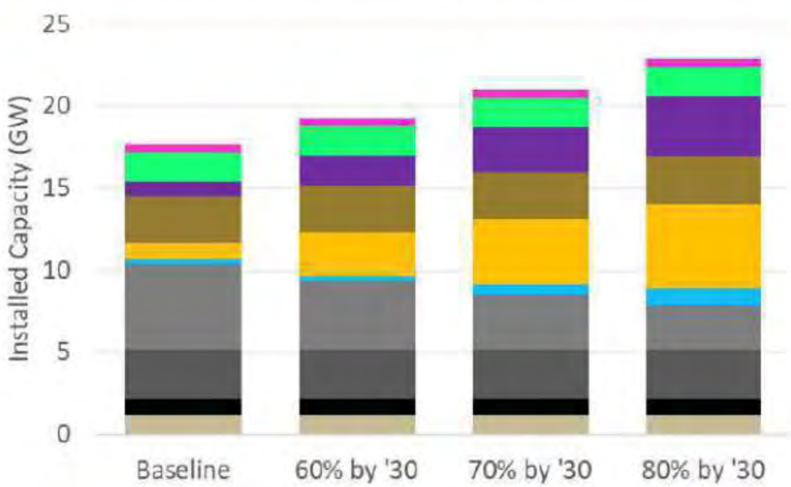

| Total New | Capacity (MW) | Capital ($B) |
|---|---|---|
| Renewables | 14,000 | $18 |
| Storage | 11,000 | $11 |
| Gas | — | — |

# Comparison of 2035 portfolios
## Clean Energy Standard scenarios

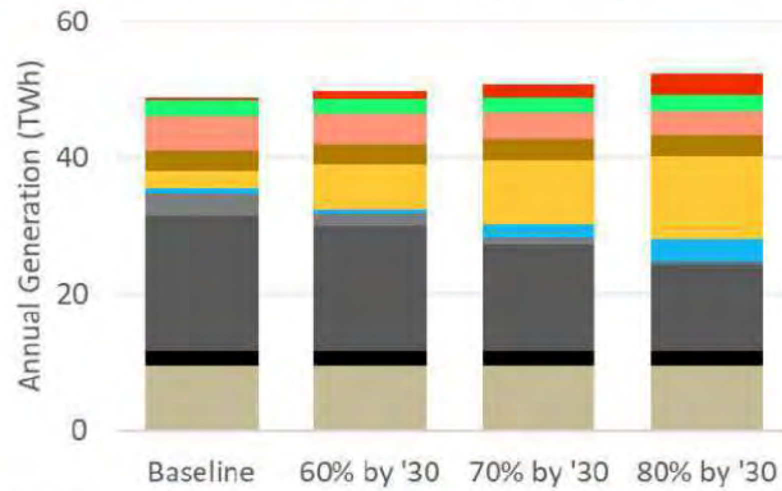
- **Clean Energy Standard scenarios lead to large investments in renewables, continue to make use of clean imports**
- **Without a direct incentive to reduce coal output, Four Corners remains in the generation mix through 2038 and limits carbon reductions**

| Scenario | NPV Cost, 2020-'50 ($B) | Total Carbon Reductions, 2020-'35 (MMT) |
|---|---|---|
| Baseline | — | 86 |
| 60% by '30 | $428 | 100 |
| 70% by '30 | $1,313 | 117 |
| 80% by '30 | $2,908 | 132 |

### 2035 Installed Capacity (MW)




### 2035 Annual Energy Mix (GWh)




Nuclear ■ Coal ■ Gas CCGT ■ Gas CT ■ Biomass ■ Geothermal ■ Wind ■ Utility-Scale Solar ■ BTM Solar ■ Battery ■ Energy Efficiency ■ Demand Response ■ Curtailment

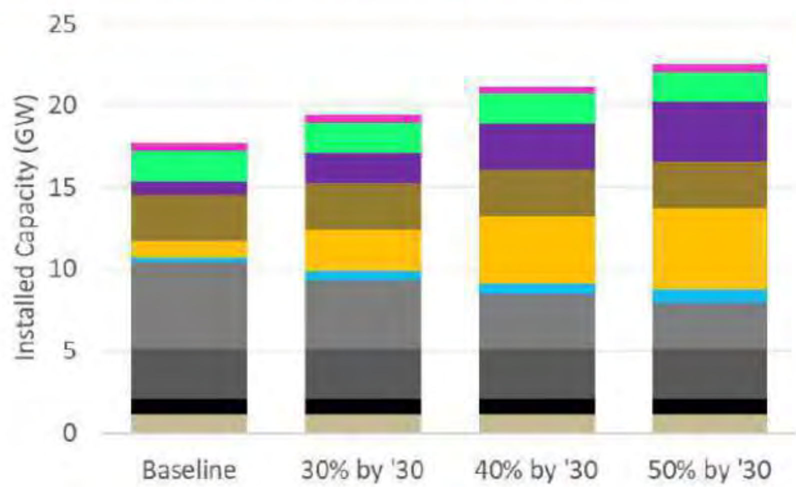
# Comparison of 2035 portfolios

## Renewables Portfolio Standard scenarios

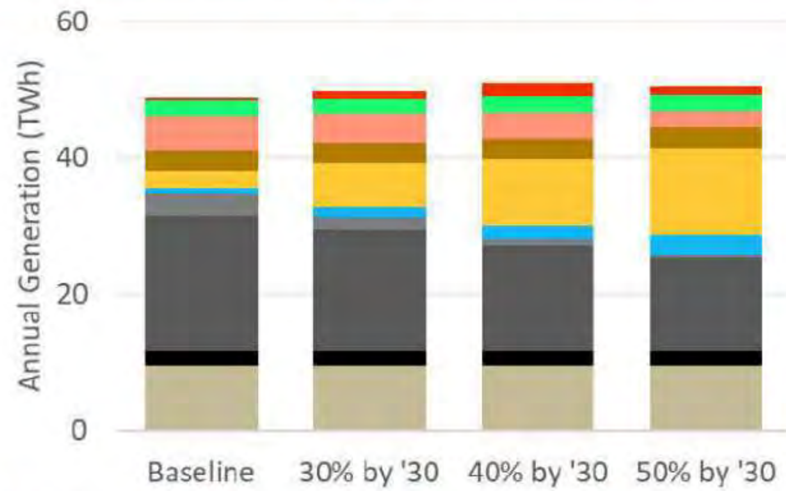
- Renewables Portfolio Standard scenarios lead to large investments in renewables at the expense of other clean energy building blocks
- RPS scenarios result in the highest costs and lowest carbon reductions among the three policy levers

| Scenario | NPV Cost, 2020-'50 ($B) | Total Carbon Reductions, 2020-'35 (MMT) |
|---|---|---|
| Baseline | — | 86 |
| 30% by '30 | $538 | 104 |
| 40% by '30 | $1,328 | 115 |
| 50% by '30 | $2,790 | 128 |

### 2035 Installed Capacity (MW)




### 2035 Annual Energy Mix (GWh)




Nuclear ■ Coal ■ Gas CCGT ■ Gas CT ■ Biomass ■ Geothermal ■ Wind ■ Utility-Scale Solar ■ BTM Solar ■ Battery ■ Energy Efficiency ■ Demand Response ■ Curtailment

# Change in installed capacity by scenario 2020 - 2035

| Scenario | Utility Solar | Wind | BTM Solar | Batteries | Gas CT | Gas CCGT | Coal | Energy Efficiency | DR |
|---|---|---|---|---|---|---|---|---|---|
| ***2020 Installed Capacity (MW)*** | | | | | | | | | |
| 2020 System | 526 | 283 | 1,269 | 140 | 1,618 | 3,006 | 1,357 | 1,118 | 88 |
| ***2020-2035 Change in Capacity (MW)*** | | | | | | | | | |
| Baseline | +500 | — | +1,549 | +716 | +3,663 | — | -387 | +713 | +375 |
| Carbon-40 | +1,536 | — | +1,549 | +1,418 | +2,961 | — | -387 | +713 | +375 |
| Carbon-55 | +2,845 | +190 | +1,549 | +2,034 | +3,275 | — | -1,357 | +713 | +375 |
| Carbon-70 | +4,063 | +1,306 | +1,549 | +2,602 | +2,407 | — | -1,357 | +713 | +375 |
| RPS-30 | +2,012 | +299 | +1,549 | +1,719 | +2,553 | — | -387 | +713 | +375 |
| RPS-40 | +3,572 | +338 | +1,549 | +2,701 | +1,742 | — | -387 | +713 | +375 |
| RPS-50 | +4,413 | +586 | +1,549 | +3,547 | +1,184 | — | -387 | +713 | +375 |
| Clean-60 | +2,090 | +0 | +1,549 | +1,734 | +2,657 | — | -387 | +713 | +375 |
| Clean-70 | +3,452 | +323 | +1,549 | +2,572 | +1,827 | — | -387 | +713 | +375 |
| Clean-80 | +4,649 | +776 | +1,549 | +3,565 | +1,093 | — | -387 | +713 | +375 |

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# Key Findings

# Key takeaways from analysis

1. APS and Arizona are experiencing continued population and load growth which could drive significant investment needs across all scenarios analyzed
2. All modeled scenarios show that significant investment in new clean resources would be needed to achieve substantial carbon reductions
3. Scenarios with broadly-defined policies to encourage clean energy and carbon reductions provide more affordable and flexible options than prescriptive targets for specific technologies that narrow utilities' choices (e.g., RPS)
4. Palo Verde is critical to meeting future clean energy goals at low costs; replacing it with other resources would considerably increase customer costs and require substantial development time
5. Scenarios with early retirement of Four Corners show significant carbon benefits, but would require large replacement investments in the next decade to maintain reliability
6. Even in deep decarbonization scenarios, firm gas resources play a crucial reliability role but operate infrequently and at low capacity factors

# Towards a clean low-carbon grid

+ A balanced portfolio of resources will best enable a transition to a low-carbon grid while still meeting objectives of affordability and reliability
+ The characteristics of each resource inform its role in a low-carbon grid
+ Removing any single component from this picture could considerably increase the challenge of achieving objectives

## Meeting grid needs in a clean, low-carbon grid

| | Energy | Flexibility | Capacity | Description of Role |
|---|---|---|---|---|
| **Nuclear** | ● | — | ● | Provides stable source of firm carbon-free power |
| **Renewables** | ● | ○ | — | Offers low-cost but intermittent carbon-free power |
| **Storage** | — | ● | ○ | Balances renewable variability, provides some capacity |
| **Gas** | — | ○ | ● | Serves as low-cost standby resource to meet reliability |
| **DSM** | ○/● | ○/● | ○/● | Offers dynamic customer response to grid needs |

How **clean** is my portfolio? (Energy)

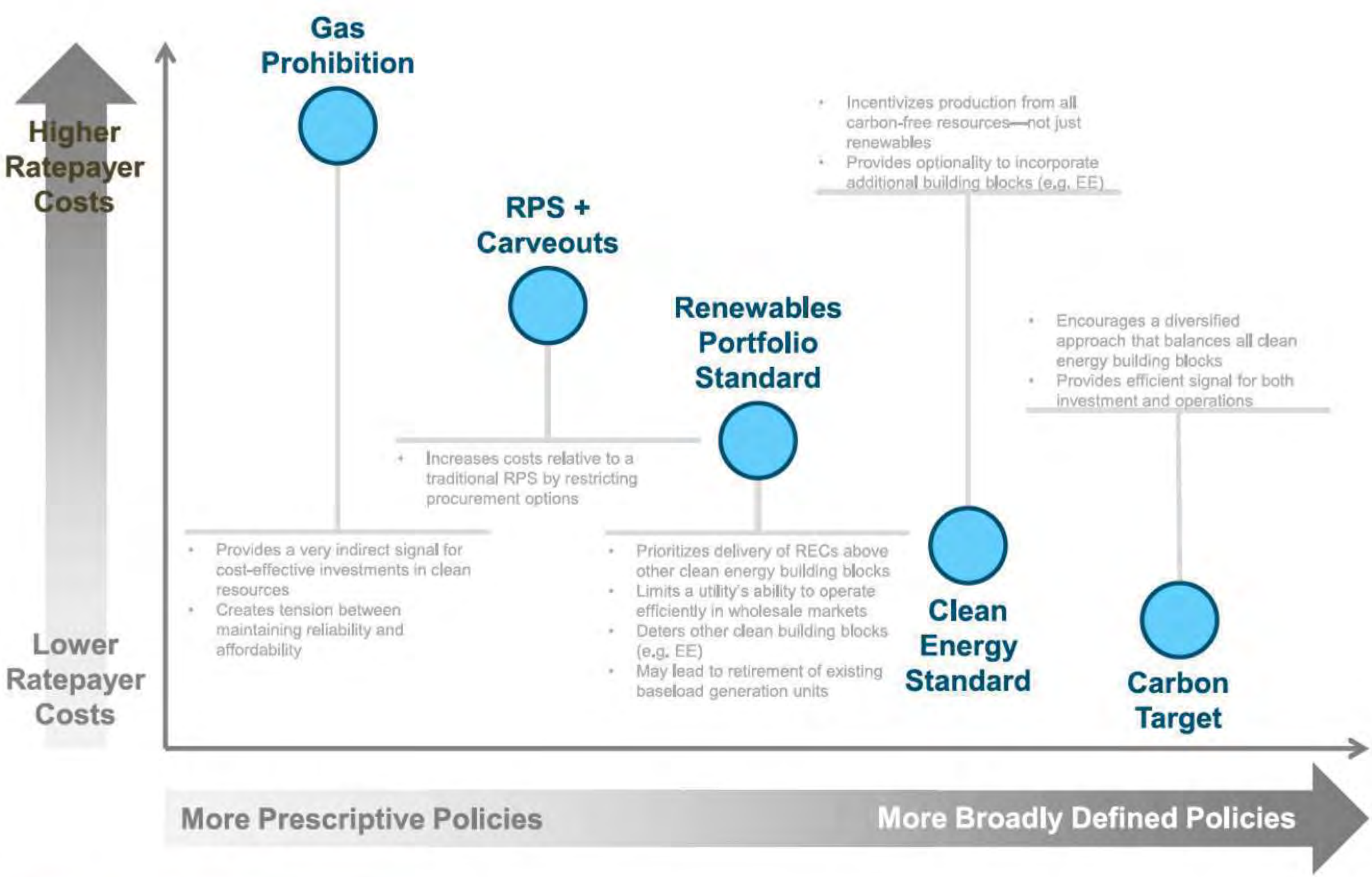
How **reliable** is my portfolio? (Capacity)

● **Primary purpose(s)**

○ *Secondary purpose(s)*

— *Small or negligible contribution*

# Defining a spectrum of policy options



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# Appendix: Sensitivity Analysis

# Matrix of sensitivities tested

+ **Additional sensitivities added to explore issues and questions raised by stakeholders**

Results shared with NDA stakeholder group on 6/24 — New sensitivities

| Scenario ID | | Base Case | Sensitivity Analyses: High DR | Low DG | No Tolling Renewal | Lower Wind Costs | High DSM | No Storage Goal | Low Load Growth | High Load Growth | Lower Solar Costs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Baseline | | ● | | | | | ● | | ● | ● | ● |
| Carbon Targets | 40% by 2030 | ● | | | | | | | | | |
| | 50% by 2030 | ● | | | | | | | | | |
| | 60% by 2030 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| RPS Targets | 30% by 2030 | ● | | | | | | | | | |
| | 40% by 2030 | ● | | | | | | | | | |
| | 50% by 2030 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Clean Targets | 60% by 2030 | ● | | | | | | | | | |
| | 70% by 2030 | ● | | | | | | | | | |
| | 80% by 2030 | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Limited Gas Investment | | ● | | | | | | | | | |

* These scenarios assume Four Corners ceases operations at end of current fuel supply agreement (2031)

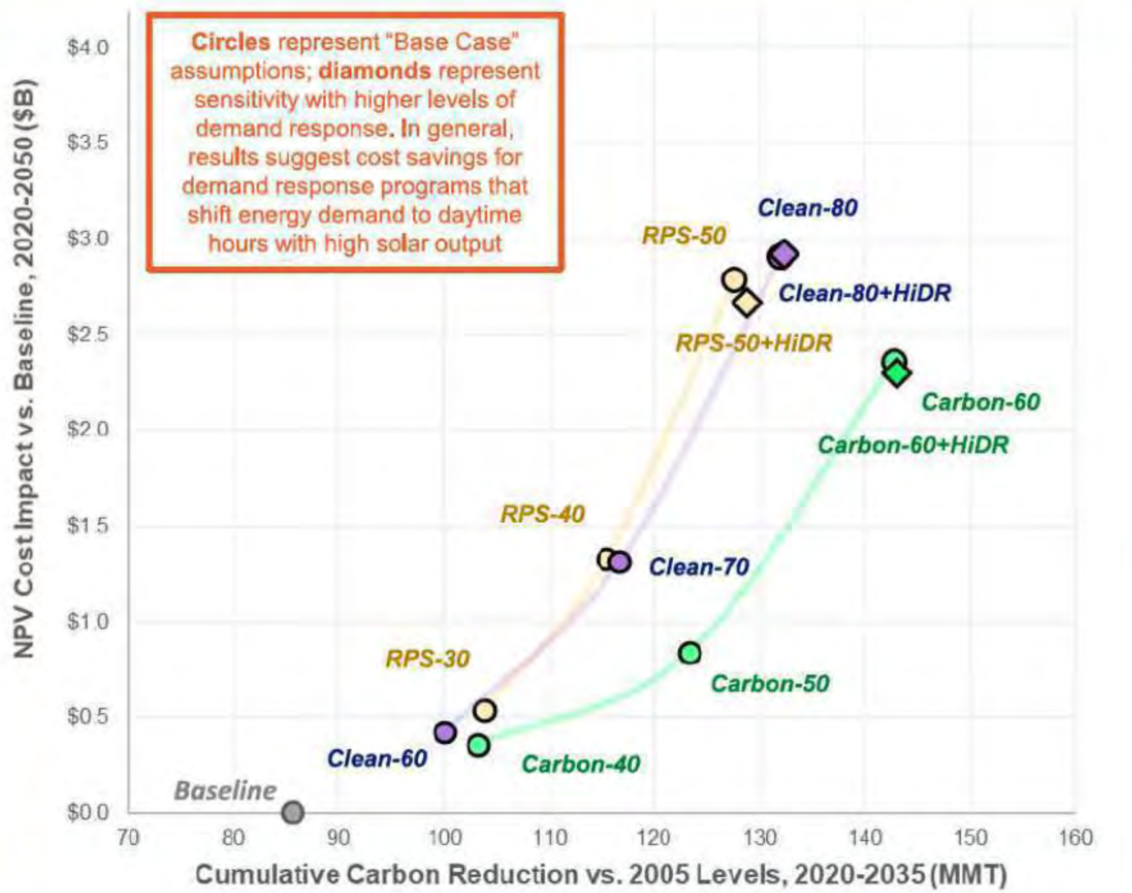
# Summary of sensitivity findings across sensitivities

## + Sensitivities have a range of impacts on portfolios, costs, and emissions—but none fundamentally alter the directional relationship among the policy scenarios analyzed

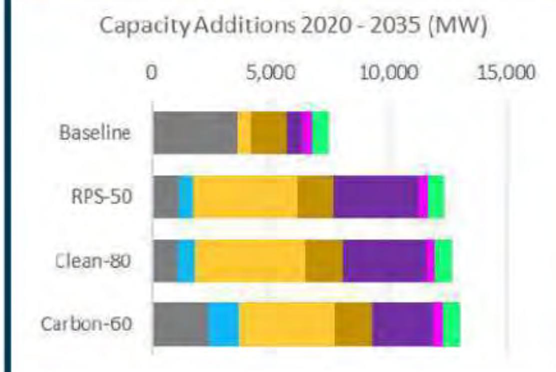
| Sensitivity | Observations |
|---|---|
| High DR | • Enables small cost reductions across all scenarios |
| Low DG | • Substantial potential reductions in costs of achieving RPS, Clean, and Carbon goals |
| High DSM | • Lower carbon in Baseline Case enables deeper carbon reductions at lower incremental costs in all scenarios |
| No Tolling Renewal | • Increase in costs for all scenarios—but particularly in Carbon scenarios that no longer benefit from the use of efficient CCGT capacity |
| No Storage Goal | • Minor impact on overall portfolio costs; no change in directional relationship among scenarios |
| Lower Wind Costs | • Additional wind resources and lower costs across RPS, Clean, and Carbon scenarios, but no change in directional relationship |
| Lower Solar Costs | • Results in significant reduction in the cost of achieving clean/carbon reductions, but no impact on directional relationship |
| Low/Flat Load Growth | • Leads to substantial reductions of carbon even in the Baseline case; exacerbates cost differences between meeting carbon reduction targets and targets focused on renewables/clean |
| High Load Growth | • Moderate increases in cost across all scenarios due to higher level of costs |

# Summary of Sensitivity Analysis
## High DR

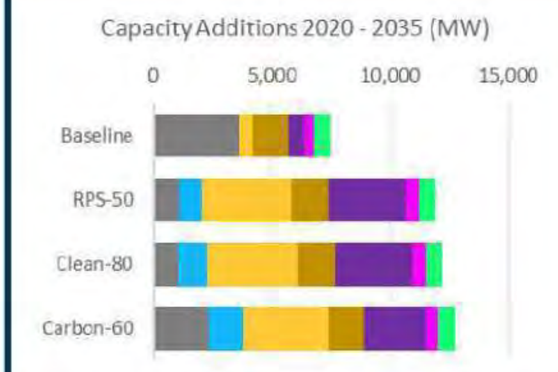
### Base Case vs. High DR Sensitivity




### Base Case



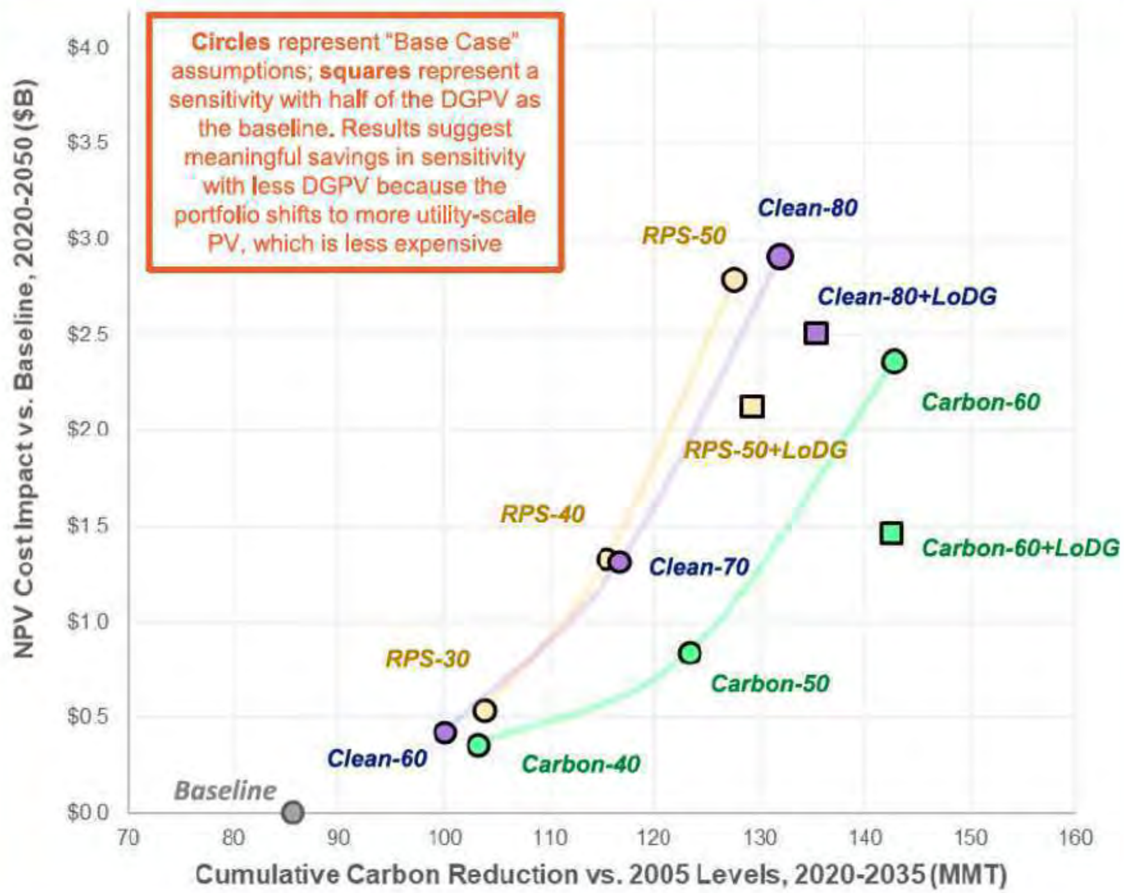

### High DR Sensitivity



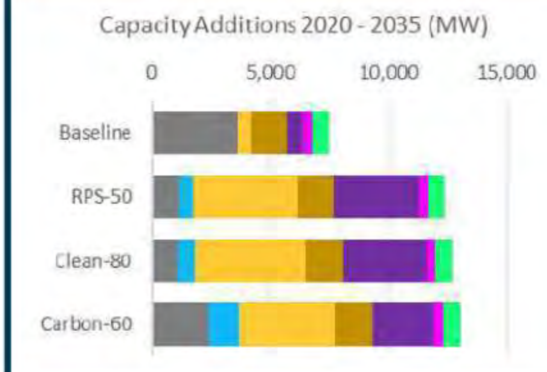

CT Wind BTM PV Solar Battery DR EE

# Summary of Sensitivity Analysis
## Low DG sensitivities

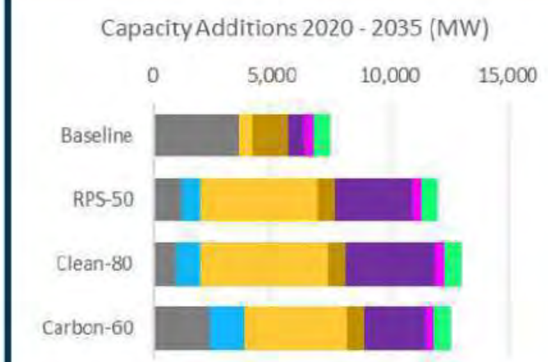
### Base Case vs. Low DG Sensitivity




### Base Case



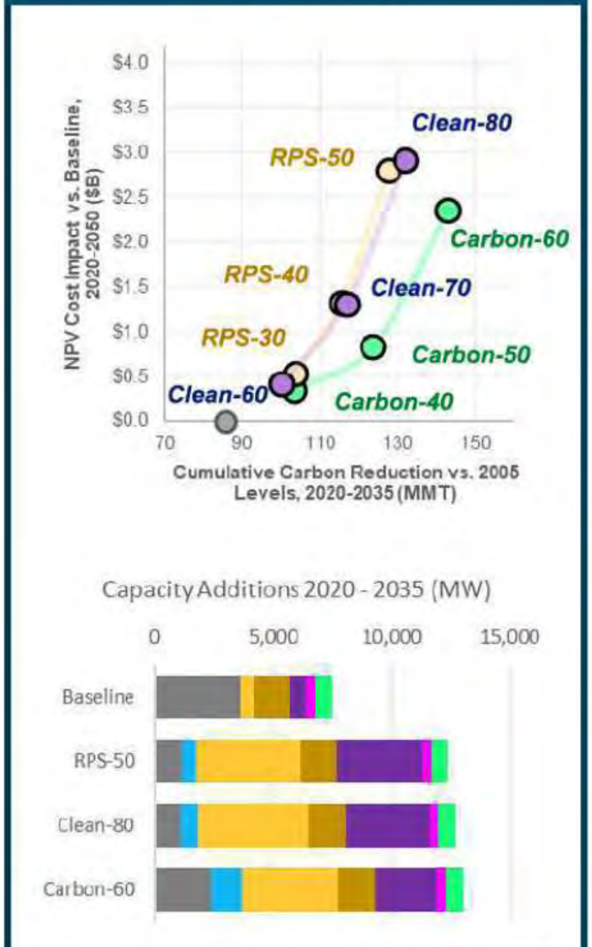

### Low DG Sensitivity



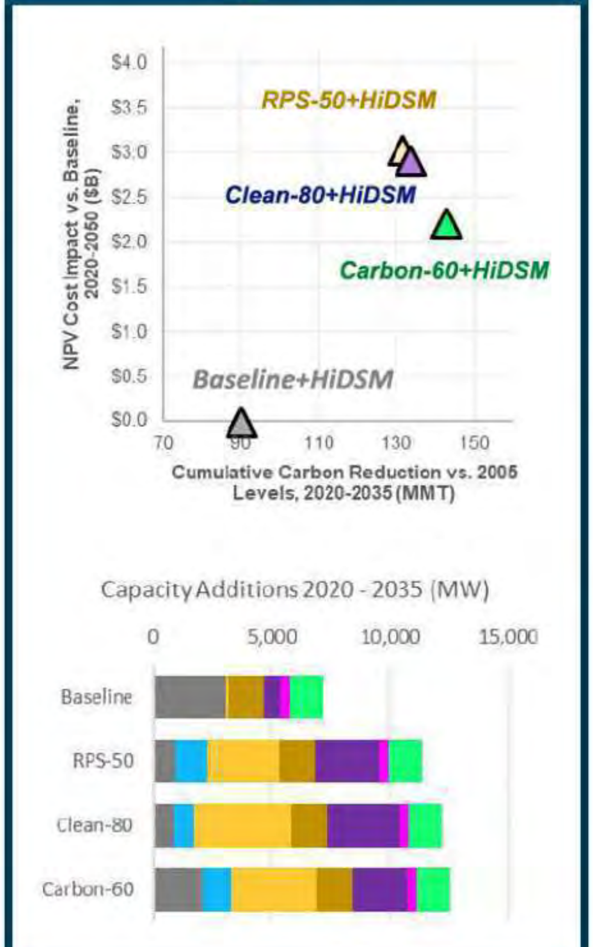

CT Wind BTM PV Solar Battery DR EE

# Summary of Sensitivity Analysis
## High DSM

### Base Case



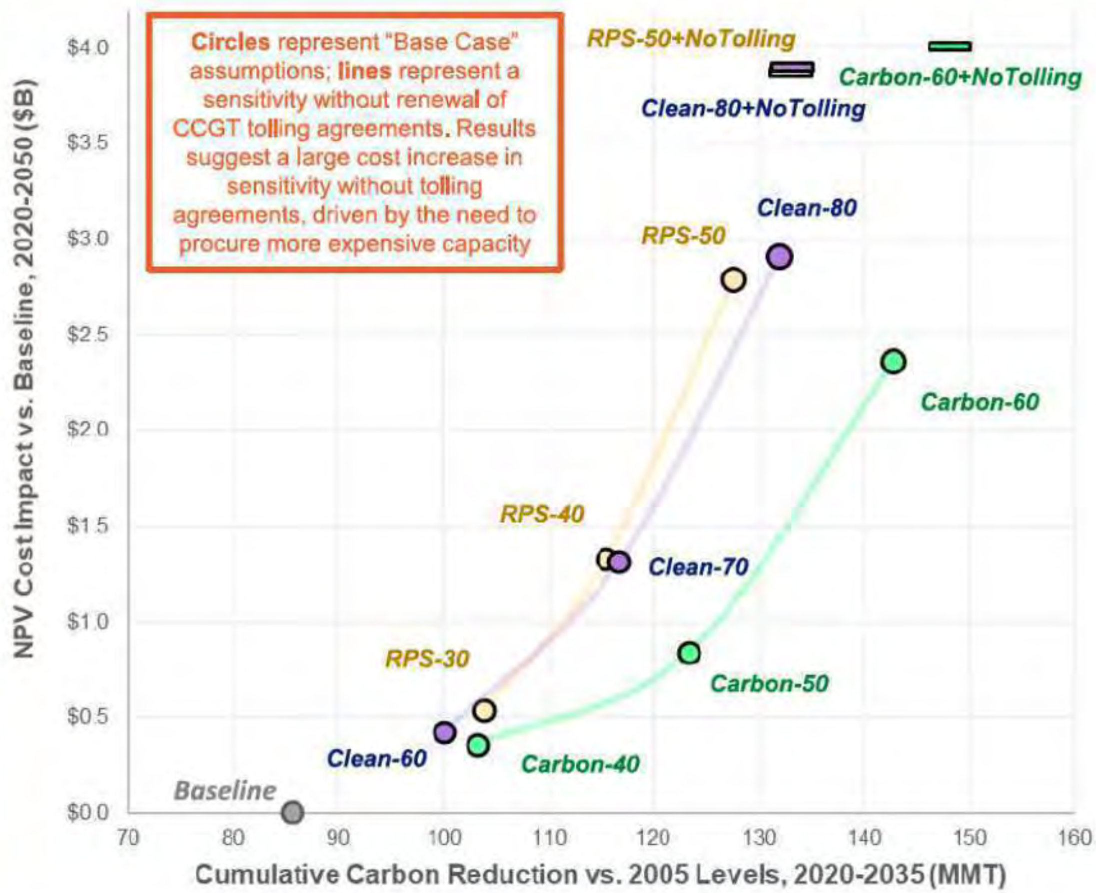

### High DSM



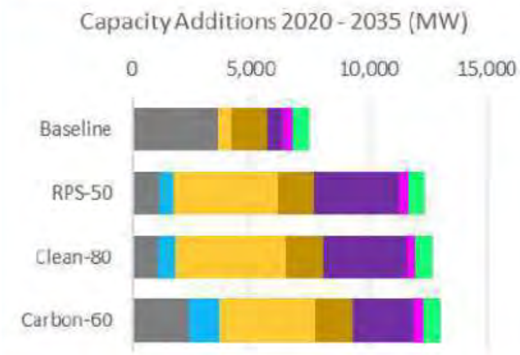

- **+ Lower incremental cost to achieve Carbon Target, but no significant change for RPS or Clean Energy Standard scenarios**
- **+ No impact on directional relationship**
- **+ Decrease in solar and storage buildout across scenarios**

# Summary of Sensitivity Analysis
## No Tolling Renewal

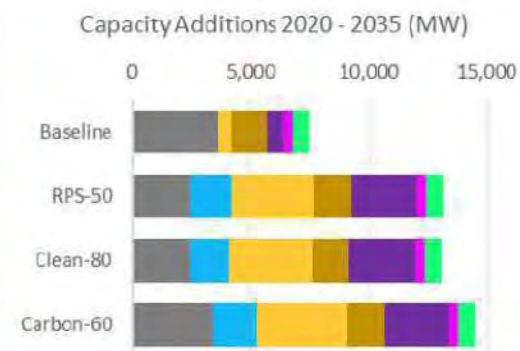
### Base Case vs. No Tolling Renewal Sensitivity




### Base Case




### No Tolling Renewal Sens.

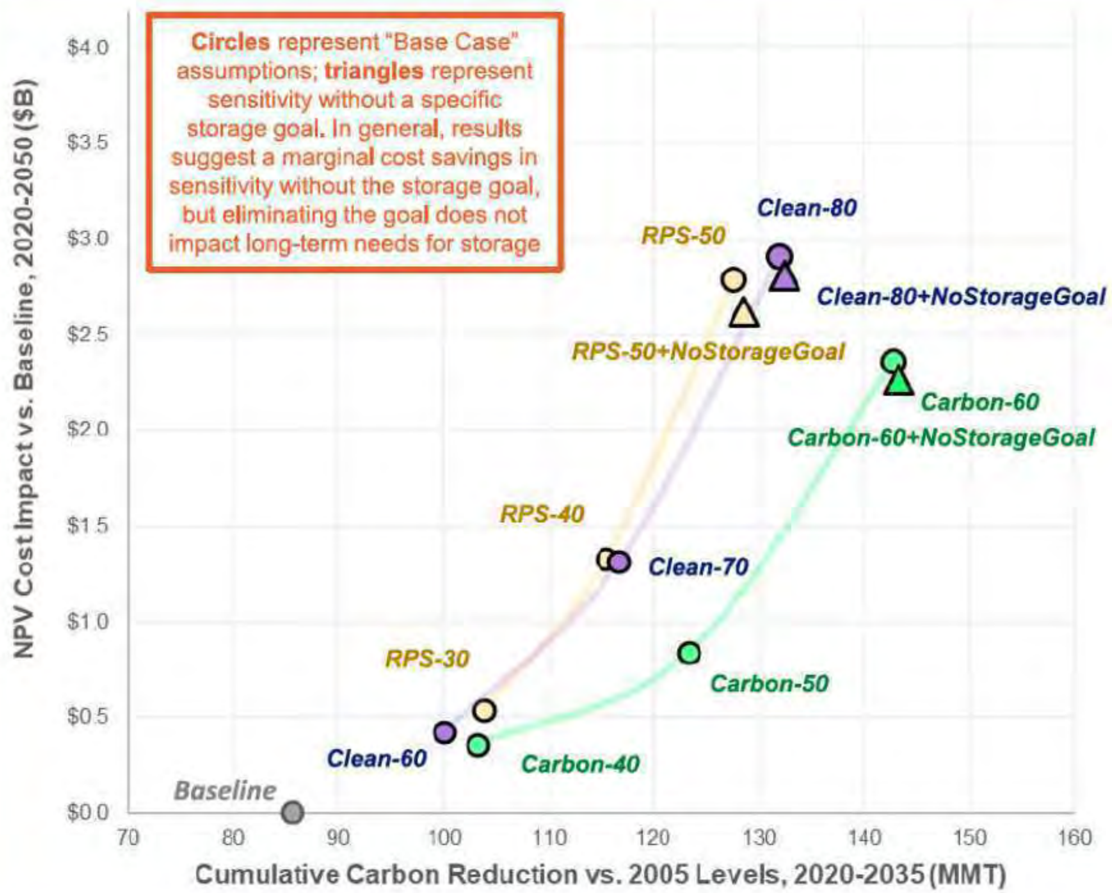



CT Wind BTM PV Solar Battery DR EE

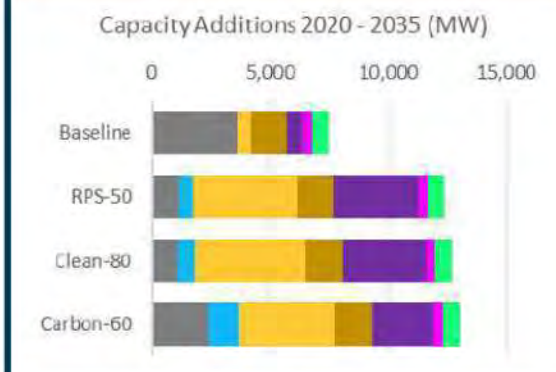
# Summary of Sensitivity Analysis

## No Storage Goal

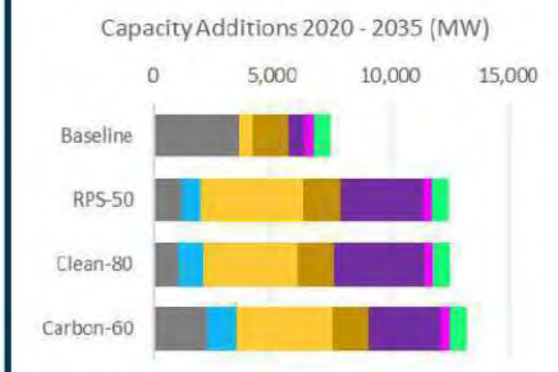
### Base Case vs. No Storage Goal Sensitivity




### Base Case




### No Storage Goal Sens.

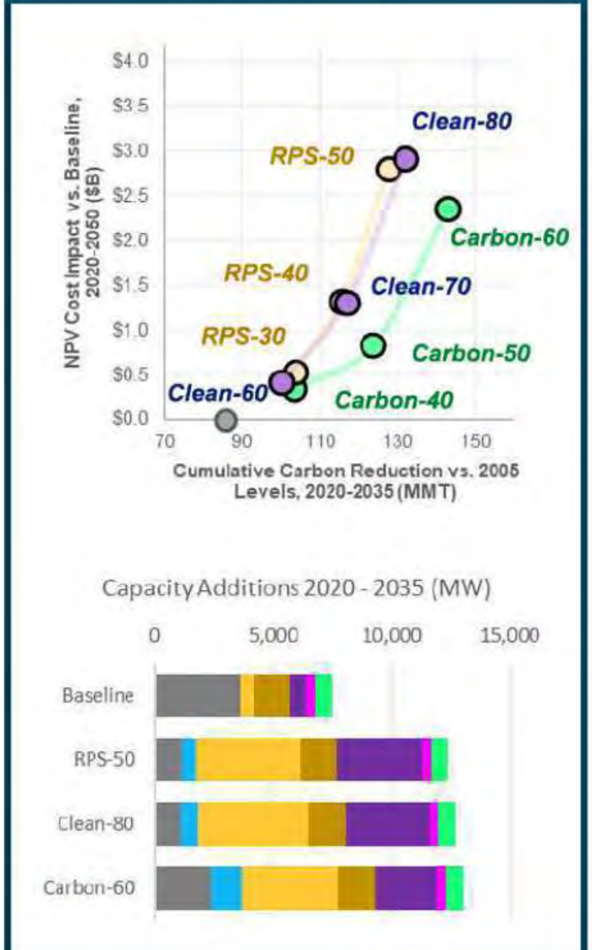



CT Wind BTM PV Solar Battery DR EE

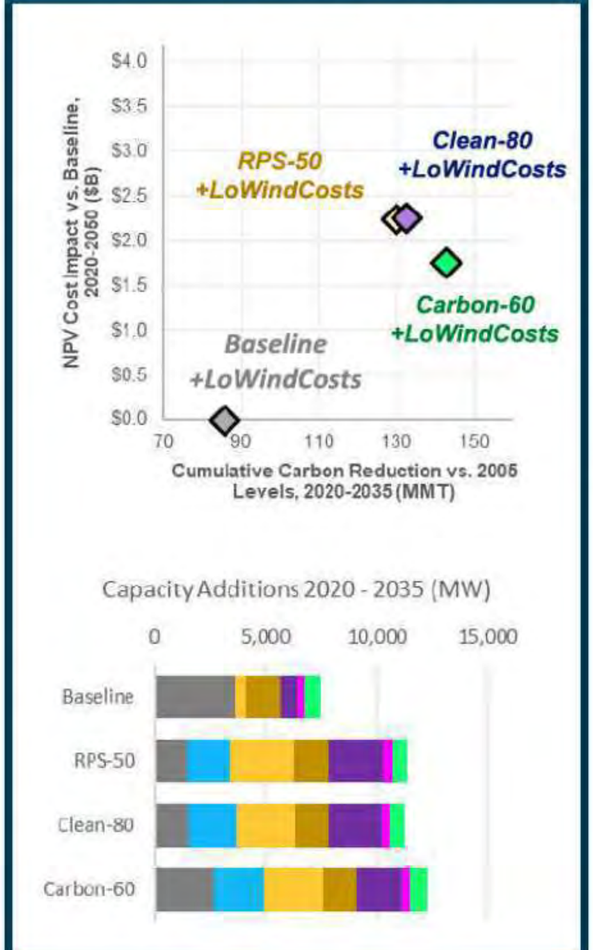
# Summary of Sensitivity Analysis

## Lower Wind Cost Sensitivity

### Base Case

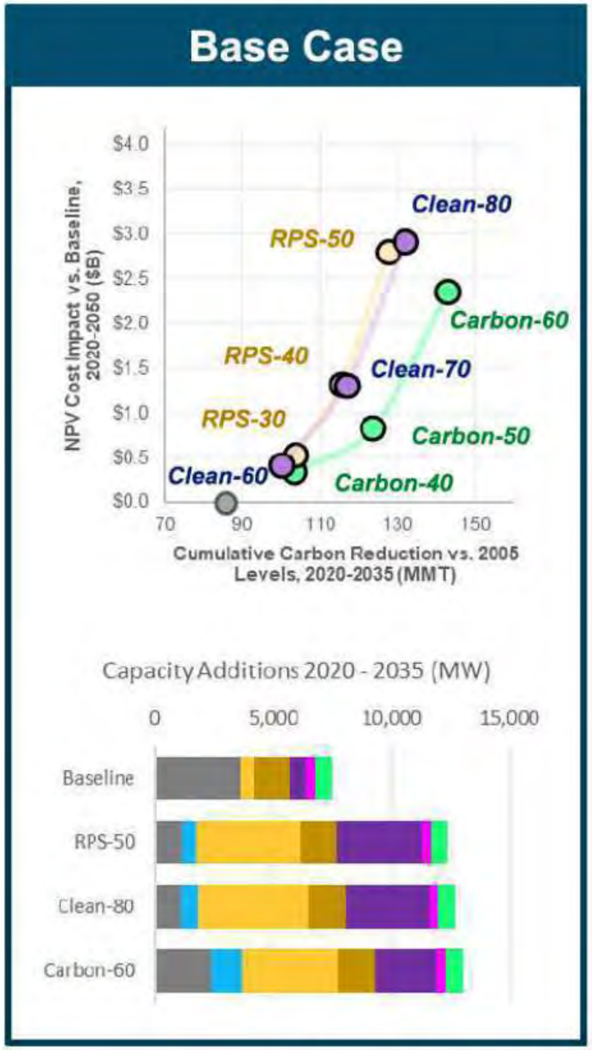


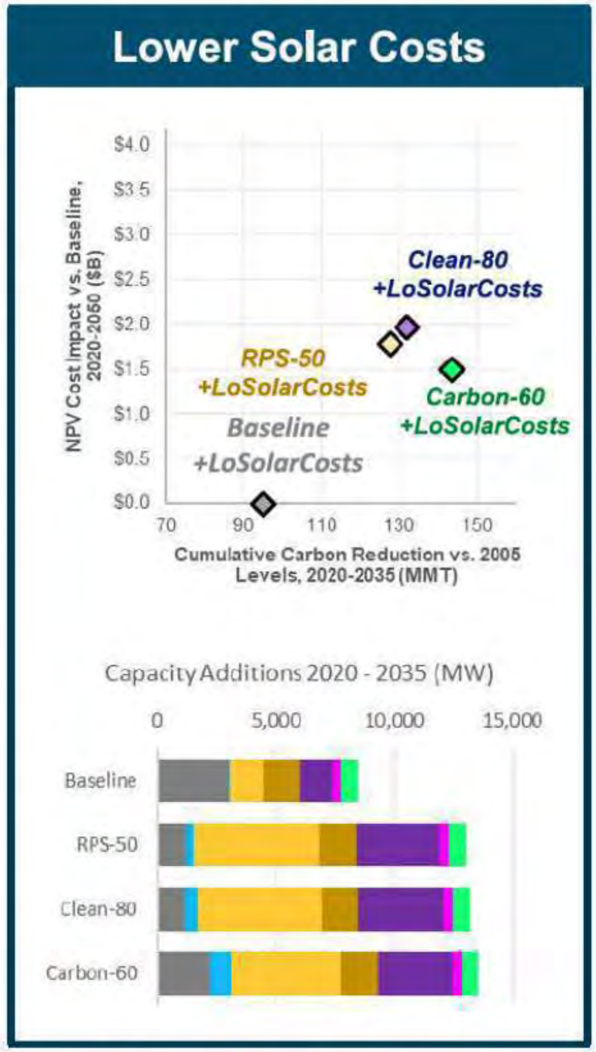

### Lower Wind Costs




- **Significantly lower costs to achieve incremental carbon reduction across scenarios**
- **No impact on directional relationship**
- **Increase in wind build and decrease in solar and storage build, resulting in a more even mix of resource additions**

# Summary of Sensitivity Analysis
## Lower Solar Cost Sensitivity



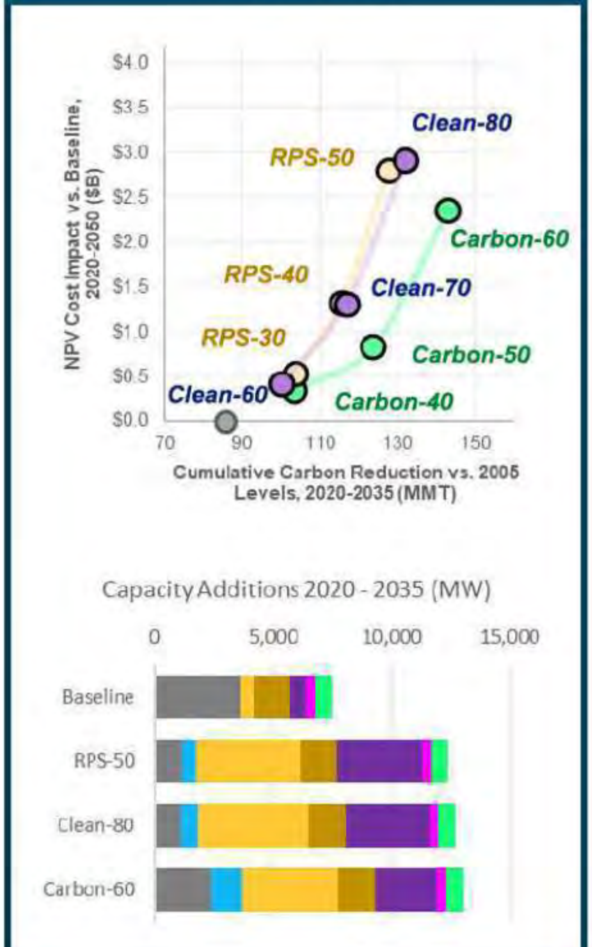

CT Wind BTM PV Solar Battery DR EE

- **Significantly lower costs to achieve incremental carbon reduction across scenarios**
- **No impact on directional relationship**
- **Small increase in solar buildout across scenarios**
  - Solar already the predominant resource selected in cases to meet needs for clean energy

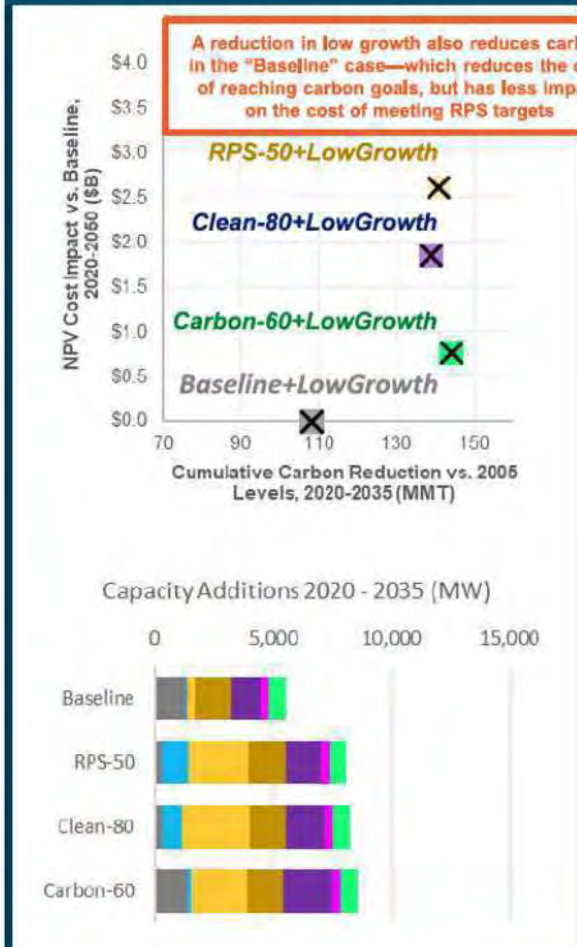
# Summary of Sensitivity Analysis

## Low Load Growth Sensitivities

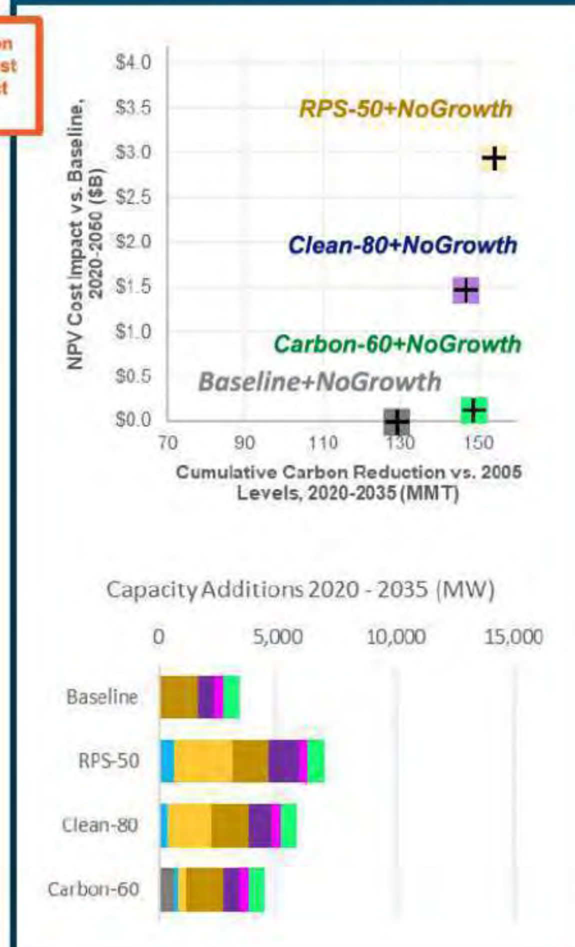
### Base Case




### Low Load Growth




### No Load Growth

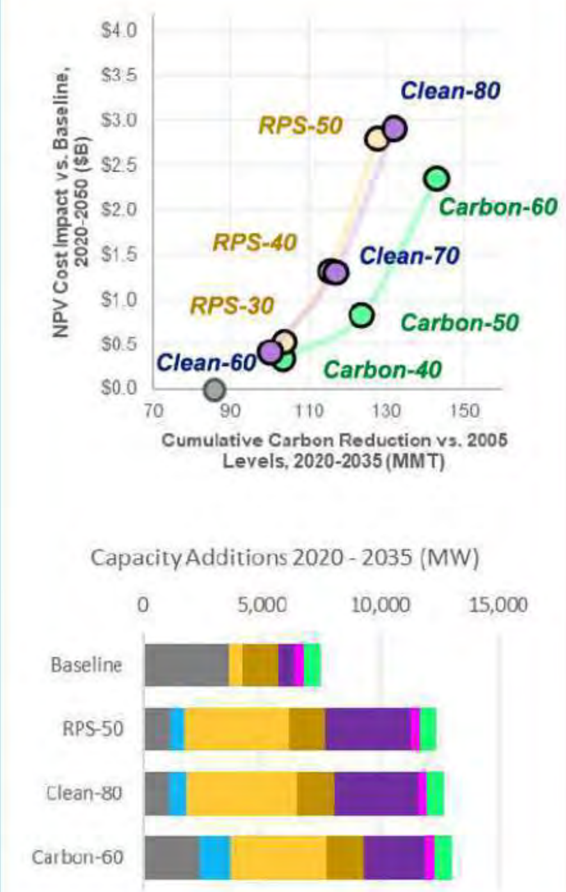



**CT** **Wind** **BTM PV** **Solar** **Battery** **DR** **EE**

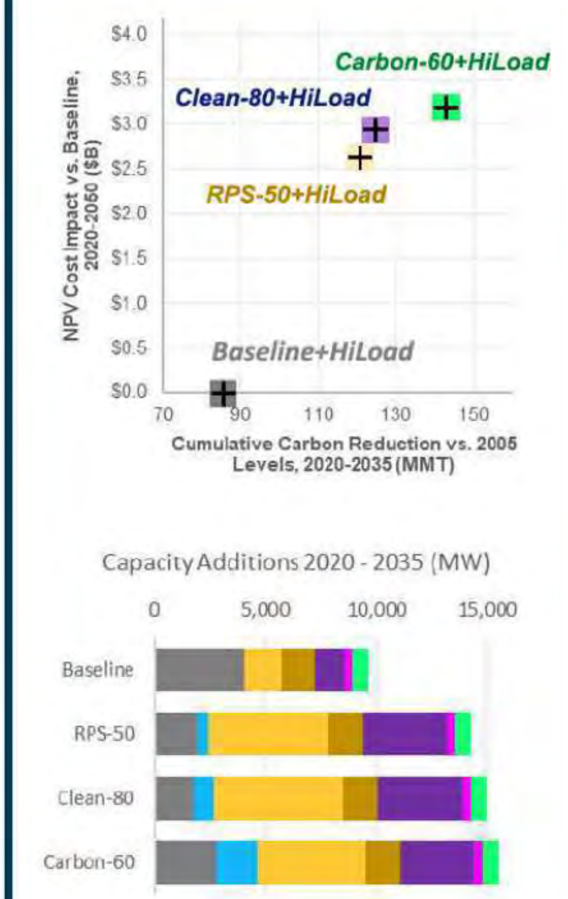
# Summary of Sensitivity Analysis

## High Load Growth Sensitivities

### Base Case




### High Load Growth




**CT Wind BTM PV Solar Battery DR EE**

- **High annual energy and peak needs result in increases in investment across all scenarios**
- **Moderate increase in costs to achieve the same level of carbon reduction across all scenarios**
- **No directional impact in cost different types of policies**

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# Appendix: Additional Detailed Results

# Change in installed capacity by scenario 2020 - 2025

| Scenario | Utility Solar | Wind | BTM Solar | Batteries | Gas CT | Gas CCGT* | Coal | Energy Efficiency | DR |
|---|---|---|---|---|---|---|---|---|---|
| ***2020 Installed Capacity (MW)*** | | | | | | | | | |
| 2020 System | 526 | 283 | 1,269 | 140 | 1,618 | 3,006 | 1,357 | 1,118 | 88 |
| ***2020-2025 Change in Capacity (MW)*** | | | | | | | | | |
| Baseline | +82 | — | +404 | +710 | +971 | +463 | -387 | +242 | +125 |
| Carbon-40 | +405 | — | +404 | +710 | +825 | +463 | -387 | +242 | +125 |
| Carbon-55 | +1,223 | — | +404 | +710 | +538 | +463 | -387 | +242 | +125 |
| Carbon-70 | +1,854 | +141 | +404 | +710 | +348 | +463 | -387 | +242 | +125 |
| RPS-30 | +526 | +42 | +404 | +722 | +754 | +463 | -387 | +242 | +125 |
| RPS-40 | +1,153 | — | +404 | +724 | +548 | +463 | -387 | +242 | +125 |
| RPS-50 | +1,873 | — | +404 | +710 | +412 | +463 | -387 | +242 | +125 |
| Clean-60 | +675 | — | +404 | +710 | +716 | +463 | -387 | +242 | +125 |
| Clean-70 | +1,347 | — | +404 | +710 | +510 | +463 | -387 | +242 | +125 |
| Clean-80 | +1,850 | +119 | +404 | +710 | +357 | +463 | -387 | +242 | +125 |

* Changes in CCGT capacity from one period to the next represent the planned addition and subsequent expiration of a tolling agreement with a merchant gas generator

# Change in installed capacity by scenario 2020 - 2030

| Scenario | Utility Solar | Wind | BTM Solar | Batteries | Gas CT | Gas CCGT* | Coal | Energy Efficiency | DR |
|---|---|---|---|---|---|---|---|---|---|
| ***2020 Installed Capacity (MW)*** | | | | | | | | | |
| 2020 System | 526 | 283 | 1,269 | 140 | 1,618 | 3,006 | 1,357 | 1,118 | 88 |
| ***2020-2030 Change in Capacity (MW)*** | | | | | | | | | |
| Baseline | +201 | +3 | +954 | +711 | +2,412 | — | -387 | +481 | +250 |
| Carbon-40 | +1,096 | — | +954 | +866 | +2,034 | — | -387 | +481 | +250 |
| Carbon-55 | +2,037 | +190 | +954 | +995 | +1,682 | — | -387 | +481 | +250 |
| Carbon-70 | +3,615 | +661 | +954 | +1,344 | +1,078 | — | -387 | +481 | +250 |
| RPS-30 | +1,981 | +274 | +954 | +1,073 | +1,608 | — | -387 | +481 | +250 |
| RPS-40 | +2,875 | +320 | +954 | +1,199 | +1,387 | — | -387 | +481 | +250 |
| RPS-50 | +4,340 | +581 | +954 | +1,957 | +1,184 | — | -387 | +481 | +250 |
| Clean-60 | +1,713 | +0 | +954 | +1,144 | +1,714 | — | -387 | +481 | +250 |
| Clean-70 | +3,452 | +323 | +954 | +1,105 | +1,410 | — | -387 | +481 | +250 |
| Clean-80 | +4,174 | +776 | +954 | +2,384 | +1,054 | — | -387 | +481 | +250 |

* Changes in CCGT capacity from one period to the next represent the planned addition and subsequent expiration of a tolling agreement with a merchant gas generator

# Change in installed capacity by scenario 2020 - 2035

| Scenario | Utility Solar | Wind | BTM Solar | Batteries | Gas CT | Gas CCGT* | Coal | Energy Efficiency | DR |
|---|---|---|---|---|---|---|---|---|---|
| ***2020 Installed Capacity (MW)*** | | | | | | | | | |
| 2020 System | 526 | 283 | 1,269 | 140 | 1,618 | 3,006 | 1,357 | 1,118 | 88 |
| ***2020-2035 Change in Capacity (MW)*** | | | | | | | | | |
| Baseline | +500 | +4 | +1,549 | +716 | +3,663 | — | -387 | +713 | +375 |
| Carbon-40 | +1,536 | +0 | +1,549 | +1,418 | +2,961 | — | -387 | +713 | +375 |
| Carbon-55 | +2,845 | +190 | +1,549 | +2,034 | +3,275 | — | -1,357 | +713 | +375 |
| Carbon-70 | +4,063 | +1,306 | +1,549 | +2,602 | +2,407 | — | -1,357 | +713 | +375 |
| RPS-30 | +2,012 | +299 | +1,549 | +1,719 | +2,553 | — | -387 | +713 | +375 |
| RPS-40 | +3,572 | +338 | +1,549 | +2,701 | +1,742 | — | -387 | +713 | +375 |
| RPS-50 | +4,413 | +586 | +1,549 | +3,547 | +1,184 | — | -387 | +713 | +375 |
| Clean-60 | +2,090 | +0 | +1,549 | +1,734 | +2,657 | — | -387 | +713 | +375 |
| Clean-70 | +3,452 | +323 | +1,549 | +2,572 | +1,827 | — | -387 | +713 | +375 |
| Clean-80 | +4,649 | +776 | +1,549 | +3,565 | +1,093 | — | -387 | +713 | +375 |

* Changes in CCGT capacity from one period to the next represent the planned addition and subsequent expiration of a tolling agreement with a merchant gas generator

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# Appendix: Review of E3's Regional Planning Studies

# Key E3 resource planning studies

- E3's resource planning studies focus on questions of how to meet aggressive carbon reduction and clean energy goals in the electric sector while maintaining reliability and managing costs

- 2016 Power Supply Improvement Plan (HECO, 2016)
- Pacific Northwest Low Carbon Scenario Analysis (PGP, 2017)
- Ongoing IRP Support (CPUC, 2016-'19)
- 2018 IRP Support (SMUD, 2018)
- Deep Decarbonization in a High Renewables Future (CEC, 2018)
- Upper Midwest 2019 IRP Support (Xcel, 2018-'19)
- Resource Adequacy in the Pacific Northwest (Various utilities, 2019)
- Resource Adequacy under Deep Decarbonization (Calpine, 2019)

# Key findings common across E3 studies

1. **Achieving a low-carbon grid is technically feasible and can be affordable, but eliminating carbon from the electricity sector entirely appears challenging and cost-prohibitive with current technologies**

2. A technology-neutral policy focused on carbon reductions will enable utilities to meet clean energy goals more affordably than policies that establish goals for specific technologies

3. Even in a deeply decarbonized grid, natural gas resources will continue to play a crucial role in meeting reliability needs as "firm" resources, dispatchable on demand but rarely called upon

4. Openness and transparency have become foundational characteristics of successful resource planning efforts, and collaboration between utilities and stakeholders is key to enabling a clean energy transition

# Reductions in technology costs have reduced costs to decarbonize supply

+ **Cost trends for emerging technologies have transformed the economics of decarbonization of electricity**
  - Availability of solar and wind at low PPA prices ($15-35/MWh) offers a competitive source of **energy** supply to displace fossil resources
  - Anticipated trends in costs of battery storage may offer a low cost solution to balancing & integration challenges
+ **Planning challenge for utilities seeking to decarbonize is balancing integration of renewables with maintaining a reliable system**

## Historical Solar PPA Price Trends

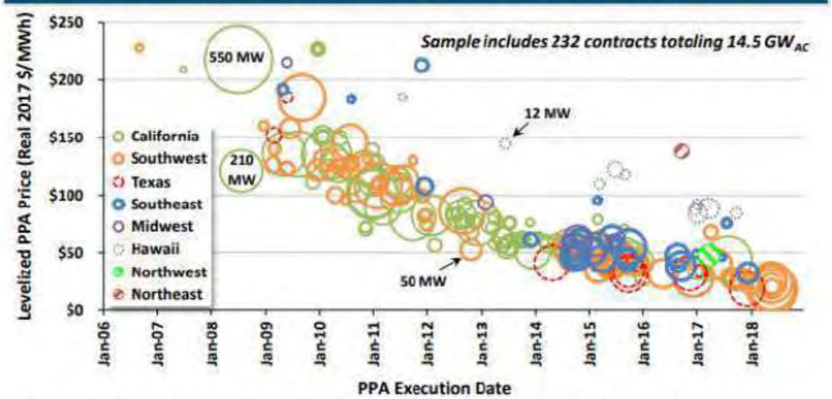



**Figure Source:** Utility Scale Solar, 2018 Edition (LBNL)

## Historical Wind PPA Price Trends

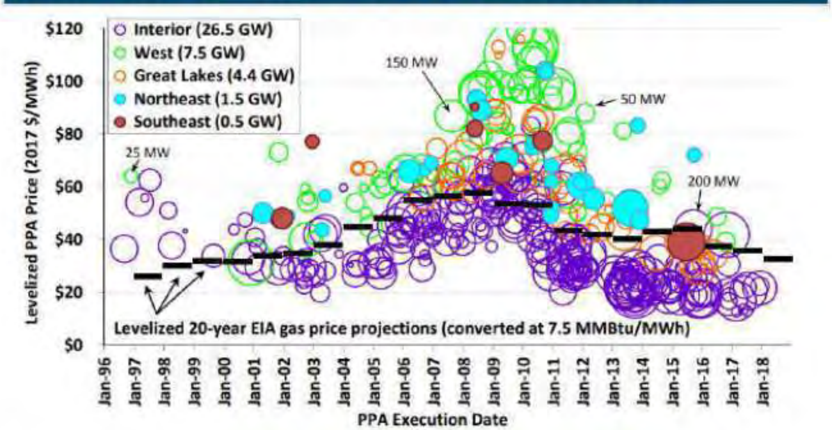


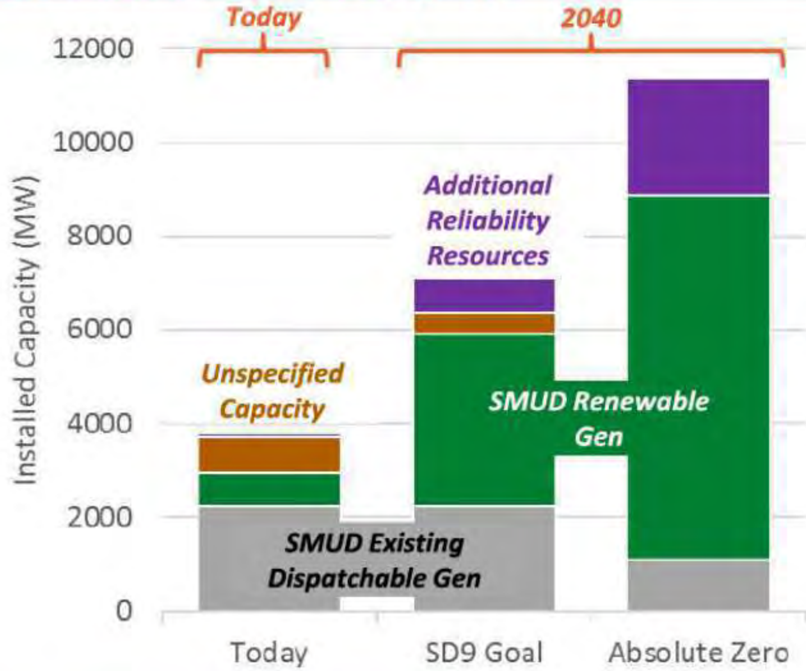

**Figure Source:** 2017 Wind Technologies Market Report (LBNL)

# SMUD 2018 Integrated Resource Plan

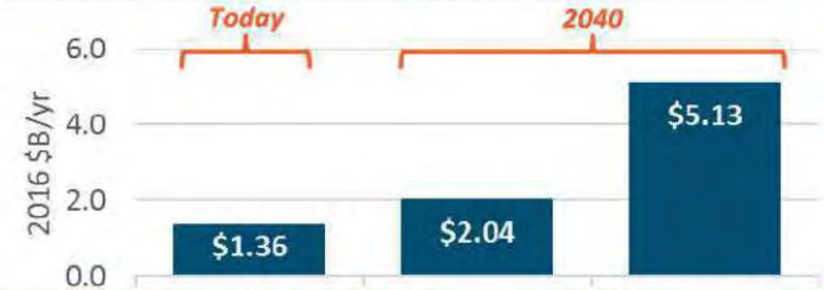
## Future Portfolios and Costs to Meet Carbon Goals

- **SMUD examined two bookend scenarios in its 2018 IRP process:**
  1. **SD9 Goal,** which is on a straightline path to meet the SMUD's goal of 90% carbon reductions by 2050; and
  2. **Absolute Zero,** which requires SMUD divest of its gas resources and serve all loads with carbon-free resources
- **Meeting SD9 goal appears affordable, but exponential cost increase to achieve "Absolute Zero" target is driven by reliability challenges without dispatchable resource capacity**

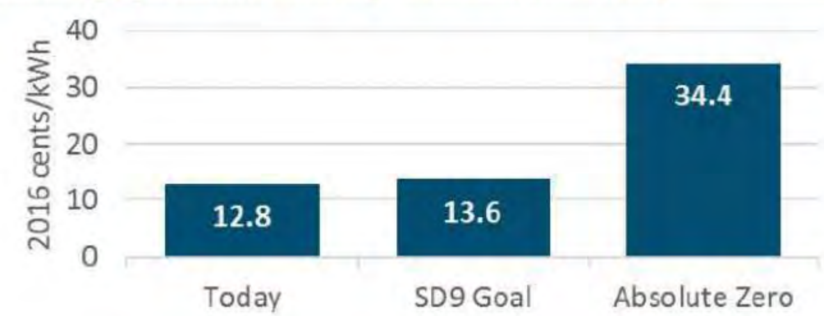
### Total Installed Capacity (MW)




### Revenue Requirement (2016 $B/yr)




### Average Retail Rate (2016 cents/kWh)

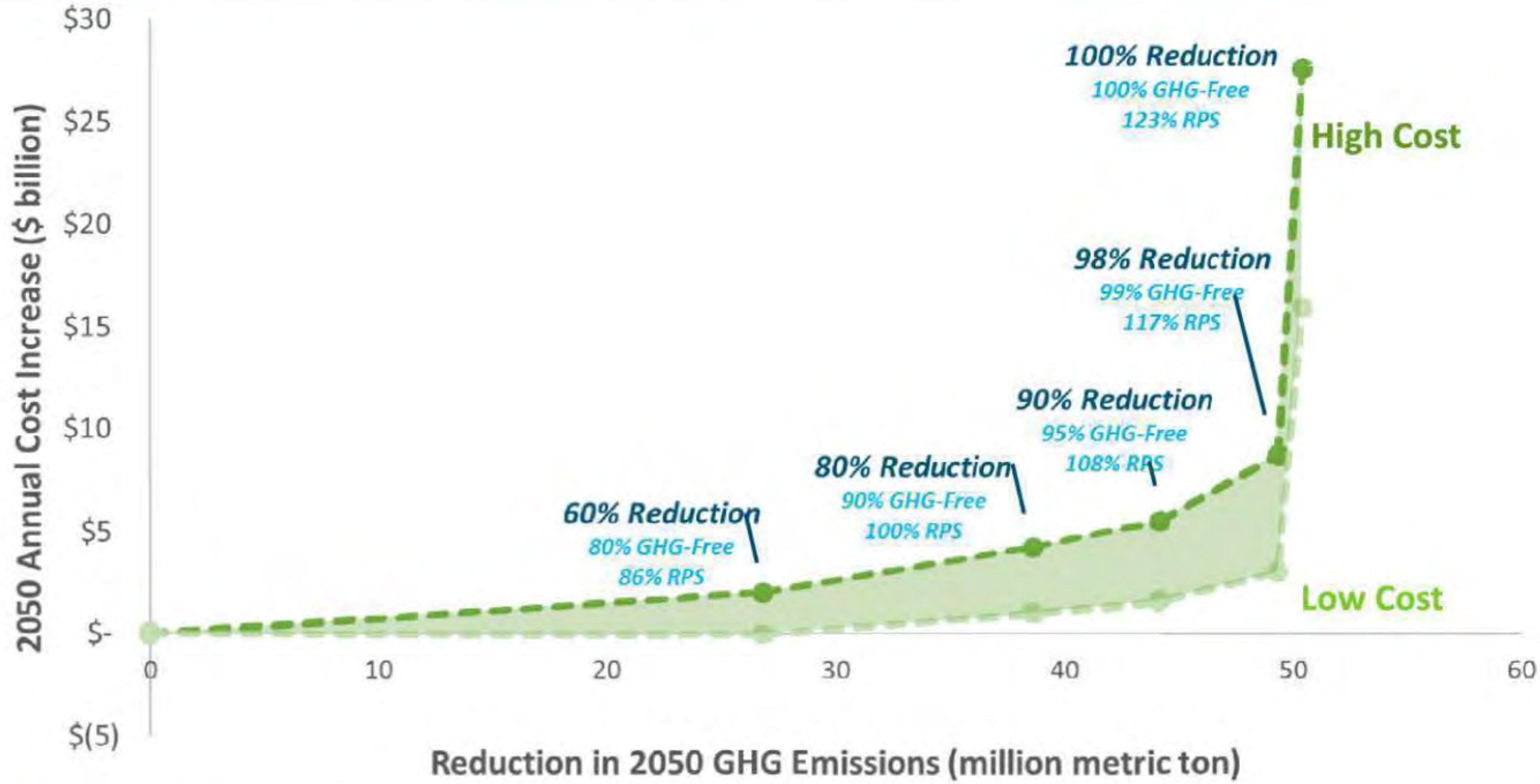


# Northwest Resource Adequacy Study

## Cost Curve for Decarbonizing Electricity

+ **Scenario analysis in the Northwest highlights low-cost opportunities to achieve significant carbon reductions with investment in renewables & coal shutdown**

### Annual Cost of Carbon Reductions in the Pacific Northwest



# Key findings common across E3 studies

1. Achieving a low-carbon grid is technically feasible and can be affordable, but eliminating carbon from the electricity sector entirely appears challenging and cost-prohibitive with current technologies

2. **A technology-neutral policy focused on carbon reductions will enable utilities to meet clean energy goals more affordably than policies that establish goals for specific technologies**

3. Even in a deeply decarbonized grid, natural gas resources will continue to play a crucial role in meeting reliability needs as "firm" resources, dispatchable on demand but rarely called upon

4. Openness and transparency have become foundational characteristics of successful resource planning efforts, and collaboration between utilities and stakeholders is key to enabling a clean energy transition

# Different approaches provide contrasting signals to clean energy building blocks

+ **The choice of a specific policy approach will have direct implications upon the types of resources that utilities are encouraged—and discouraged—from pursuing**

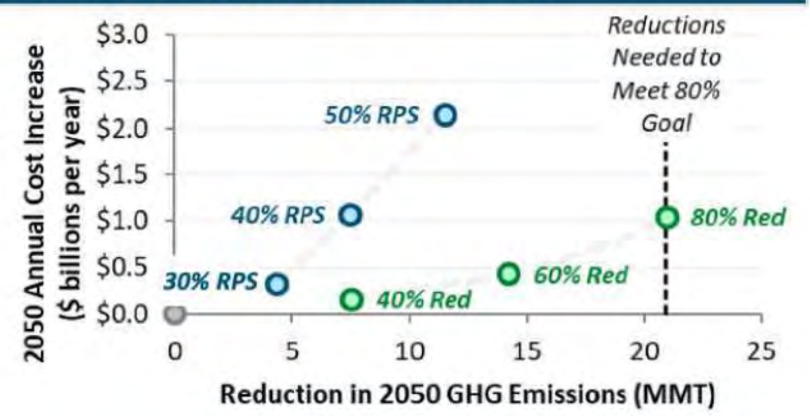
| Building Block | RPS | Clean | Carbon | No Gas |
|---|---|---|---|---|
| Nuclear | | ● | ● | ○ |
| Renewables | ● | ● | ● | ○ |
| Fuel switching | | | ● | |
| Clean imports | | ● | ● | |
| Electrification | | | ● | |
| Energy storage | ○ | ○ | ○ | ○ |
| Demand side management | | ● | ● | ○ |

● **Directly encouraged** ○ *Indirectly encouraged*

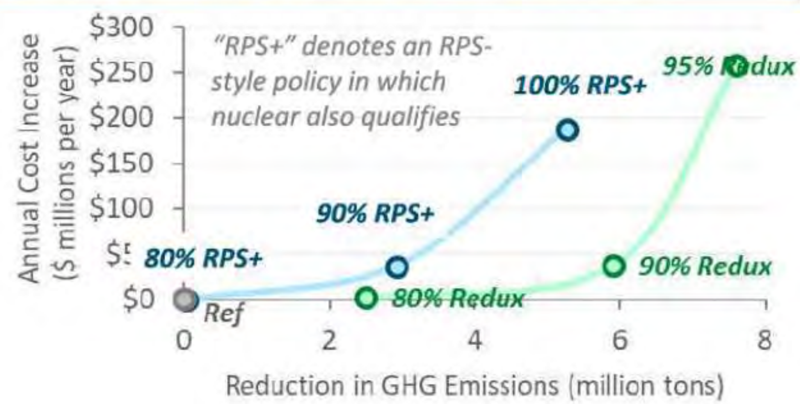
# Policy & strategy choices drive economics of decarbonization

- **Establishing policies, targets, and goals using carbon as the "currency" provides opportunities for least-cost emissions reductions**
  - RPS-style production quotas lead to higher costs and lower carbon reductions due to renewable integration challenges
  - Targets on carbon enables utilities to identify least-cost approach to meet clean energy goal using a combination of building blocks
- **Under all deep carbon reduction scenarios examined, expansion of renewable development is crucial to meeting targets**

## Cost vs. Carbon: Northwest




## Cost vs. Carbon: Xcel Minnesota



# Key findings common across E3 studies

1. Achieving a low-carbon grid is technically feasible and can be affordable, but eliminating carbon from the electricity sector entirely appears challenging and cost-prohibitive with current technologies

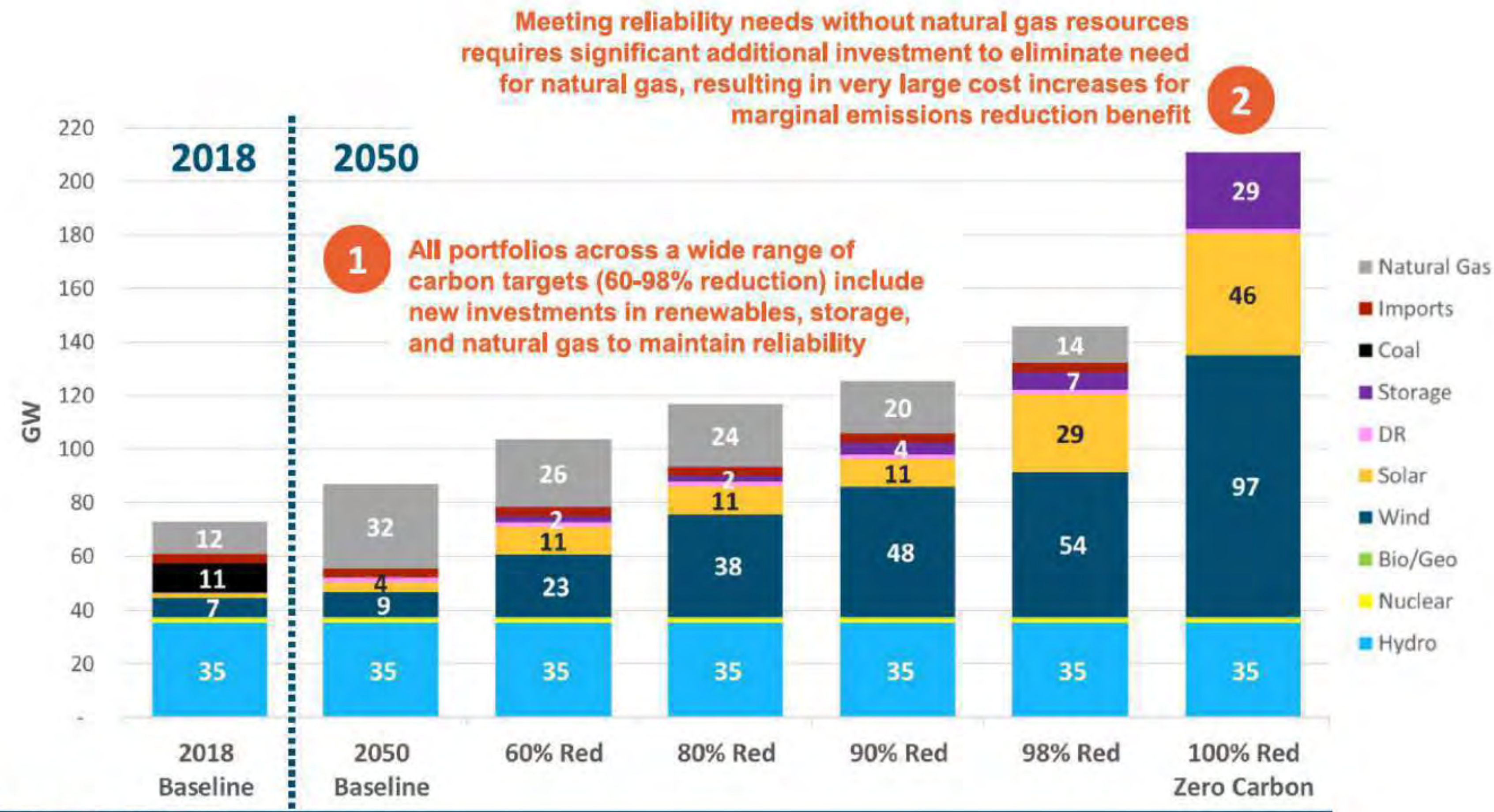
2. A technology-neutral policy focused on carbon reductions will enable utilities to meet clean energy goals more affordably than policies that establish goals for specific technologies

3. **Even in a deeply decarbonized grid, natural gas resources will continue to play a crucial role in meeting reliability needs as "firm" resources, dispatchable on demand but rarely called upon**

4. Openness and transparency have become foundational characteristics of successful resource planning efforts, and collaboration between utilities and stakeholders is key to enabling a clean energy transition

# Northwest Resource Adequacy Study

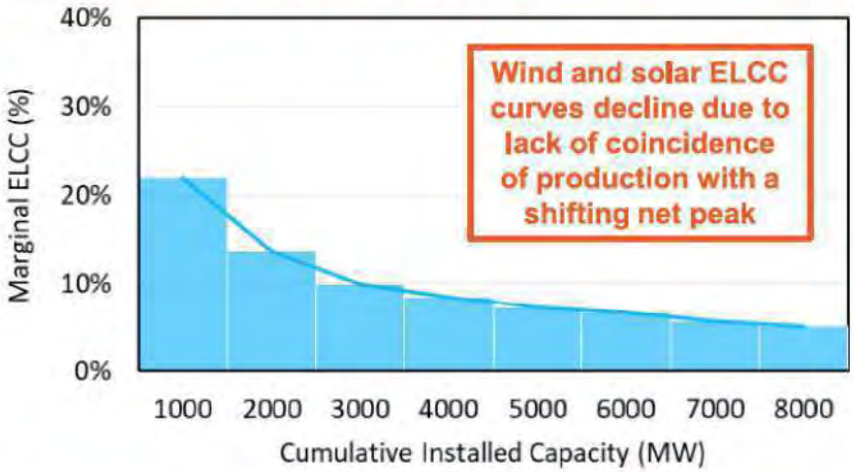
## Portfolios to Achieve a Range of Carbon Reductions



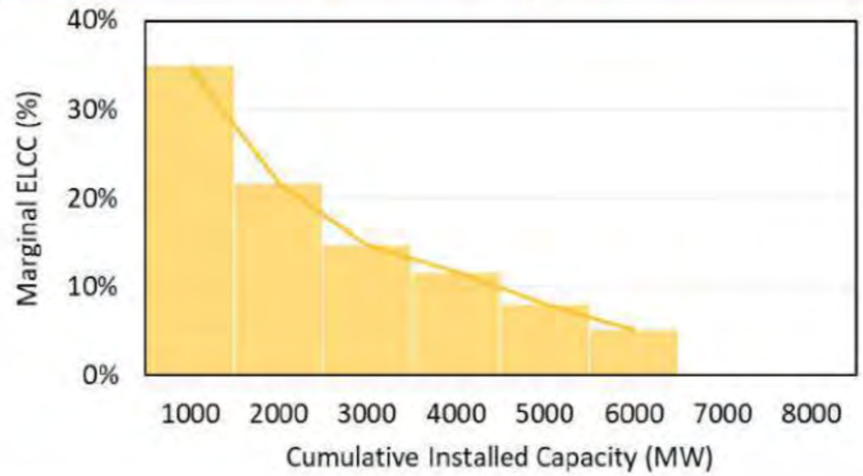

| Key Portfolio Metrics | 2018 Baseline | 2050 Baseline | 60% Red | 80% Red | 90% Red | 98% Red | 100% Red Zero Carbon |
|---|---|---|---|---|---|---|---|
| Annual Cost Delta ($B) | | — | $0 - $2 | $1 - $4 | $2 - $5 | $3 - $9 | $16 - $28 |
| Additional Cost ($/MWh) | | — | $0 - $7 | $3 - $14 | $5 - $18 | $10 - $28 | $52 - $89 |
| Gas Capacity Factor (%) | | 46% | 27% | 16% | 9% | 3% | 0% |

# Decarbonization Analysis for Xcel Energy
## ELCC Curves for Renewables & Storage

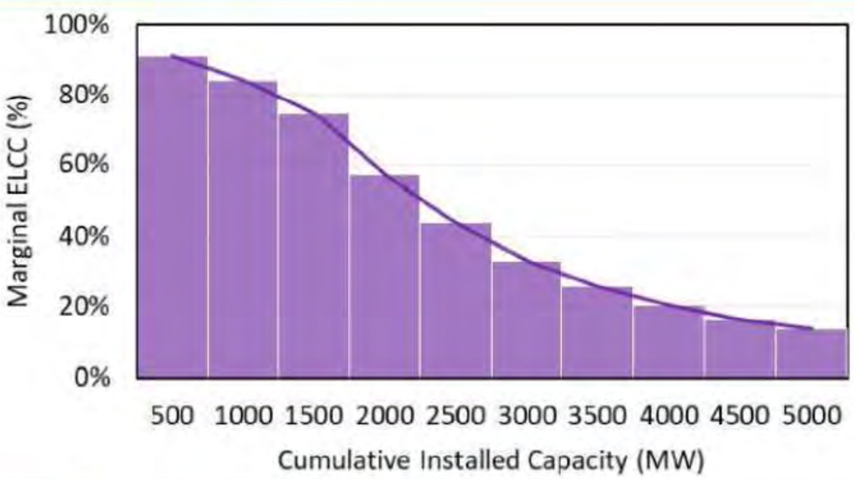
### Marginal ELCC (%) - Wind



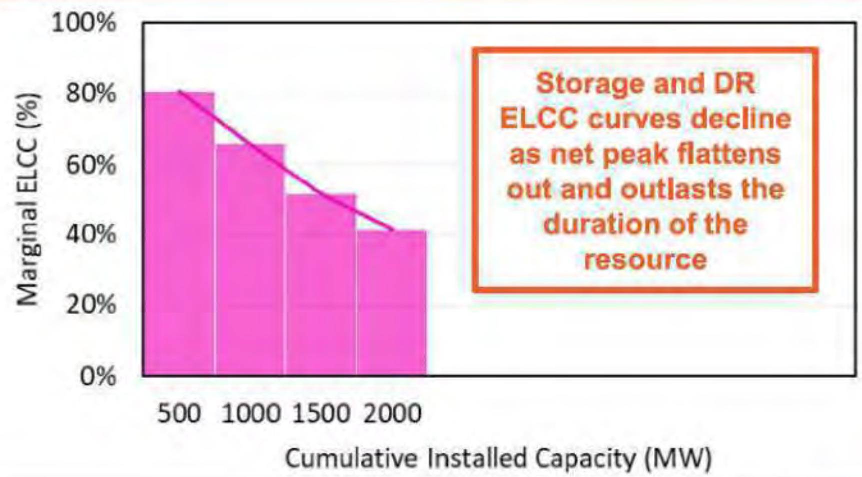

### Marginal ELCC (%) - Solar




### Marginal ELCC (%) – 4-hr Battery Storage



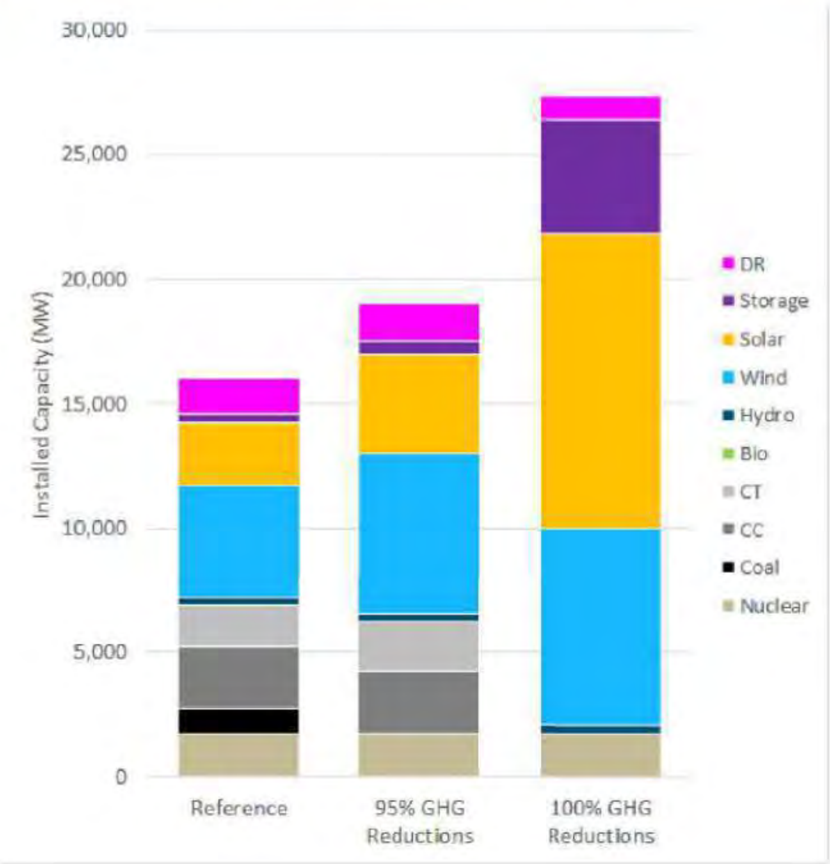

### Marginal ELCC (%) – 4-hr DR



# Decarbonization Analysis for Xcel Energy
## Portfolio Development to Reach Deep Carbon Reductions

- **In the absence of dispatchable gas and coal resources, significant new investment in renewables and storage are needed for reliability**
  - **20 GW** of wind and solar
  - **5 GW** of 17-hr storage
  - **+$2.9 billion/yr** in incremental fixed costs
- **Meeting reliability needs results in significant "overbuild" of renewables**
  - Renewables + nuclear capable of meeting **160%** of Xcel annual energy needs—but large quantities must be curtailed
- **Scale of investments results in exponential cost increase to achieve final 5% GHG reductions**

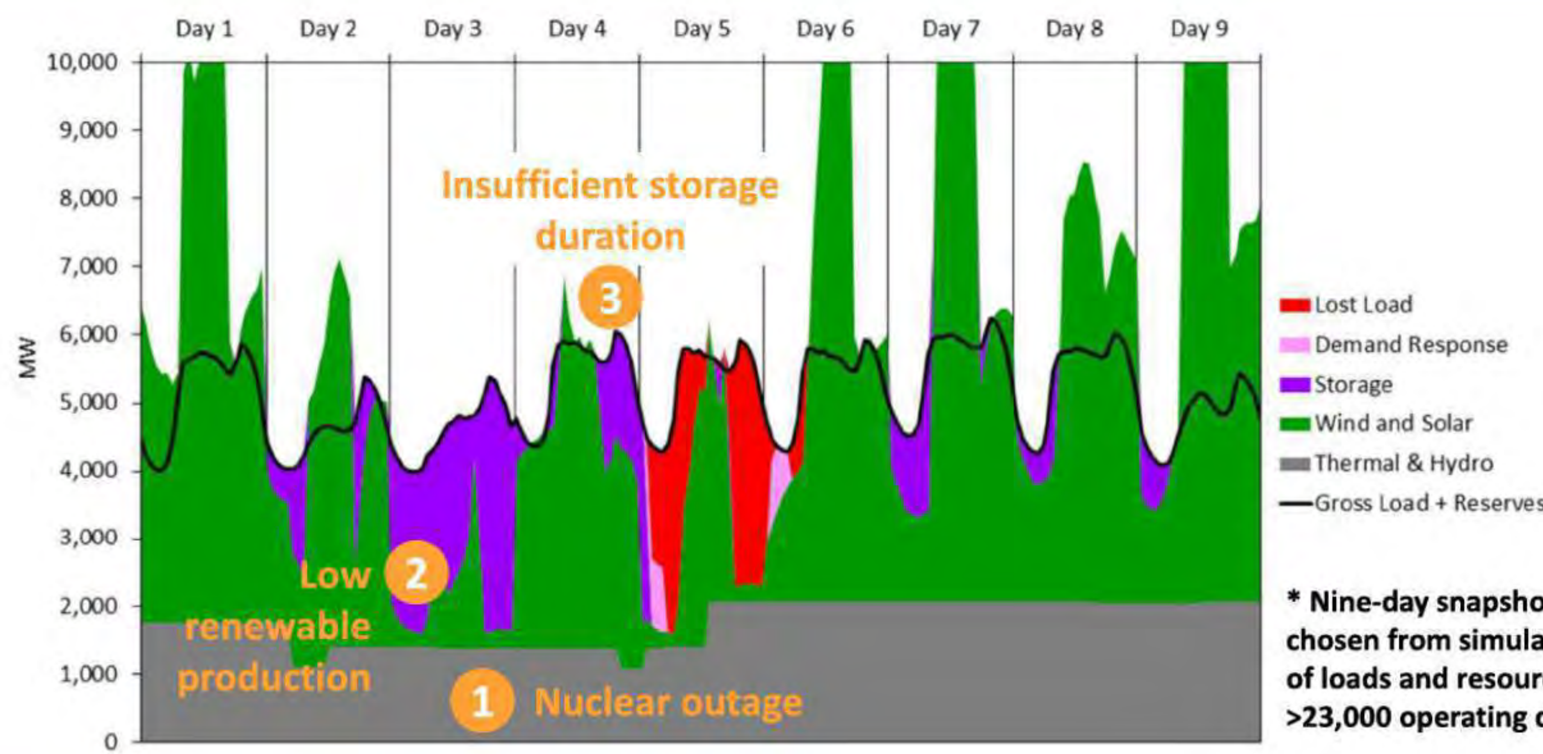
**Xcel 2030 Resource Portfolios**



# Decarbonization Analysis for Xcel Energy
## Reliability challenges in a 100% GHG reduction portfolio

- On a system that relies predominantly on variable resources & storage to meet reliability needs, reliability events result from sustained energy shortages—not peak needs
- Reliability challenges could alternatively be solved by resources that can dispatch on demand across extended periods but are rarely used

### Nine-Day Snapshot* of Resource Availability, 100% GHG Reduction Scenario




*** Nine-day snapshot chosen from simulation of loads and resources on >23,000 operating days**

# Key findings common across E3 studies

1. Achieving a low-carbon grid is technically feasible and can be affordable, but eliminating carbon from the electricity sector entirely appears challenging and cost-prohibitive with current technologies

2. A technology-neutral policy focused on carbon reductions will enable utilities to meet clean energy goals more affordably than policies that establish goals for specific technologies

3. Even in a deeply decarbonized grid, natural gas resources will continue to play a crucial role in meeting reliability needs as "firm" resources, dispatchable on demand but rarely called upon

4. **Openness and transparency have become foundational characteristics of successful resource planning efforts, and collaboration between utilities and stakeholders is key to enabling a clean energy transition**

# HECO Power Supply Improvement Plan
## Role of Stakeholder Process

+ **In support of HECO's 2016 PSIP, E3 developed portfolios to meet Hawaii's 100% renewable goal by 2045**
  - Analysis conducted using RESOLVE for optimal capacity expansion
+ **PSIP process design included a phase in which stakeholders submitted proposals for alternative scenarios for the company to evaluate and compare against its own plan**
+ **E3 worked closely with stakeholders to ensure their requests were accurately captured in the analysis, which helped inform comments**

**Oahu Installed Capacity, 2016 PSIP**