Attachment D

E3 Technical Review of Pasadena Water and Power's Integrated Resource Plan

Executive Summary

October 31, 2023

Energy Environment and Economics (E3) was contracted by Pasadena Water and Power (PWP) as a technical reviewer to provide validation, critiques, and insights to support the 2023 Integrated Resource Plan (IRP), which explores a set of scenarios to achieve a goal of a carbon-free electricity portfolio by 2030. E3 has worked extensively with utilities throughout North America (and specifically California) to develop high-quality, robust IRPs, providing both direct analytical support and critical analytical review to utilities seeking to decarbonize their portfolios while maintaining reliability.

The scope of this review consisted of a 1) evaluation of the methodology for consistency with industry standards, 2) review of inputs and assumptions, and 3) validation of results and key findings.

Overall, E3 found that the IRP framework as well as inputs and assumptions to be consistent with industry standard practices used by many utilities in long-term planning. Additionally, the results align with common trends seen in other jurisdictions seeking to decarbonize the electricity sector. All scenarios considered, including the Reference Case, reach ambitious carbon reduction goals by 2030 and 2040, achieving 80-100% and 90-100% carbon emissions reductions, respectively.

Key Takeaways

E3 finds that the overall IRP process and methodology is consistent with regulatory requirements and current industry standard practice.

- IRP aligns with the California Energy Commission (CEC) submission guidelines.
- Planning framework is transparent, engages stakeholders, and sets clear objectives.
- Analysis utilizes industry standard capacity expansion and system operation models.

E3 finds that the IRP inputs and assumptions, which were accessible for this review, are reasonable long-term planning assumptions, sourced from credible public sources where possible.

- Key sources include the CEC Integrated Energy Policy Report (IEPR) and the National Renewable Energy Laboratory Annual Technology Baseline (NREL ATB).
- Results of the IRP should be interpreted within the context of a rapidly shifting and uncertain market for clean energy; recent increases in PPA pricing provide an indication of directional changes in the industry that will impact costs of future decisions and will warrant continued monitoring as PWP makes progress towards its goals.

E3 concludes that the technical results are generally consistent with studies of ambitious clean energy objectives studied by other utilities and research institutions.

- All portfolios include a mix of renewables, energy storage, and "firm" resources (resources capable of operating at full capacity over sustained periods of time), following a common blueprint for electricity sector decarbonization observed across a range of studies.

- Scenarios that meet PWP's 2030 carbon-free goal are more ambitious than most of its peers' current goals, which requires significant additional resources and results in high costs: the implied cost of carbon abatement in these scenarios exceeds the social cost of carbon.
- Reliance on hydrogen fuel cells is a unique aspect of PWP's carbon-free portfolios; most other plans retain or repurpose natural gas until a commercial "clean-firm" alternative is viable.

While we find the overall IRP analysis and results to be generally reasonable, we also provide PWP with recommendations for future improvements to the IRP. Most importantly, we recommend that PWP continue to refine its forward-looking analysis of its system reliability needs to ensure that any plan developed ensures reliability for its customers.

The complete technical review report of PWP's 2023 IRP follows with additional results and recommendations.

Pasadena Water and Power Integrated Resource Plan (IRP)

E3 Review

October 31, 2023

Energy+Environmental Economics

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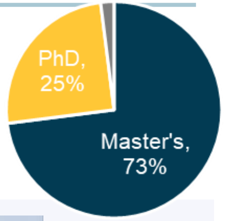
Who is E3?

Thought Leadership, Fact Based, Trusted.

100+ full-time consultants | 30 years of deep expertise | Engineering, Economics, Mathematics, Public Policy…

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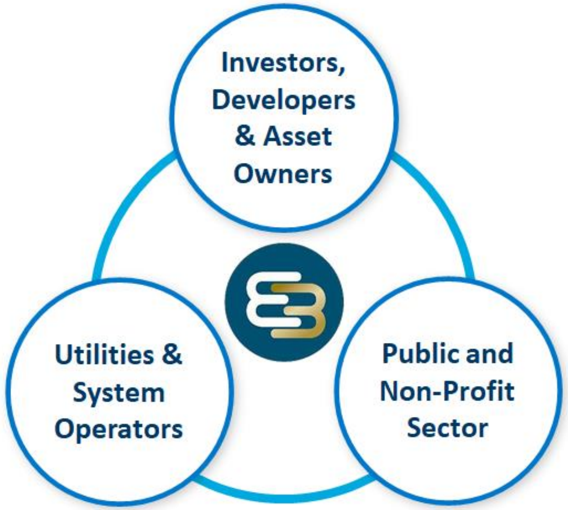
E3 Clients

300+ projects per year across our diverse client base



Recent Examples of E3 Projects

Buy-side diligence support on several successful investments in electric utilities (~$10B in total)

Acquisition support for investment in a residential demand response company (~$100M)

Supporting investment in several stand-alone storage platforms and individual assets across North America (10+ GW | ~$1B)

Acquisition support for several portfolios and individual gas-fired and renewable generation assets (20+ GW | ~$2B)

United Nations Deep Decarbonization Pathways Project

California: 100% clean energy planning and carbon market design for California agencies

Net Zero New England study with Energy Futures Initiative

New York: NYSERDA 100% clean energy planning

Pacific Northwest: 100% renewables and resource adequacy studies for multiple utilities

Integrated Resource Plan (IRP) Review Purpose

+ **E3 served as a technical reviewer of Pasadena Water and Power's (PWP's) IRP analysis.**
+ **The scope included an evaluation of the methodology for consistency with industry standards, review of inputs and assumptions, and validation of results and key findings, among others:**

Process & Methodology	• *CEC Alignment* • *IRP framework*	• *Modeling Methods* • *Scenario Design*
Inputs & Assumptions	• *Load Forecast* • *Resources*	• *Market Prices* • *Policies*
Results & Key Findings	• *Resource Mix* • *System Costs*	• *Benchmarking* • *Carbon Abatement Costs*

Pasadena set an ambitious goal of delivering hourly carbon free electricity … PWP's IRP explores strategies to accomplish that goal by 2030

Given the importance and impact for Pasadena, this review provides confirmations, critiques, and insights to support PWP in this challenge

Key Findings: Review of PWP's 2023 IRP

+ **IRP framework and inputs and assumptions generally follow industry standards and best practices**
+ **IRP results align with common trends seen in other jurisdictions seeking to decarbonize**

Process & Methodology

IRP complies with California Energy Commission (CEC) submission guidelines

—

Framework is transparent, engages stakeholders, and sets clear objectives

—

Modeling relies on industry standard standard capacity expansion and system operation modeling methods

E3 recommends additional reliability analysis in scenarios that include fossil retirement and hourly carbon-free goals

Inputs & Assumptions

Key inputs (load forecast, market and commodity prices, resource costs, etc.) are from reliable sources or analytical processes

Key sources: CEC Integrated Energy Policy Report, NREL Annual Technologies Baseline

—

Today's market environment is rapidly shifting, and results should be interpreted within this context

Recent upward pressure on resource PPA pricing will warrant continue market monitoring for future IRP updates

Results & Key Findings

Technical results are generally consistent with studies of low-carbon and carbon-free portfolios conducted by utilities and research institutions:

Significant additions of renewables and energy storage across all scenarios

Scenarios that meet PWP's carbon-free goal are more ambitious than most of its peers' current goals, requiring additional resources and resulting in higher costs

Reliance on fuel cells is a unique aspect of PWP's carbon-free portfolios; most other plans retain or repurpose natural gas until a commercial alternative is viable

Deep Decarbonization Planning Studies: Common Trends

+ **E3's work with utilities and regulators to develop long-term electric system resource plans that achieve ambitious clean energy targets support four common findings:**

1. **Technologies available today can enable significant progress** towards ambitious state and utility clean energy objectives
2. A **technology-neutral approach** to planning and procurement will enable utilities to meet reliability and clean energy goals most affordably
3. Decarbonization of **the "last 10%" poses the greatest challenge**, and may lead to significant increases in costs
4. Some form of **firm capacity is needed for reliability** even under a deeply decarbonized grid

+ These findings are supported by a growing body of literature, including recent studies by the National Renewable Energy Laboratory (NREL), Princeton University, the Electric Power Research Institute (EPRI), and the Massachusetts Institute of Technology (MIT)

Blueprint for a Low Carbon Grid

Scalable Low-Cost Clean Energy Resources

Today: wind, solar, efficiency

Future: nuclear small modular reactors (SMR), carbon capture & sequestration (CCS)

Balancing Resources

Today: batteries, pumped storage, hydro, demand response

Future: advanced flexible loads, other storage technologies

Firm Resources

Today: nuclear, natural gas, geothermal, biogas

Future: hydrogen, long-duration storage, nuclear SMR, CCS

Key Takeaways: PWP IRP Results Benchmarking

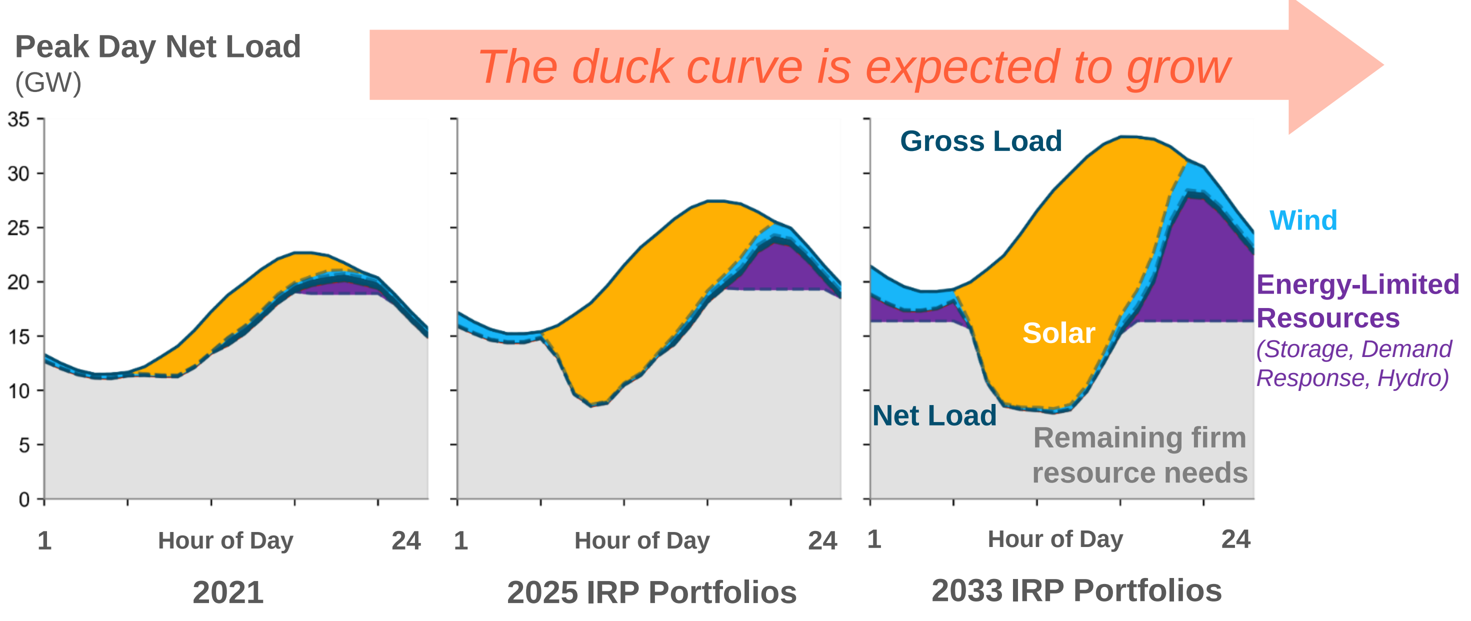
- **PWP's resource portfolios are consistent with common the blueprint for a low carbon grid**
  - All resulting portfolios include a mix of firm capacity, scalable clean energy generation, and balancing resources
- **Carbon-free portfolios (scen. 1-3) require higher quantities of clean energy and storage capacity, resulting in considerably higher costs**
  - PWP's carbon-free portfolios result in high "implied carbon abatement" costs **(~$600-1,200 per ton in 2030)** compared to the social cost of carbon assumed in Scenario 5 **($400 per ton)**
- **Among California utilities' plans, PWP's consideration of hydrogen fuel cells for firm capacity is unique**
  - No other California utilities have committed to plans that include retirement of all existing natural gas plants that play critical roles in maintaining reliability
  - Sacramento Municipal Utility District's current plan anticipates relying on existing gas resources for firm capacity through 2030, planning a transition to renewable fuels or CCS to support further decarbonization

IRP Benchmarking Framework

Despite differences among utilities and their modeling methods and assumptions, common findings observed across a broad range of decarbonization studies should be broadly applicable and consistent across them

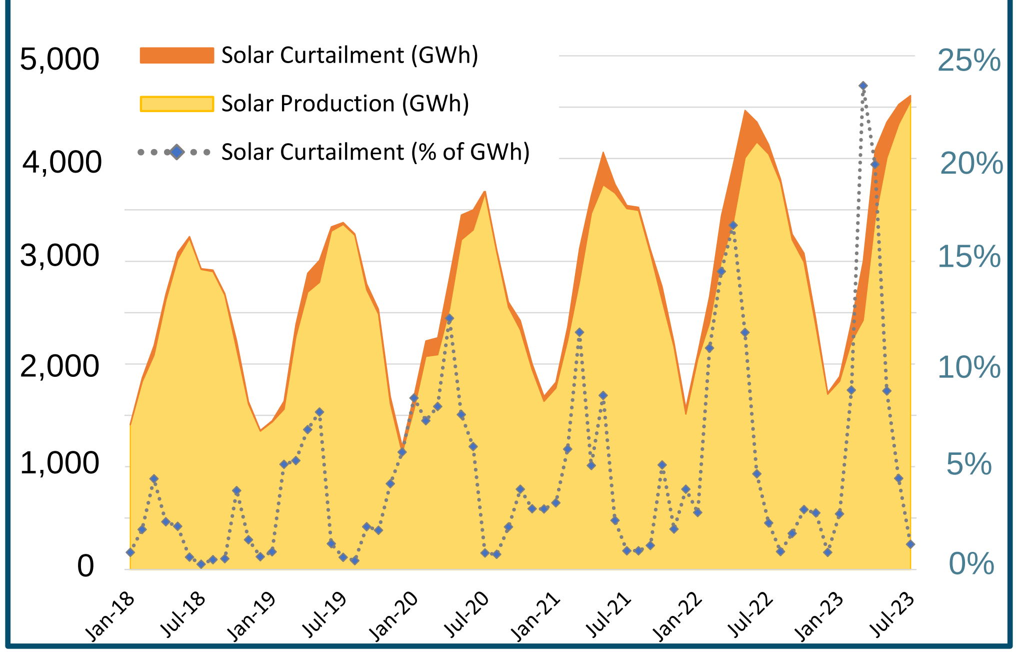
*PWP IRP results were compared against three California planning activities to identify key differences and validate model results:
1. California Public Utilities Commission IRP *Preferred System Plan* (CPUC Resource Plan): A 73% Renewable Portfolio Standard, with 86% GHG free resources by 2032
2. Sacramento Municipal Utility District *Case A* (SMUD 2030 Carbon Neutrality): No allowance of combustion generation beyond currently contracted biogas; no unspecified market purchases in 2030
3. NREL LA 100% Renewable *Scenario SB100* (LA 100% Renewable Plan): 100% renewable energy by 2045

Current Trends: A Large Share of California's Long-term Needs Will Be Met With Solar, Storage, and Other "Non-firm" Resources



As more solar is integrated, the duck curve will deepen

Additional storage will help shift energy to hours of greater need



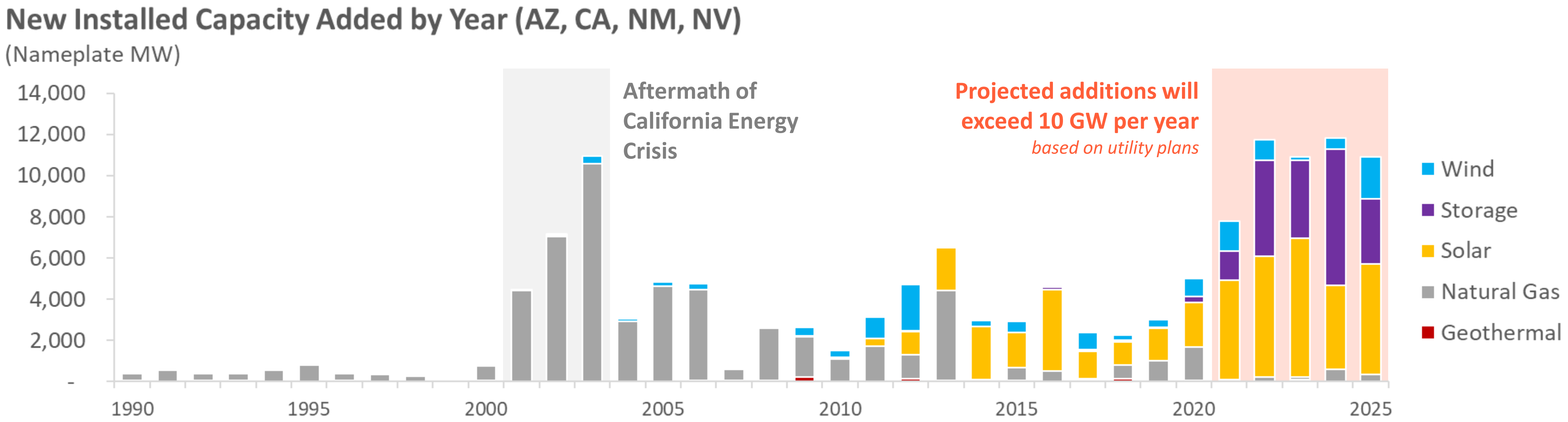
Already, annual curtailment is growing in California and with additional solar set to be deployed, the trend will only continue.

Curtailment happens the most during spring months when solar production is high and demand levels are lower

CAISO. Production and Curtailment Data.

Current Trends: Development Of New Resources Is Expected to Occur at an Unprecedented Rate

- To maintain reliability and meet clean energy objectives, utilities in California and the Southwest will add significant quantities of renewables and storage resources in the next decade
- Coupled with supply chain constraints and interconnection queue issues, there is uncertainty in both cost and project execution timelines



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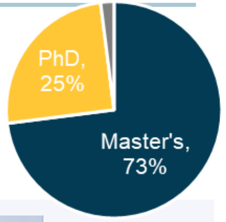


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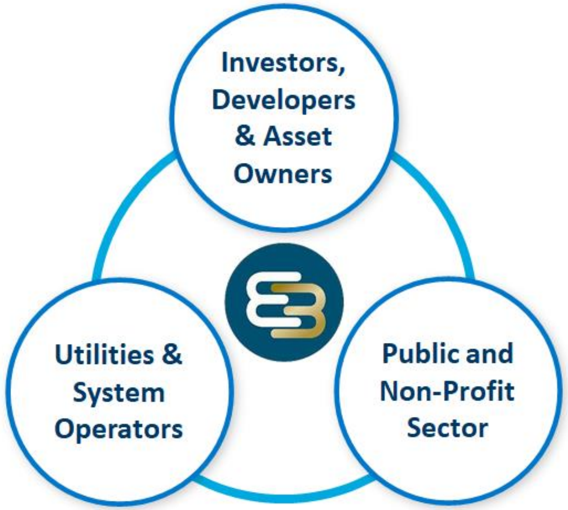
E3 Clients

300+ projects per year across our diverse client base



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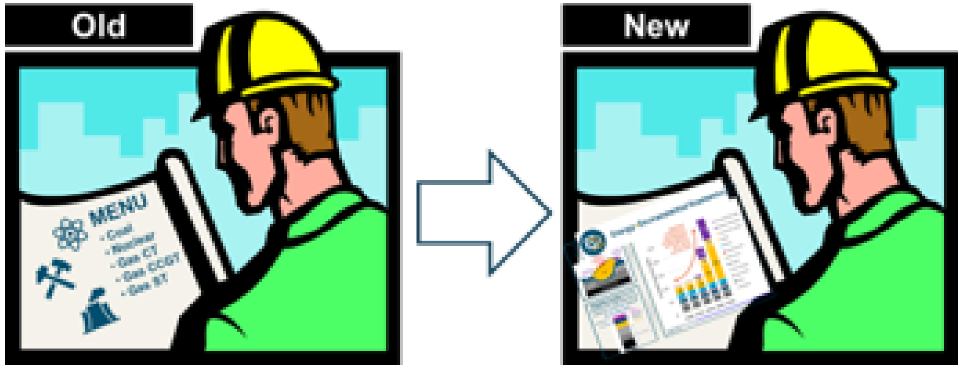
E3's experience in resource planning

+ **E3 has worked with a wide range of clients that are increasingly writing the script for the emerging clean energy transition to understand how to plan deeply decarbonized electricity systems**
  - **California PUC:** Assisting the CPUC in administration of IRP program mandated by SB 350 by developing a 'Reference System Plan' that achieves 40% GHG emission reductions by 2030
  - **Pacific Northwest Low Carbon Scenarios Study:** Investigated the costs and emission reductions associated with various policies in the Northwest, including a higher renewable portfolio standard, cap and trade, and a carbon tax
  - **Sacramento Municipal Utilities District:** Assisting with 2018 IRP to evaluate long-term clean energy goals including GHG emission reductions of 90-100% by 2040
  - **Los Angeles Department of Water and Power (LADWP):** Evaluated reliability contributions of clean energy alternatives to natural gas once-through-cooling plant repowerings
  - **Hawaiian Electric Company (HECO):** Developed an affordable, technical feasible Power Supply Improvement Plan (PSIP) consistent with Hawaii's goal of 100 percent renewable energy by 2045
  - **Xcel Energy Upper Midwest IRP:** Provided support to Xcel Minnesota by conducting independent technical analysis to examine how to meet long-term carbon reduction goals along with associated costs as part of their 2019 IRP process
  - **Nova Scotia Power:** Full support for Nova Scotia Power's 2021 IRP considering coal retirements and deep decarbonization in a geographically constrained region
+ **Through these projects, E3 has developed an unparalleled understanding of resource planning within highly decarbonized renewable electricity systems**

Emerging trends in Integrated Resource Planning

- **Technological, economic, societal, and political factors are rapidly transforming the electricity sector:**
  - **Climate change** and the policy imperative to decarbonize the economy require deployment of massive quantities of low-carbon electricity
  - **Renewable resources** including wind, solar and batteries have fallen dramatically in cost, offering attractive alternatives to conventional resources
  - **Consumers** increasingly wish to control their own destiny, decentralizing the locus of decision-making
  - **Innovation** in data processing, telemetry and metering are enabling greater utility *and* customer engagement in energy use

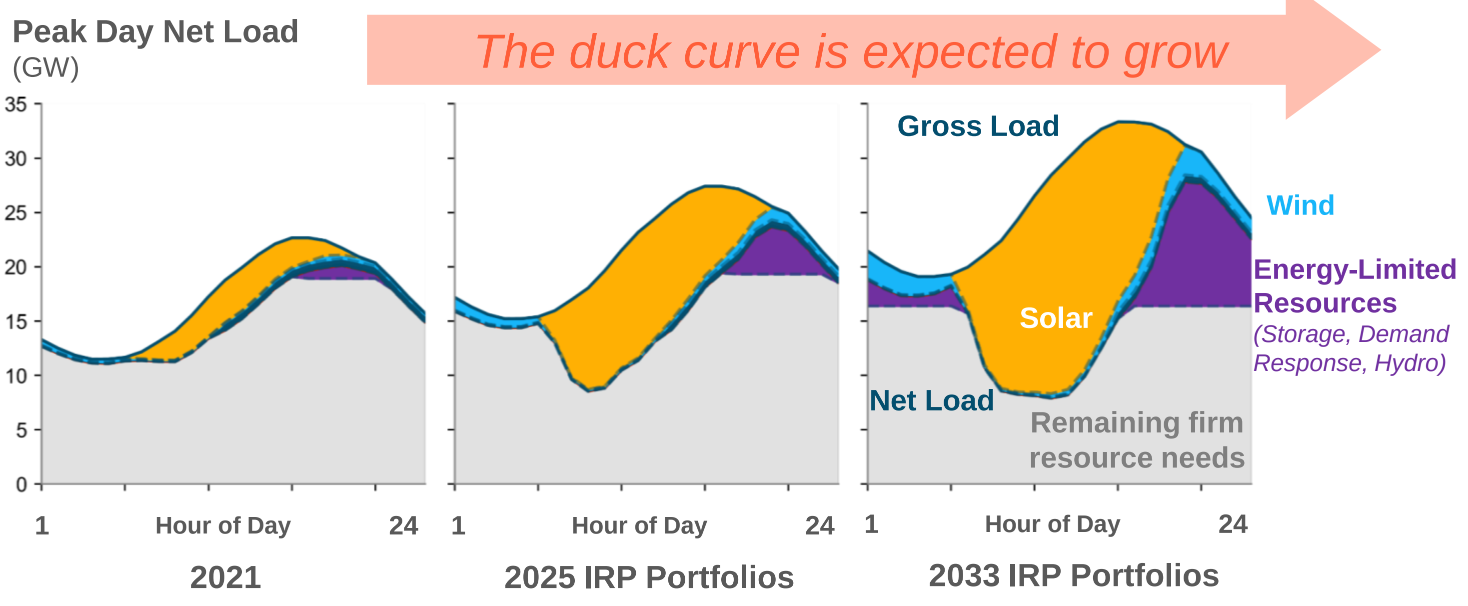
- **In response to these trends, integrated resource planning is evolving – modern IRPs have come a long way since their origins in the 1980s**
  - New tools and techniques to address increasing complexity of planning problems
  - A new “dual” purpose to (1) support near-term actions and (2) articulate long-term vision
  - Expanded scope to consider implications beyond electric sector and linkages with other planning functions
  - More open and proactive stakeholder engagement process



Current Trends and Risks in California Energy Markets

Energy+Environmental Economics

A Large Share of California's Long-term Needs Will Be Met With Solar, Storage, and Other "Non-firm" Resources



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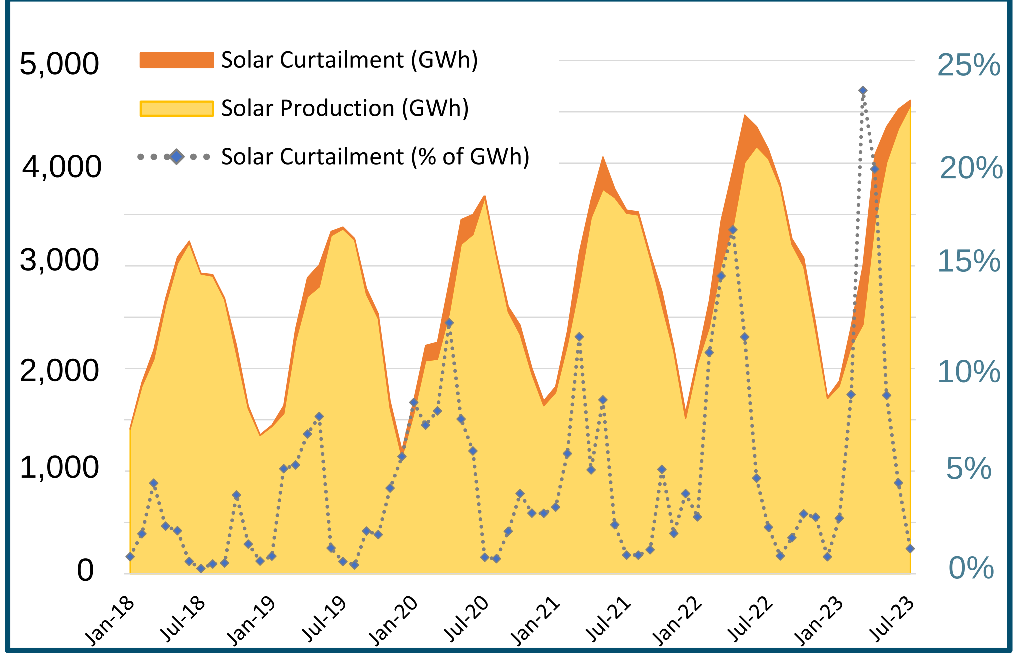

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Development Of New Resources Is Expected to Occur at an Unprecedented Rate

- To maintain reliability and meet clean energy objectives, utilities in California and the Southwest will add significant quantities of renewables and storage resources in the next decade
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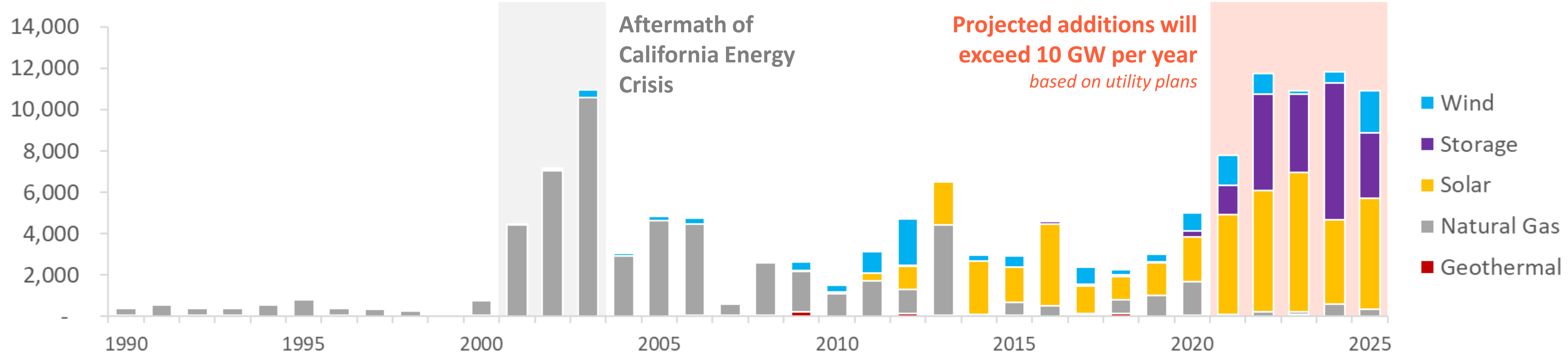
New Installed Capacity Added by Year (AZ, CA, NM, NV)
(Nameplate MW)



Review of IRP Methodology and Inputs and Assumptions

Energy+Environmental Economics

Elements of a Robust Integrated Resource Planning Process

1. Identify Objectives
Cost

Reliability

Environmental Goals & Regulatory Requirements
Carbon Emissions
Other Emissions
Water Use
RPS Targets
EE Standards

2. Define Scenarios
Identify Key Decisions

Identify Sources of Uncertainty

Select Scenarios, Futures & Sensitivities

3. Gather Data
Load Forecast

Generation
Existing Resources
Demand-Side Programs
New Resource Options

Transmission

Commodity Forecasts

4. Conduct Analysis
Create Portfolios
Capacity expansion

Simulate Operations
Production simulation

Test Reliability
Loss of load probability

5. Evaluate Options
Compare Costs

Assess Risks

Compare Environmental Impacts

6. Finalize Plan
Select Most Cost-Effective Portfolio

Establish Four-Year Action Plan

File IRP Report

Engage Stakeholders and Integrate Feedback

Figure adapted from Public Service Company of New Mexico 2020 Integrated Resource Plan

Utility Planning Processes Balance Multiple Objectives

+ **Primary objective of utility planning: identify and procure a portfolio of resources that minimizes costs to ratepayers while maintaining reliability and achieving clean energy objectives**

+ **Elements of a successful plan:**
  - Robust technical analysis of resource options
  - Evaluation of key risks and uncertainties
  - Consideration of short- and long-term implications of planning decisions
  - Engagement of a wide range of industry stakeholders

Areas of Review: IRP Framework and Inputs and Assumptions

E3 reviewed PWP's overall IRP framework and key inputs and assumptions for alignment with industry standards and best practices. The results of this review are presented as follows:

1. CEC IRP Submission Guidelines
2. General IRP Framework
3. Modeling Methodology
4. Load Forecast
5. Existing Resource Characterization
6. New Resource Options Considered
7. Resource Operational Characteristics
8. Commodity Price Forecasts
9. Carbon and Clean Energy Accounting

1. CEC Submission Guidelines

ID	Criteria	E3 Review
1a	Is the IRP consistent with the planning horizon filing requirements adopting an IRP that ensures the utility achieves specific goals and targes by 2030?	**Yes.** The IRP is consistent with the current planning horizon requirement to 2030. Revised CEC submission guidelines, currently in the docket, would extend the planning horizon requirement to 2045, and under this revision PWP's IRP would also remain in compliance.
1b	Do the scenarios and sensitivity analyses adhere to the CEC IRP filing requirements?	**Yes.** The IRP considers five planning scenarios utilizing different resource option and emission constraints, with sensitivities on temperature impacts, generation technology costs, and transmission contingencies.
1c	Are all Standardized Tables, required for filing, completed for the adopted strategy/plan?	**Yes**. The following standardized tables required for filling have been completed. 1. Capacity Resource Accounting Table (CRAT) 2. Energy Balance Table (EBT) 3. RPS Procurement Table (RPT) 4. Greenhouse Gas Emissions Accounting Table (GEAT)
1d	Does the IRP provide additional and supporting information?	**Yes.** Supporting documents are available to indicate the methodology for selecting resources, load forecasts, and resource costs.
1e	Does the IRP include the demand forecast required for filing?	**Yes.** Demand forecasts based on IEPR forecasts are provided following CEC recommendations.
1f	Does the IRP report the mix of resources used by the POU as required for the IRP filing?	**Yes**. IRP considers a resource mix considers a diverse set of emissions free resources; **however,** energy efficiency and transportation electrification sensitivities are not considered.
1g	Does the IRP demonstrate how PWP will ensure it meets system and local reliability goals?	**Yes.** The IRP considers system reliability and models potential loss of load; **however**, concerns remain that with limited guidance from CEC and CAISO on how future resource adequacy requirements will evolve, the approach used in this IRP will not be sufficient to guarantee a reliable outcomes.
1h	Does the IRP show how PWP will ensure how it will meet CARB established GHG emission targets?	**Yes.** PWP has a zero emissions goal by 2030, set by the City of Pasadena, which surpasses the requirement established by CARB.
1i	Does the IRP show how PWP will serve customers at just and reasonable rates and minimize bill impacts?	**Yes.** Rates were calculated for each scenario studied. **However**, E3 suggests consideration of an additional write up of potential rate impacts and comparisons between studied scenarios and sensitivities.
1j	Does the IRP ensure PWP strengthens the diversity, sustainability and resilience of the transmission and distribution systems?	**Yes**. The IRP explores a Goodrich transfer contingency sensitivity, which is a vital interconnection for the PWP system. An additional writeup of the risks has been provided in the filing with the CEC.
1k	Does the IRP ensure PWP achieves the goal of minimizing local air pollutants for disadvantaged communities?	**Yes.** IRP contains a discussion on air quality impacts in Pasadena's disadvantaged communities. Fossil fuel generation occurs outside of the DAC, but positive impacts from plant decommissioning are discussed.

2. General IRP Framework

Criteria		E3 Review
2a	Does the IRP articulate a clear set of motivating questions & objectives?	**Yes**. PWP established a clear vision with a set of goals for the IRP, a set of objectives, and a purpose, "to serve as a blueprint for PWP to deliver reliable, environmentally responsible electricity service at competitive rates over a ~20-year planning period."
2b	Does the IRP explore a coherent set of scenarios and sensitivities clearly linked to the objectives?	**Yes**. With this IRP, PWP explores the requirements to achieve the City of Pasadena's ambitious goal to provide 100% carbon free electricity by 2030 through a set of scenarios and sensitivities that test stresses tied to heat wave impacts, Goodrich intertie transfer contingencies, and technology cost impacts. **However**, by focusing only on bookend scenarios, i.e., a "Reference" case and cases that entirely eliminate carbon emissions, the analysis misses an opportunity to explore tradeoffs between cost, environmental objectives, and reliability impacts that could be useful to decisionmakers.
2c	Are the modeling inputs and assumptions gathered from reputable and (where possible) public sources?	**Yes**. Inputs and assumptions are from reputable and public sources, such as industry standard technical assumptions and costs data sources were cited for generic expansion resources. **However**, for key assumptions that employ proprietary datasets, such as market and gas prices and renewable resource profiles, providing additional information on methodology and assumptions and/or aggregated data in the final IRP would allow for more transparency around impacts.
2d	Does the analysis follow best practices and apply industry-standard modeling tools and approaches to quantify metrics connected to the IRP objectives?	**Yes**. The overall IRP process aligned with best practices and employed industry-recognized modeling tools. **However**, ensuring that capacity expansion modeling optimizes portfolios to meet reliability goals in a robust manner together with and clean energy goals while minimizing cost would help to ensure PWP meets reliability as well as environmental and cost goals.
2e	Is a concrete action plan identified based on analysis?	**Pending**. At the time of E3's original review, the IRP analysis and synthesis did not result in a specific action plan. With feedback from the Municipal Services Committee, PWP agreed to define a specific set of waypoints in the near future that would provide for concrete action and indicate progress towards the goals of this IRP. At the time this review was finalized, the specifics of those waypoints were still being determined.
2f	Has the IRP process been transparent and accessible to stakeholders?	**Yes**. PWP hosted regular Stakeholder Advisory Group (STAG) meetings; shared updates on the IRP process through multiple channels, e.g., online, print, social media, etc.; and provided opportunities for public input to shape the process.

2b – Scenario Design

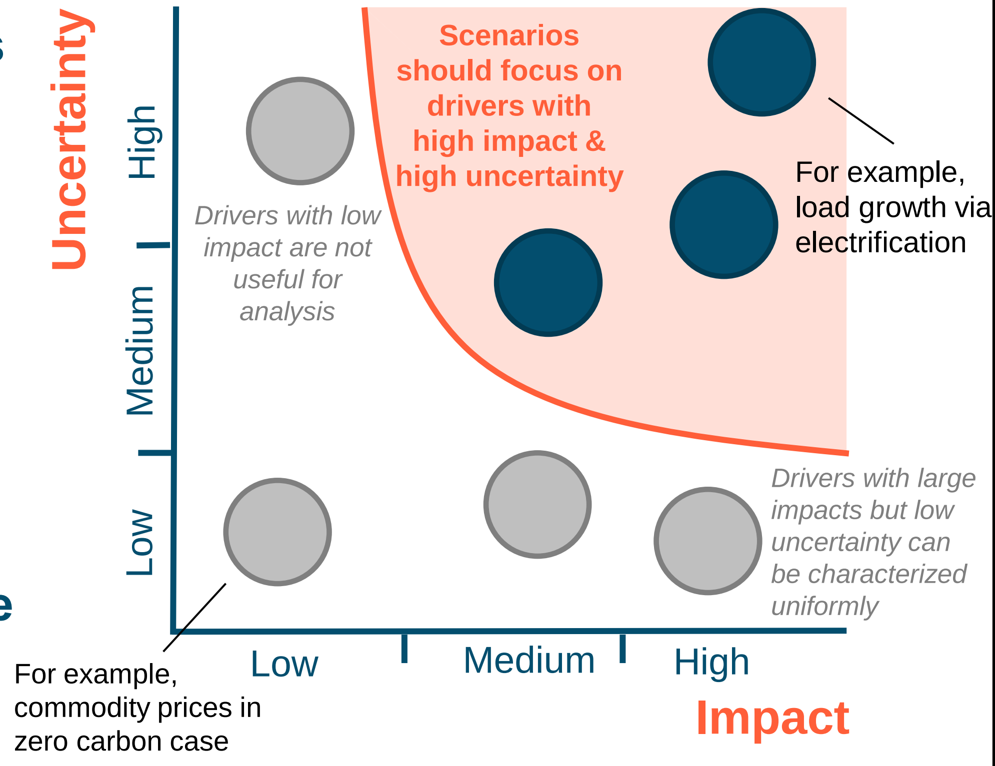
+ The PWP IRP explored a range of scenarios and sensitivities that follow a similar trend other small utilities have analyzed

Scenarios

- **Carbon Policy**: 100% Carbon-Free by 2030 *vs* CA State policy (treated as reference)
- **Resource availability**: Local (internal) buildout constraints in 100% carbon-free cases
- **Social cost of carbon**: Impact on reference

Sensitivities

- **Extreme Weather**: Heat wave impact
- **Market Ties**: Goodrich Transfer Contingency
- **Technology Costs**: High / Low case



+ Extreme weather and a portfolio's reliability and/or resilience are more often considered via a specific LOLP analysis

- Given this was out of scope in this IRP, its inclusion as a sensitivity acknowledges its importance

+ A range of variables were not evaluated in the scenarios

- Load growth from electrification and alternate resource and policy decisions (i.e., retention of Glenarm, no clean and firm, net zero policy, etc.)

!

E3 Recommendation

E3 found the scenarios and sensitivities explored as "bookends" – in the realm of what's possible – with less focus on plausible or probable futures to help guide PWP's decision-making. E3 recommends exploring options between the bookends during future IRPs.

3a - Portfolio Development

Industry Best Practices

Utilities should develop and evaluate a range of resource portfolio options. Current best practice entails the use of optimal, typically least-cost, Long-Term Capacity Expansion (LTCE) software to create portfolios modeling that account for:

- **Expected changes to loads and existing/planned resource portfolio over a long (20+ year) planning horizon**
- **System reliability, greenhouse gas (GHG), and clean energy objectives**
- **Costs to develop and operate new generation resources**
- **Hourly (or similar) operational dynamics of the electricity system**

+ PWP uses an industry standard tool to develop long-term resource expansion portfolios across multiple scenarios and sensitivities, applying constraints to represent applicable state and city policies

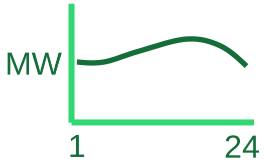
Model: ENCOMPASS POWER PLANNING SOFTWARE

- Used by many across the industry (*Public Service Company of New Mexico, Xcel Energy, others*)
- Long-term capacity expansion model for portfolio analysis which aligns with best practice

Horizon: Now → 2050

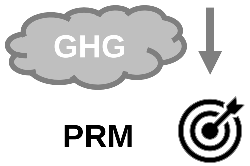
- PWP model years for the long-term capacity expansion study extend through 2050
- This is a common study horizon for utilities and aligns with best practice

Simulation:



- EnCompass allows hourly resolution of system operations with a reduced set of sample days
- This is common practice, capturing a range of conditions across the year for resource planning

Constraints:



- System reliability is represented in the model via a planning reserve margin and capacity accreditation
- Clean energy and GHG constraints are applied
- Ensuring these are modeled is best practice

3. Modeling Methodology

ID	Criteria	Explanation
3a	Are least-cost portfolios developed for each scenario using capacity expansion modeling?	**Yes.** PWP's portfolios are created using EnCompass, which uses optimization to construct portfolios to meet utilities' needs. This tool is used by many utilities throughout the industry in the creation of IRPs, including Public Service Company of New Mexico, Xcel Energy, and others.
3b	Are system operations simulated on an hourly basis?	**Yes.** PWP's analysis accounts for hourly operational needs of the system in two places: • The capacity expansion analysis conducted in EnCompass includes an hourly representation of system operations on a reduced set of sample days • Portfolio outputs from the capacity expansion module are subsequently simulated across a full year (8,760 hours) in EnCompass This two-stage approach (capacity expansion followed by production simulation) is industry standard.
3c	Does the PWP IRP methodology consider system reliability needs?	**Yes.** A planning target is modeled with resources accredited using ELCCs or NQCs following CPUC guidance and using its datasets. **However,** with limited guidance from the CEC and CAISO on how future resource adequacy requirements will evolve, the approach used in this IRP will not be sufficient to guarantee a reliable outcome. Currently, the IRP analysis accounts for PWP's reliability needs in three ways: 1. Requiring PWP to meet an annual planning reserve margin constraint, assuming capacity credits for all resources remain at today's levels as calculated by the CPUC 2. Ensuring that load is served across all 8,760 hours of the operational simulation 3. Evaluating several "stress tests" to examine portfolios performs under extreme conditions, including a heat wave and a transmission contingency This approach is not sufficient to demonstrate conclusively that the portfolios developed would be sufficient to meet PWP's resource adequacy obligations and local reliability needs.

3b - Operational Simulation

Industry Best Practices

Utilities should evaluate resulting portfolios through full hourly operational simulations across the model horizon

- **Simulate operations for 8,760 hours in all model years**
- **Ensure operational resource constraints are captured**
- **Operational simulation for least-cost system operations**
- **System costs flow into revenue requirement calculation**

PWP leverages the same model for full operational simulation modeling to evaluate annual dispatch of its portfolios and calculate system costs for its revenue requirement calculation.

Operational Simulation using Encompass

- EnCompass also used for full operational simulation
- PWP system is represented as single zone connected to "market" price strip zone
- 8,760 hours for model years
- Heat rate, Pmin, Pmax, and other operational parameters reflected
- Hourly load and renewable generation is represented
- Costs resulting from production simulation runs fed into revenue requirement calculations

!

E3 Recommendation

Whenever the full 8,760 simulation resulted in unserved energy, additional fuel cell and/or storage capacity was added (depending on the scenario) and the simulation was re-run to ensure reliability; however, with more robust reliability modeling, E3 anticipates this iteration and "true-up" would not be necessary and better align with best practices.

3c – Portfolio Reliability

Industry Best Practices

Utilities should ensure that their resource portfolio plans are sufficient to meet their reliability needs, depending on their unique regulatory environment and physical characteristics:

1. **Establish a clear reliability standard that may be one or more of the following:**
   - Based on a statistical standard for portfolio reliability, such as Loss of Load Expectation or an alternative measure,
   - Set by a resource adequacy program administrator, and/or
   - Tied to an N-1 (or other) operating criterion.
2. **Identify future system needs and ability to meet those needs using:**
   - Loss of Load probability modeling to simulate resource availability across a broad sampling of conditions,
   - Projections of future capacity credits assigned to resources in the context of a resource adequacy obligation, and/or
   - Detailed modeling of system performance under N-1 conditions.

+ **Reliably meeting PWP's loads entails overlapping reliability requirements:**
  - Long-term planning of its system to operate reliably under N-1 transmission contingency on its intertie with CAISO, and
  - Annual obligation to CAISO to ensure the PWP portfolio has sufficient resources to meet local and system resource adequacy requirements
+ **Despite limited guidance from the CEC and CAISO on how future resource adequacy requirements will evolve, PWP does address future resource adequacy needs in its IRP**
  - However, the capacity accreditation assumptions do not fully account for changing resource adequacy needs and are not sufficient to ensure PWP will meet its future resource adequacy obligations – particularly in scenarios with Glenarm retirement

Aspect of Current Methodology	Outstanding Risks & Vulnerabilities
Portfolio is designed to meet resource adequacy needs as reflected by a Planning Reserve Margin (PRM) requirement using present-day, technology-specific capacity credit assumptions established by the CPUC and CAISO.	**Resource adequacy modeling does not capture future capacity credit declines for renewables (only solar) and storage resources likely to occur as their penetrations in California increase**; portfolio may be insufficient to meet CAISO RA obligations.
Additional adjustments to each portfolio are made to ensure resources can meet PWP demand across a single 8,760 operational simulation.	**A single deterministic simulation will usually fail to capture the types of extreme conditions that ultimately lead to reliability events**, which are not present in most years.
Additional stress tests – reflecting a heat wave and transmission contingency that reduces PWP's import capacity – are evaluated.	These events evaluate system performance under summer stress conditions; however, many **studies have shown that portfolios that are heavily reliant on renewables and energy storage tend to experience higher reliability risks in the winter.**

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E3 Recommendation

E3 suggests that during routine reliability due diligence, scenarios are tested for extreme winter events to ensure adequacy. Also, E3 suggests that future IRPs incorporate a forward-looking perspective on resource adequacy requirements and capacity accreditation. Finally, E3 recommends existing ongoing reliability studies directly assess implications of Glenarm retirement on local reliability.*

**Glenarm retirement would require PWP due diligence & all standard required approvals*

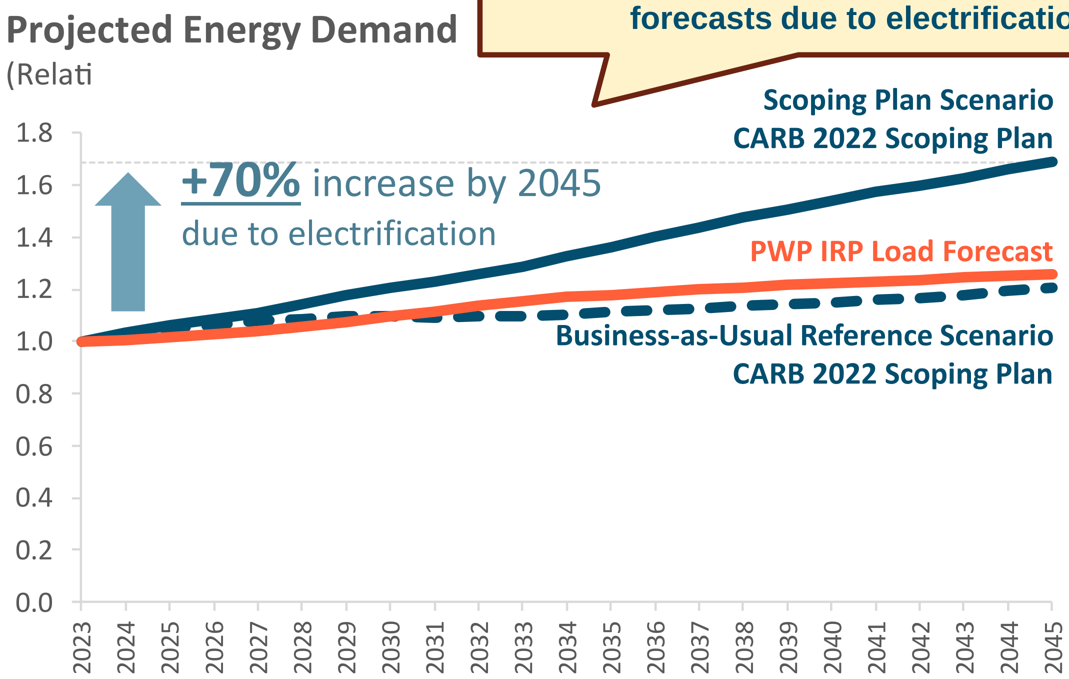
4. Load Forecast

ID	Criteria	E3 Review
4a	Is the load forecast developed using industry-standard approaches?	**Yes.** PWP's load forecast is derived from the California Energy Commission's (CEC's) Integrated Energy Policy Report (IEPR) by applying a ratio of PWP to Southern California Edison (SCE) historical load to the IERP's SCE forecast. The CEC develops load forecasts for each California Load Serving Entity that reflect projected economic & demographic trends and impacts of policy. This load forecast is used directly by most California municipal utilities in their IRPs and serves as the basis for the California Public Utilities Commission's development of a "Preferred System Plan" for the utilities and Community Choice Aggregators under its jurisdiction. By adopting the IERP forecasts, PWP follows the industry standard approach for load serving entities.
4b	Does the demand forecast account for load modifiers resulting from future energy efficiency and distributed energy resources?	**Yes**. The IEPR load forecast captures expected impacts of key load modifiers, including additional achievable energy efficiency, behind-the-meter solar PV and energy storage, and transportation and building electrification. PWP modifies the SCE fraction-based results using its own energy efficiency, distributed resources, TOU rate impacts, electric vehicle adoption, and native load. By adopting the IEPR forecasts and modifying via PWP-specific assumptions and analysis, this follows a best-in-class approach accounting for the impact of load modifiers.
4c	Does the load forecast account for expected impacts of climate change?	**Yes.** The CEC incorporates a climate change adjustment into its projections of annual energy and peak demand. By adopting the CEC forecasts, PWP is reflecting climate change impacts as captured within IEPR.
4d	Are various components of load, including future load modifiers, represented by hourly profiles developed from reasonable historical or simulated data?	**Yes**. PWP uses individual hourly profiles for each load component. These are calculated as a fraction of the hourly SCE forecasts available in the CEC's IEPR. **However**, final, disaggregated hourly load component data were not available to show how PWP's hourly load shapes may differ from SCE's hourly IEPR load data. While the future load modifiers were noted to capture PWP-specific load adjustments on an *annual* basis for various components, *hourly* load profile adjustments are not detailed in the methodology to be made PWP-specific. Altogether, the representation of hourly profiles is adequate and follows common practices across the industry.
4e	Are uncertainties in load forecasts explored through sensitivity analysis or alternative scenarios?	**No**. Alternative load forecasts and load sensitivities were not explicitly studied in the IRP. Ultimately, the scenario and sensitivity design process conducted by PWP resulted in a focus around decarbonization policy, technology availability, and reliability via a "heat wave" and transmission availability sensitivity; but not load uncertainty. While not detrimental to the IRP, E3 recommends evaluation of load uncertainty during ongoing due diligence to understand the impacts on PWP resource portfolios and costs.

4e – Load Forecast Sensitivities

- **Assessing the impacts of alternative future load forecasts is common in utility IRPs**
  - Particularly when uncertainties or policy drivers could cause variations from the "base" forecast
- **Electrification level assumptions are embedded in PWP's IRP forecast are consistent with a "Reference" scenario**
- **Studies show significant future load increases linked to the levels of transportation and building electrification needed to achieve California's decarbonization goals, i.e., the CARB Scoping Plan**
- **These load growth levels could directly impact conclusions regarding:**
  1. Cost and viability of achieving a 100% carbon-free portfolio
  2. Implications of retiring existing resources related to reliability of portfolio

The adopted CARB 2022 Scoping Plan Scenario shows substantially higher loads than the Business-as-Usual Reference, highlighting the range of uncertainty in California's load forecasts due to electrification



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E3 Recommendation

E3 recommends, during ongoing utility diligence, evaluation of impacts of higher electrification levels consistent with state policy goals to inform any specific commitments regarding clean energy targets or plant retirements.

5. Existing System

ID	Criteria	E3 Review
5a	Are the retirements and commercial operations dates (CODs) of existing and planned resources, reflected in the portfolio?	**Yes.** The IRP retires existing thermal resources by 2030 to meet the zero-carbon emissions goal and includes CODs for all planned resources. In reference scenarios, there are planned retirements for the existing coal plants and an assumed 20-year lifetime for renewable projects. Retirements for natural gas facilities are dependent on the scenario assumptions. Although not explicitly modeled in the IRP, additional costs associated with the retirement, or potential termination of contracts, of emitting resources should be part of the decision making related to achieving 100% carbon free electricity by 2030. This may be the case for resources such as Glenarm, Magnolia, and Intermountain Project units.
5b	Are existing and planned resources' technical and cost inputs and assumptions sourced from historic and/or recent RFP data, respectively?	**Yes.** The IRP assumes resource costs based on historic operations costs for existing resources or RFP data for planned resources. Existing coal resource costs are based on IPP budget projections while planned solar and geothermal project costs are sourced from RFP data. Natural gas resource costs are developed from natural gas costs, transportation, and facility O&M.
5c	Are transmission constraints within the planning area represented?	**Yes**. The IRP considers transmission constraints within the planning area by using a zonal representation where PWP's local zone is connected to an external market zone in a single pipeline construct. PWP can utilize the Goodrich line and import up to 280 MW and export up to 100 MW. The limits reflect "real world" risk preferences and operational constraints.

6. New Resource Options

ID	Criteria	E3 Review
6a	Does the IRP consider a reasonably broad set of options, including both commercially available and emerging technologies?	**Yes.** The IRP considers a broad set of resources applicable for Pasadena's ambitious clean energy goals, while considering technological feasibility. **However**, additional disaggregation of solar and wind resources by region through resource profiles would help to capture resource diversity contributions and can potentially impact resource selection.
6b	Are cost and financing assumptions developed based on reputable public data sources and/or market intelligence?	**Yes.** The IRP develops cost assumptions based on current market conditions and long-term energy forecasts according to industry standards. Near-term costs are based on recent RFPs for geothermal, solar, wind, and battery resources while long-term costs are calculated using NREL (or EIA) cost projections.
6c	Do future resource costs account for availability of tax credits established by Inflation Reduction Act?	**Yes,** resource costs are adjusted to account for tax credits made available by the IRA. However, E3 does provide several recommendations for future refinement of treatment of IRA tax credits: • IRP assumes a 2035 credit expiration, when it is likely credits will remain in effect after this time due to national emissions not reaching the 75% reduction 2022 emissions . Potential credit extensions should be tracked in future IRPs. • Analysis does not consider the PTC as an option for new solar – this may limit the selection of future solar as the PTC provides larger incentives at the assumed capacity factor of 32% • Hydrogen fuel cost projections do not account for available IRA credits. This may cause an overestimation in future hydrogen fuel costs and limit resource selection. • Analysis does not account for costs of lost PTC when PTC-eligible resources are curtailed and may affect the way resources are deployed and curtailed.
6d	Are new resource options characterized by reasonable limits on technoeconomic potential and other factors that could limit timing or amount of development?	**Yes**. The IRP limits new resource build options to a 1 GW build limit per technology per year. Space constraints are considered in different scenarios by favoring distributed resources. Local constraints versus resource constraints for resources built externally on CAISO are unclear.
6e	Are transmission costs to deliver new resources to loads accounted for in the analysis?	**Yes.** Transmission costs for new resources are accounted for through a transmission access charge (TAC) applied to external resources.
6f	Are the impacts of future technology cost uncertainty explored?	**Yes.** The IRP considers technology cost uncertainties by performing sensitivity analyses around high and low technology costs.
6g	Are financial assumptions from public, reputable sources?	**Yes**. The IRP does rely on public reputable sources for financial sources. PWP should ensure that these are clearly cited in the final IRP filing for transparency.

6a – Technologies Options Considered

Included

- Community solar & paired solar
- 4-, 6-, 8-hr storage (local & system)
- Fuel cells (local & system)
- Residential solar & batteries
- Commercial solar & storage
- Biogas
- Onshore wind & paired wind
- Offshore wind
- Utility solar & paired solar
- Geothermal

Excluded

- Small modular nuclear reactors*
- Hydrogen conversion at existing gas plants*
- Carbon capture retrofits at existing gas plants*
- Fossil Fuels
- Long duration storage*
- Tidal / wave power
- New gas with CCS*

+ The technologies included in the IRP were reasonable based on technology readiness and policy considerations

- ✓ All mature renewable technologies and storage were included, including configuration variants (paired vs non-paired)
- ✓ Local and system resource options were considered, which is important for transmission-constrained utilities
- ✓ Firm, dispatchable, zero-carbon technologies were considered (fuel cells & biogas), which many utilities have found crucial to ensure reliability in low-carbon systems
  - – While fuel cells are a less mature technology, E3 has seen this option considered as a non-combustion-based firm resource
- ✓ Exclusion of new fossil fuels or small modular nuclear reactors follows Pasadena and California policy, respectively
- ✓ Exclusion of tidal / wave power is appropriate based on technology readiness and economics
- × Long duration storage & gas with CCS *could* have been considered as firm options, but do not compromise the approach*
- × Conversion of Glenarm to hydrogen *could* have been considered as a potentially lower-cost, clean firm option, but doesn't compromise the approach*

!

E3 Recommendation

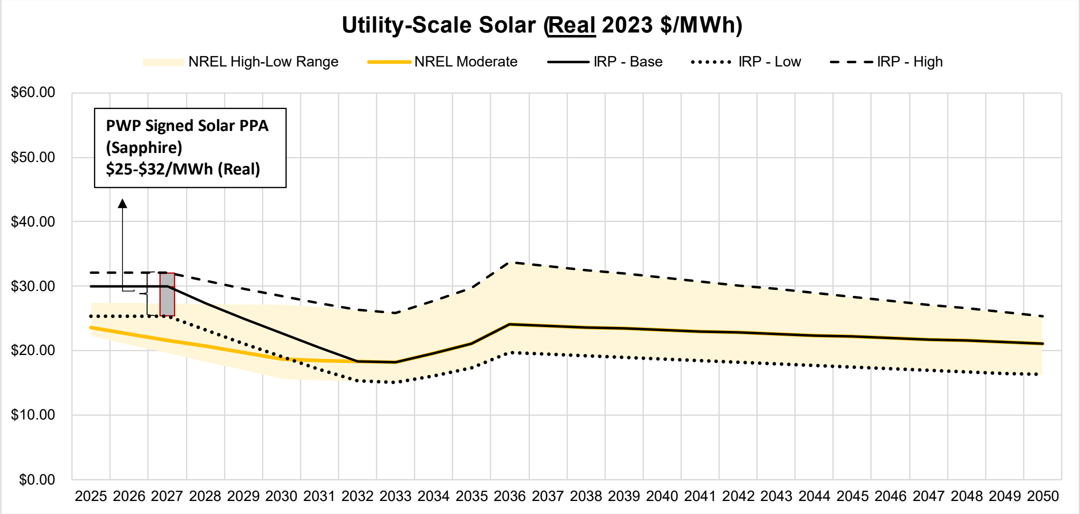
Consideration of more than one generic wind and solar resource option/location for onshore wind and solar and offshore wind may provide PWP with more diversified resource profiles contributing to a more resilient clean energy portfolio.

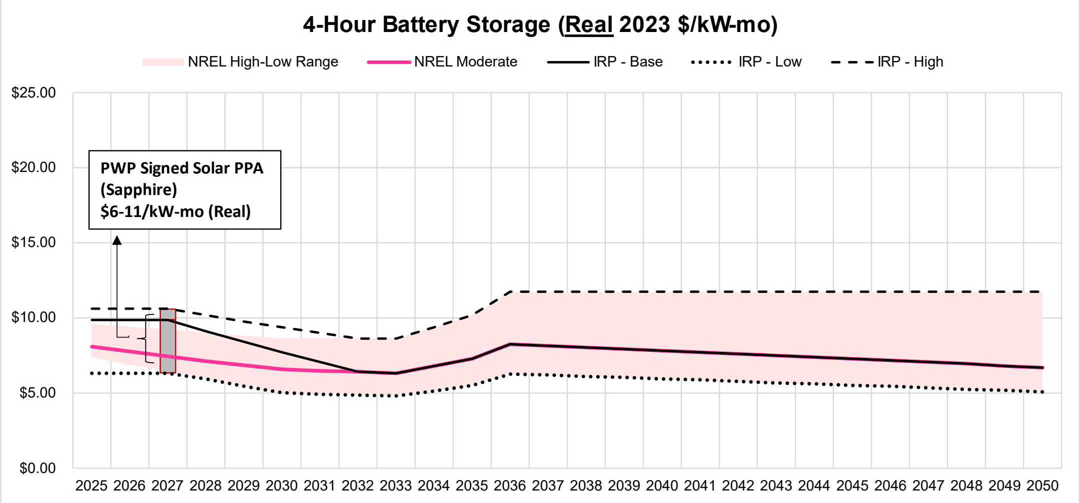
** Purposefully excluded due to Stakeholder Advisory Group (STAG) feedback*

6b - Methodology to Develop Cost Assumptions

+ **Methodology used to develop generic cost assumptions follows industry standard practices for IRPs:**
  - Near-term costs anchored to public market referents (typically executed power purchase agreements (PPAs))
  - Long-term cost trajectories defined by public data sources (NREL Annual Technologies Baseline, supplemented with EIA Annual Energy Outlook)
  - "High" and "Low" technology cost ranges developed to capture inherent future cost uncertainties
+ **Since assumptions were originally developed, inflationary pressures, global supply chain issues, and rising interest rates have continued to exert upward pressure on PPA costs**
  - "IRP - Base" cost trajectories appear optimistic based on current PPA market data
  - Cost impacts under the "IRP - High" sensitivity should be considered as a reasonably likely outcome that is consistent with today's market

Example Cost Projections Used In PWP IRP





6c - Treatment of Inflation Reduction Act

- **The IRA allows clean energy developers to select either the ITC or PTC**
- **Selection depends on both the cost and the capacity factor of resources**
  - ITC is often more favorable for higher-cost, lower capacity factor resources
  - PTC is often more favorable for lower-cost, higher capacity factor resources

PTC vs. ITC Assignment in PWP IRP

Resource	Capacity Factor	PTC	ITC
Onshore Wind	35%	✓	
Geothermal	90%	✓	
Solar	19% - 32%		✓
Offshore Wind	46%		✓
Battery Energy Storage	10% - 42%		✓
Fuel Cells	Model optimized		✓

Notable Items for Future Consideration

ZERO CARBON FUELS

- PWP did not include any fuel cost adjustments for hydrogen or biofuels that may sway the economics of achieving zero emissions on an hourly basis. E3 suggests applying this during routine utility due diligence as these resources also qualify for IRA credits.

TAX CREDIT EXPIRATION YEAR

- PWP assumes tax credits expire by 2035 which would occur if the US achieves 75% GHG reductions below 2022 levels by 2032. E3 finds this level of GHG reductions optimistic and suggests considering an extension of the "Application Year" or, at a minimum, performing cost sensitivities that explore the impact of extensions in ongoing utility analyses.

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E3 Recommendation

As the threshold for choosing PTC vs ITC is close and dependent on future system dynamics (i.e., curtailment), E3 recommends evaluating both options for resources such as wind and solar to determine the optimal choice as part of future IRP studies.

7. Resource Operational Characteristics

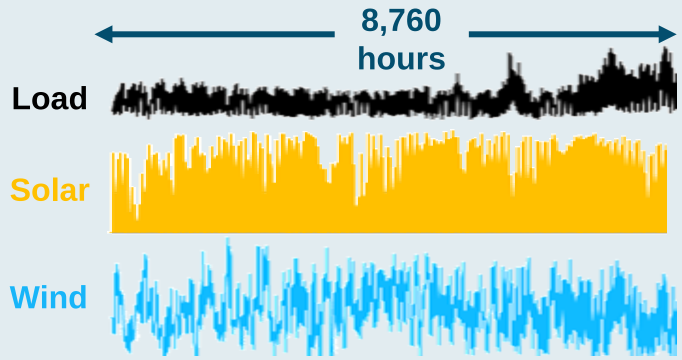
ID	Criteria	E3 Review
7a	Are operational constraints of dispatchable resources, such as gas and nuclear captured within the analysis?	**Yes**. The typical operational constraints such as pmin, pmax, must-run capacities, daily starts, min up and down times, outage rates, maintenance schedules ramp rates are reflected for the dispatchable resources. Heat rates for existing coal and natural gas resources are based on actual plant characteristics as provided by PWP and are consistent with industry standards for each technology.
7b	Are operating costs for dispatchable resources appropriately characterized within the analysis?	**Yes**. Variable O&M assumptions for existing coal and natural gas resources are based on actual plant characteristics as provided by PWP.
7c	Do resource profiles for wind and solar resources reflect expected diurnal and seasonal variability, e.g., serially complete timeseries data 8,760?	**Not Applicable.** E3 did not review hourly profiles for renewables used in the modeling due to contractual restrictions between ACES and the third-party vendor that provided the profiles. However, based on the information available, E3 believes all renewable and load profiles are not “temporally aligned”, i.e., do not reflect a common set of meteorological conditions throughout the year, considered industry best practice and an opportunity for future improvement. Existing resources appear to be modeled with an average annual capacity factor, while new resources are represented by hourly profiles. Without temporal alignment between load profiles and renewable profiles, there is a risk of mischaracterizing renewable resource availability to meet load throughout the year; additional (or less) capacity may be required, depending on if the misalignment overstates or understates renewable resource availability.
7d	Is renewable curtailment modeled in system dispatch with appropriate penalties where relevant?	**Yes.** The operational simulation in EnCompass allows for curtailment of renewable resources while ensuring that the full costs of all new resources are accounted for, i.e., under a PPA structure, resources that are curtailed are compensated at the full PPA price. **However**, no costs for the loss of the PTC when energy is curtailed are accounted for. These costs may be increasingly important if new solar resources opt for the PTC (rather than the ITC as modeled in this analysis).

7c – Renewable Energy Resource Profiles

Note: E3 was not able to review the full hourly renewable resource profiles used in PWP's IRP due to contractual restrictions between PWP's contractor and the third-party provider of the renewable profiles.

Common Industry Practice:

+ **Hourly profiles for wind and solar are simulated and match hourly load conditions, i.e., using the same weather year modeled to ensure realistic system conditions are captured.**
  - Hourly dynamics should reflect "real" generation – profiles shouldn't be averaged over years
+ **Geographic granularity of renewable profiles represent generic but distinct areas where utility would potentially procure resources.**
+ **For a representative renewable resource in each area, multiple locations are simulated and aggregated to ensure profile does not over- or under-estimate resource potential.**



Temporal alignment of wind and solar resource and load profiles determines these resources' contribution to firm capacity, or capacity credit, and has important economic implications (or renewable energy's economic value).

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E3 Recommendation

E3 recommends using temporally aligned wind and solar resource and load profiles and representing more utility-scale solar and wind resources across California, as profiles vary regionally in future IRPs.

8. Commodity Pricing - 1 of 2

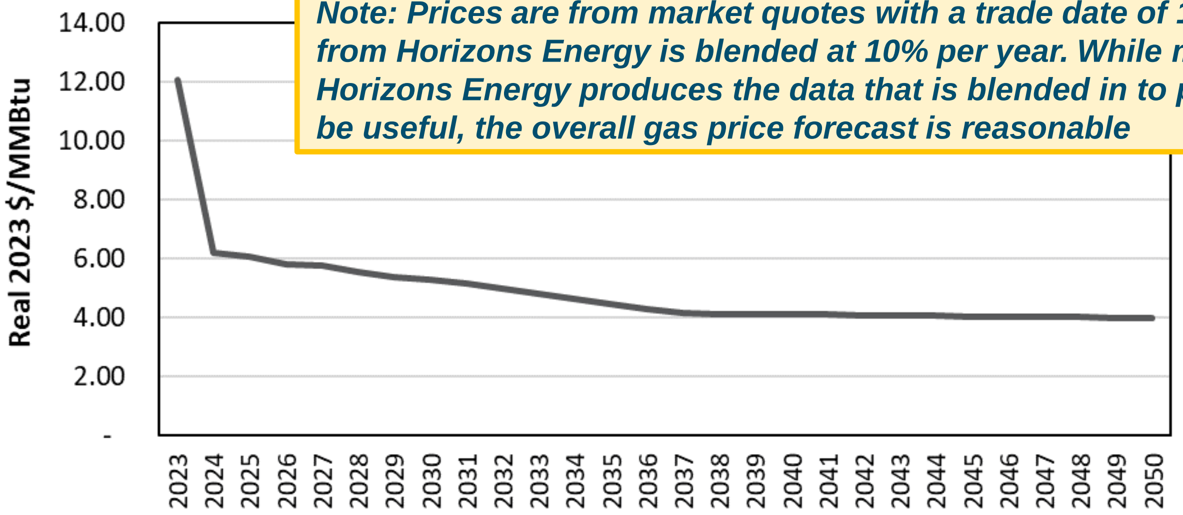
ID	Criteria	E3 Review
8a	Are cost assumptions for fuels developed based on reputable public data sources and/or market intelligence?	**Yes**. Overall, commodity prices are from appropriate sources. The fuel prices at SoCal CG are provided by Horizons Energy and utilizes a variety of sources, i.e. Natural Gas Intelligence (NGI) to obtain forwards and historical LMCs, EIA Annual Energy Outlook (AEO), and other published sources, to produce the forecasts. A transport and delivery adder is applied to the Glenarm unit fuel prices. The green hydrogen and renewable natural gas prices are sourced from Utility Dive and Bloomberg, and the Gas Foundation, respectively. **However**, green hydrogen and RNG do not consider IRA tax credits, which could make these fuels more cost effective. This could impact resource dispatch or investment decisions and the subsequent system costs (revenue requirement) of the results. Given the lack of publicly available sources with clean fuel price forecasts that embed the IRA impacts, the IRP modeling team has responded with inclusion of a disclaimer and note that PWP will monitor the market, public, and private sources of information to investigate these fuels, as necessary.
8b	Are wholesale market price forecasts developed based on reputable public data sources and/or market intelligence?	**Yes**. Horizons Energy provided market price forecast data that uses a fundamentals-based approach, simulating full grid operations in the EnCompass model to determine the market prices. More background information on the associated methodology would improve understanding, such as documentation around the assumptions of policy achievement, installed capacity and generation across regions, hourly price dynamics, etc.; however, it is understood that some of this information is sensitive and confidential for the vendor and may not be shared.
8c	Are future wholesale market prices forecasts aligned with future commodity price forecasts and impacts of policy on markets? Additionally, are market transactions (sales/purchases) appropriately accounted for and are the inputs and assumptions clearly detailed?	**Yes**. The market is represented as a price strip representing SP-15 and PWP can transact on an hourly basis constrained by the limits described in 7a (price taker model), a sound approach for a small utility, relative to the market size. The data provided is only in an average “7x24” price for a given year, but the model uses an hourly representation of market price forecast data. As described by the market price vendor, gas prices and market prices are aligned. **However**, due to contractual restrictions the full dataset and development methodology and assumptions were not available so E3 cannot fully evaluate the reasonableness of these assumptions without this review. For transparency, the inputs and assumptions behind the development of these market price forecasts shared by the vendor should be included in the IRP’s supporting information.

8. Commodity Pricing - 2 of 2

ID	Criteria	E3 Review
8d	Are cost assumptions for carbon emissions (such as emissions, compliance or social cost of carbon) based on reputable public data sources?	The California Cap and Trade Program is modeled as a limit on carbon and direct inputs from the CARB identify limits for PWP. Costs and/or revenues from the disposition of allowances under the program are considered in dispatch or revenue requirement metrics. A social cost of carbon is modeled from the EPA's "Supplemental Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, 'Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: oil and Natural Gas Sector Climate Review"
8e	Are uncertainties in commodity price forecasts explored through sensitivity analysis or alternative scenarios?	**No**. Scenario and sensitivity analysis was not conducted on commodity price forecasts. Given deep uncertainty in future market prices, it is standard practice to explore sensitivities on these commodity prices or potential constraints on market purchases and sales; **however**, PWP's approach to explore islanded and market access scenarios provides some understanding extreme ends of market exposure. Ultimately, the scenario and sensitivity design process resulted in a focus around other input assumptions.
8f	Is the cost of delivering energy contracted outside of the PWP region to the local system properly represented?	**Yes**. The PWP IRP represents this using a Transmission Access Charges (TAC), which are applied to the external resources on a $/MWh basis for getting energy to PWP's system. This is a standard approach and reasonable assumption to use in the IRP.

8a. Natural Gas Price Forecast

+ **Horizons Energy provided the gas prices representing the Southern California City Gate Hub for use in the PWP IRP, and were also used in the underlying market prices**
  - This alignment is important to ensure common economics between the market and dispatch of resources responding to those market signals
+ **PWP applied a 1.1x multiplier to gas prices for the Glenarm units to represent additional transportation costs and taxes for those units**
+ **Only average annual gas prices were provided to E3 for its review, as hourly assumptions were unavailable due to contractual restrictions between ACES and the third-party vendor**



Note: Prices are from market quotes with a trade date of 12/30/2022 and data from Horizons Energy is blended at 10% per year. While more detail on how Horizons Energy produces the data that is blended in to produce prices would be useful, the overall gas price forecast is reasonable

!

E3 Recommendation
Often, evaluating sensitivities around market prices/gas prices can help understand the range of costs utilities could experience in the future. E3 recommends consideration of these types of sensitivities during routine utility due diligence or future IRPs.

8d. Treatment of Carbon Emissions and Costs

- **California's Cap and Trade Program was modeled as an explicit cap on carbon for the PWP system based on limits set by the California Air Resources Board; and costs/revenues associated with the disposition of allowances are integrated into cost metrics**
  - Given the program results in $/ton prices on carbon emissions that falls within the range of a published "floor" and "ceiling" price, it is appropriate to model this price explicitly

- **PWP modeled a Social Cost of Carbon based on the EPA assumptions* and according to industry standard**
  - E3 has seen the modeling of a Social Cost of Carbon in many jurisdictions
  - Social Cost of Carbon has been modeled as an implicit price signal to inform investments, but does not impact the revenue requirement as it is not an explicit cost borne by PWP ratepayers

* "Supplemental Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, 'Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: oil and Natural Gas Sector Climate Review"

9. Carbon and Clean Energy Accounting

ID	Criteria	Explanation
9a	Are all applicable RPS (or clean energy targets) targets and related policies clearly defined and detailed for the planning horizon?	**Yes**. The PWP IRP adheres to applicable RPS and clean energy targets and related policies through clearly defined targets aligned with SB 100 and SB 1020 as well as City of Pasadena goals. These targets are tied to modeling constraints and resource attributes
9b	Are all applicable GHG targets and/or goals and related policies clearly defined and detailed for the planning horizon?	**Yes**. The PWP IRP planning approach explores how the ambitious climate goals of the City of Pasadena may drive resource portfolio choices. The PWP IRP model constraints adhere to the CARB target range to 2030 with straight-line reductions to zero emissions by year-end 2045, except for scenarios that meet the Pasadena Resolution to source 100% of the city's electricity from carbon free sources by 2030 (year-end), which have zero emissions from 2031 through 2045. All existing, planned and new resource candidates considered in the model have assigned carbon emission rate attributes (lb CO_2/MWh) for use in emissions accounting through the planning horizon.

Review of IRP Results

Energy+Environmental Economics

PWP IRP Results Review

E3 benchmarked PWP's IRP with peers planning for similarly ambitious energy goals and through a study of tradeoffs between metrics of total cost and carbon emissions reductions. The following sections present these results:

1. **Benchmarking of Results with California Energy Plans**
2. **Carbon Abatement Costs Review**

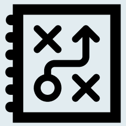
PWP IRP Results Benchmarking: Approach

+ **PWP IRP results were benchmarked with three California planning activities to identify key differences and validate model results:**
  1. ***California Public Utilities Commission IRP *Preferred System Plan* (CPUC Resource Plan):** A 73% Renewable Portfolio Standard, with 86% GHG free resources by 2032.
  2. **Sacramento Municipal Utility District *Case A* (SMUD 2030 Carbon Neutrality):** No allowance of combustion generation, only of currently contracted biogas, without unspecified market purchases in 2030.
  3. **NREL LA 100% Renewable *Scenario SB100* (LA 100% Renewable Plan):** 100% renewable energy by 2045

Hypothesis: IRP Results Benchmarking

Despite differences in terms of input assumptions, tools used, scenario design, etc.

…*similar* entities embarking on decarbonizing their systems should come to similar approaches in terms of strategies.



+ **Every power system is unique and requires tailored approaches to meet specific objectives; therefore, there are no “correct” solutions, and so E3 asks:**
  1. What trends are common across deep decarbonization energy planning strategies?
  2. How does PWP’s IRP results align with these common trends among similar ambitious “peer” planning activities?

*CPUC IRP creates a plan to meet GHG emissions goals while maintaining reliability at the lowest possible costs. Preferred plans are chosen with considerations from IOUs with independent modeling. See https://www.cpuc.ca.gov/irp

Deep Decarbonization Planning Studies: Common Trends

+ **E3's work with utilities and regulators to develop long-term resource plans support three common trends in deep decarbonization planning studies:**

1. Technologies available today can enable significant progress towards ambitious state and utility clean energy objectives
2. A technology-neutral approach to planning and procurement will enable utilities to meet reliability and clean energy goals most affordably
3. Some form of firm capacity is needed for reliability even under a deeply decarbonized grid

+ These findings are supported by a growing body of literature, including recent studies by the National Renewable Energy Laboratory (NREL), Princeton University, the Electric Power Research Institute (EPRI), and the Massachusetts Institute of Technology (MIT)

Blueprint for a Low Carbon Grid

Balancing Resources

Today: batteries, pumped storage, hydro, demand response

Future: advanced flexible loads, other storage technologies

Scalable Low-Cost Clean Energy Resources

Today: wind, solar, efficiency

Future: nuclear SMR, CCS

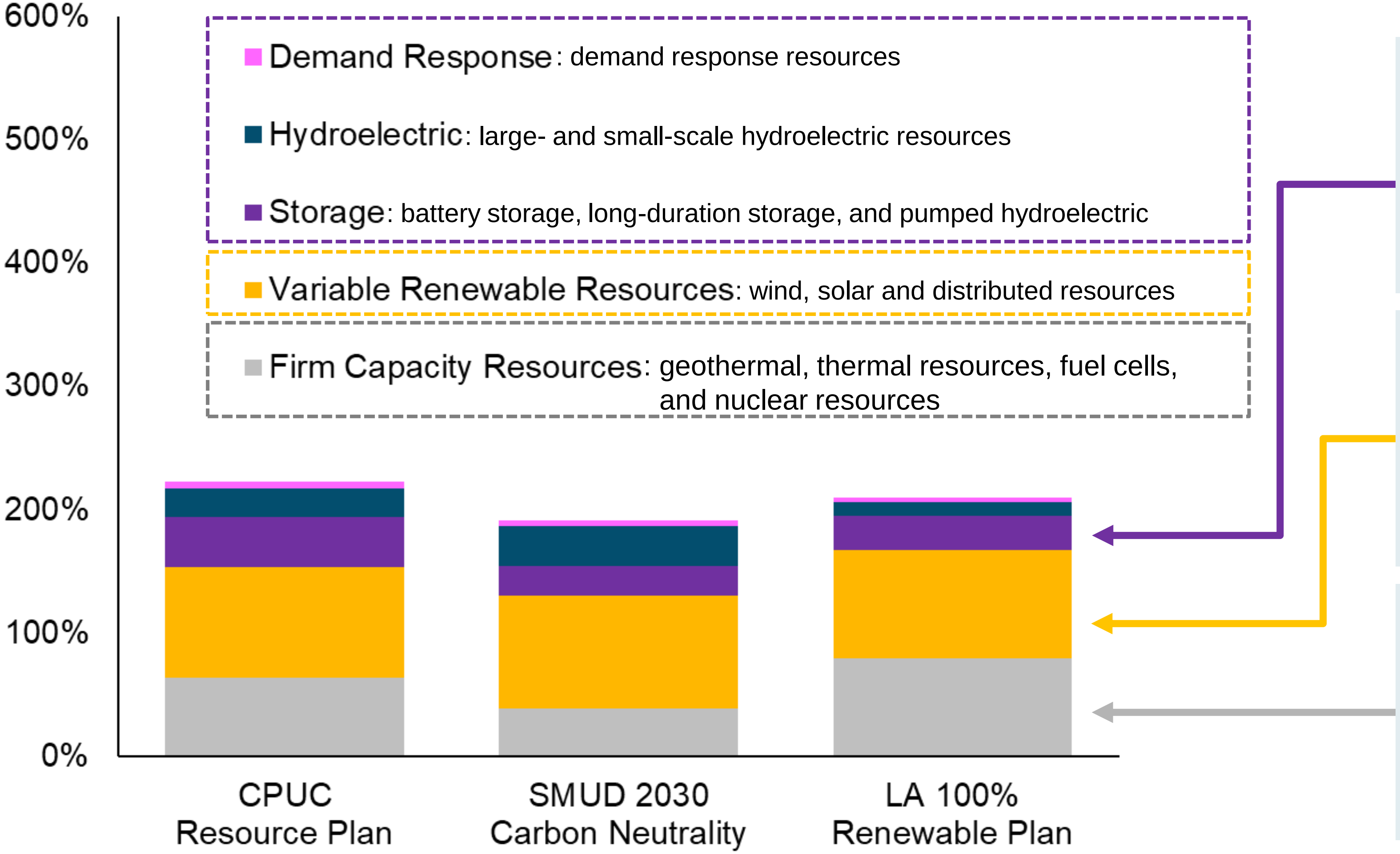
Firm Resources

Today: nuclear, natural gas, geothermal

Future: hydrogen, long-duration storage, nuclear SMR, CCS

Deep Decarbonization Planning Studies: Common Trends in California

Nameplate Capacity Normalized by System Peak Demand: 2030



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Today: wind, solar, efficiency

Future: nuclear SMR, CCS

Firm Resources

Today: nuclear, natural gas, geothermal

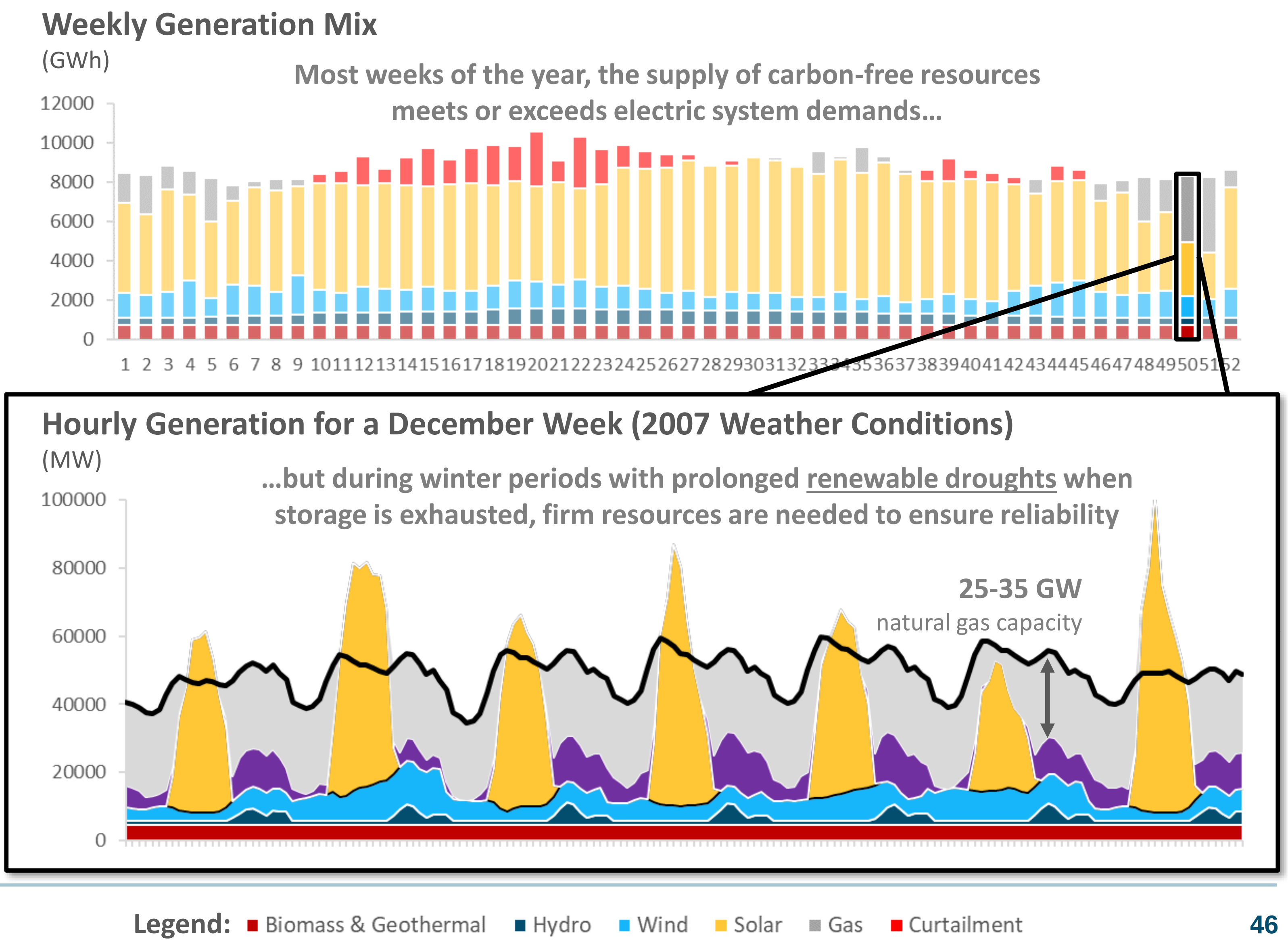
Future: hydrogen, long-duration storage, nuclear SMR, CCS

The Essential Role of Firm Generation In a Low Carbon Grid

California in 2050 at a glance:

- **93 GW** peak demand
- **90%** carbon-free generation
  - 150 GW solar PV
  - 21 GW wind
  - 8 GW hydro
  - 5 GW geothermal
  - 75 GW energy storage
- **35 GW** reliability need for firm capacity (40% of peak)
- **90% GHG reduction** relative to 2005 levels

Statistics and visuals adapted from High Electrification scenario in [Long-Run Resource Adequacy under Deep Decarbonization Pathways for California]



Multiple Analyses Conclude "Clean Firm" Resources Will Be Needed To Enable Complete Power Sector Decarbonization

Highlights from Clean Firm Power is the Key to California's Carbon-Free Energy Future:

The Environmental Defense Fund and the Clean Air Task Force convened three groups of energy system experts to model California's electricity system in order to figure out how the state might make that much affordable, clean, and reliable electricity. Groups from Princeton University, Stanford University, and Energy and Environmental Economics (E3), a San Francisco-based consulting firm, each ran separate models that sought to estimate not only how much electricity would cost under a variety of scenarios, but also the physical implications of building the decarbonized grid.

…

Despite distinct approaches to the calculations, all the models yielded very similar conclusions. The most important of these was that solar and wind can't do the job alone.

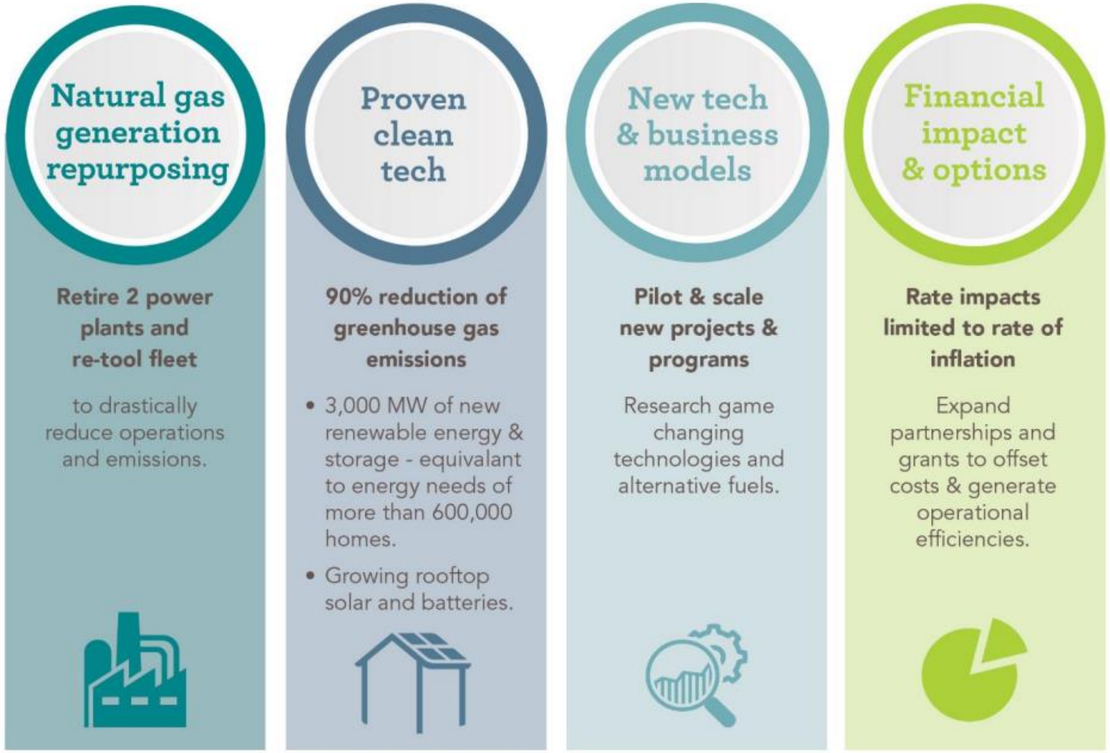
…

Our model results show that squeezing out the last increments of carbon from power generation while maintaining affordability and reliability will require clean firm power.

"Clean Firm" Technology Options
• Hydrogen Combustion • Hydrogen Fuel Cells • Natural Gas w/ Renewable Fuel • Natural Gas w/ CCS • Geothermal • Nuclear

Spotlight: SMUD 2030 Clean Energy Vision

- SMUD's 2030 Clean Energy Vision establishes an ambitious plan to decarbonize energy supply over the next decade



- After studying a range of options for existing natural gas resources, SMUD found the most viable path to be one in which plants are retooled and repurposed using carbon-free fuels
  - Need for firm capacity driven by reliability

"Retiring our thermal power plants and relying completely on proven clean technologies is possible, but it's an expensive option that may not be reliable under every weather scenario."

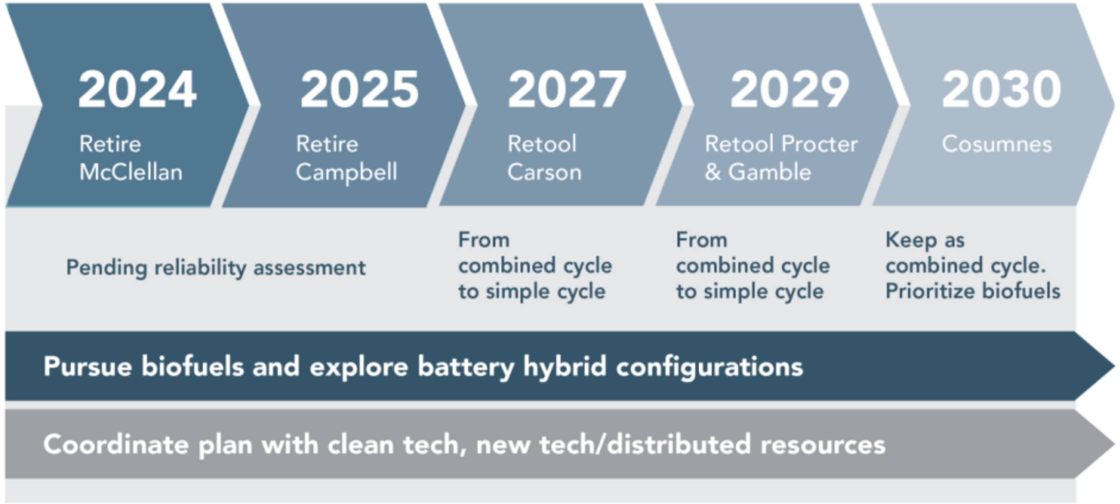
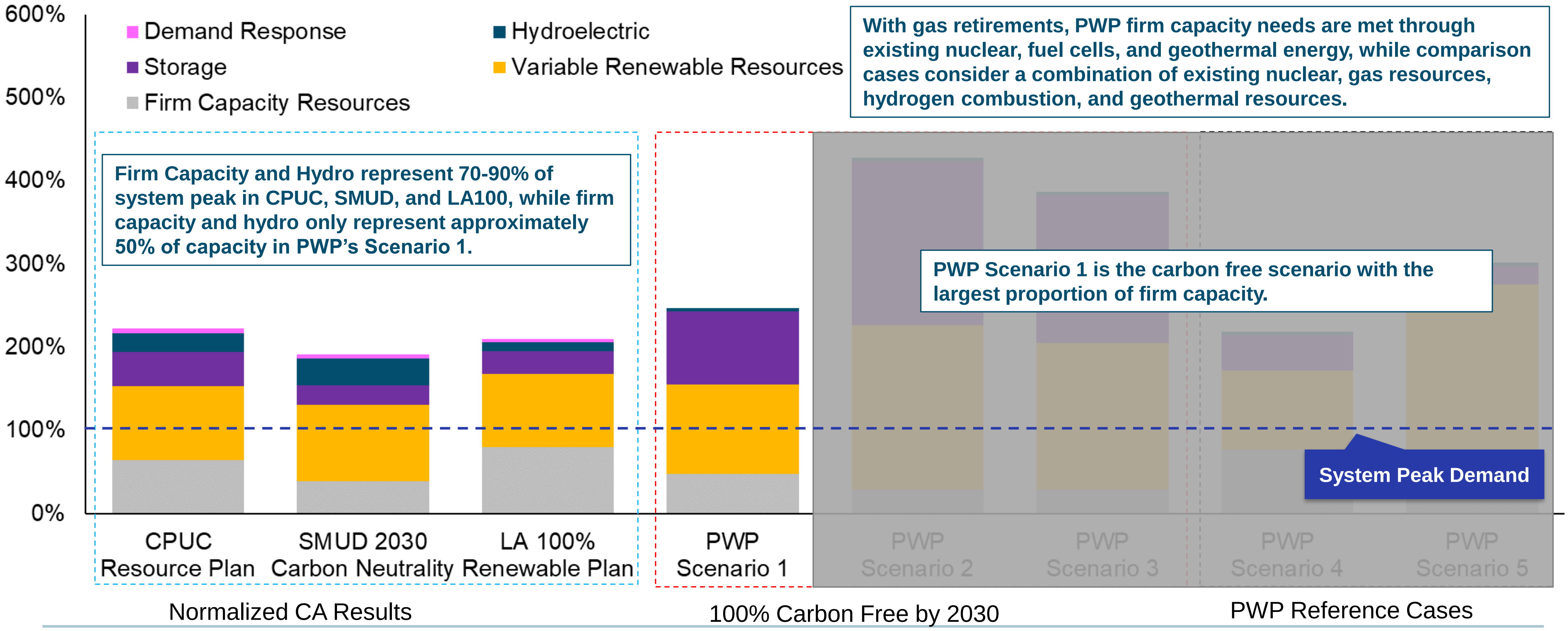


Image source: SMUD 2030 Clean Energy Vision

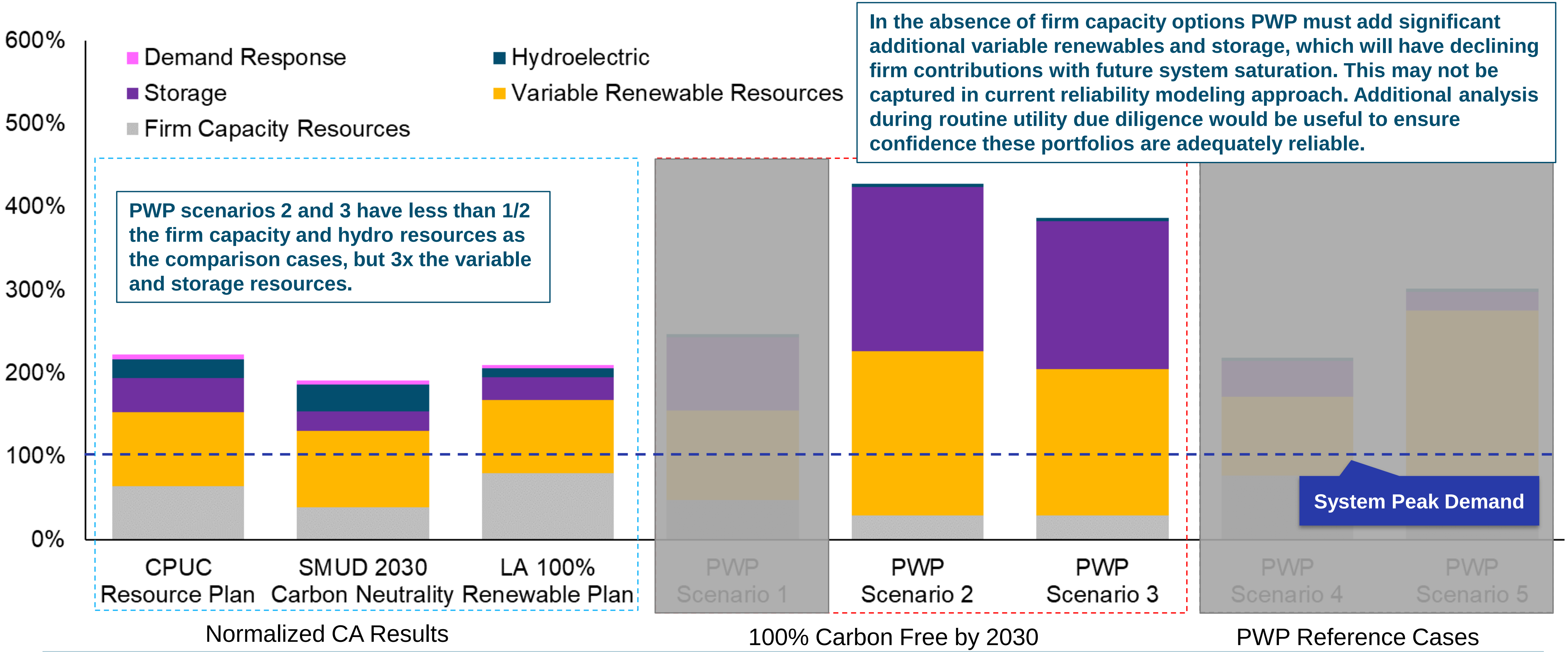
PWP IRP Benchmarking 2030 Results: 1 of 3

Nameplate Capacity Percent of System Peak Demand 2030



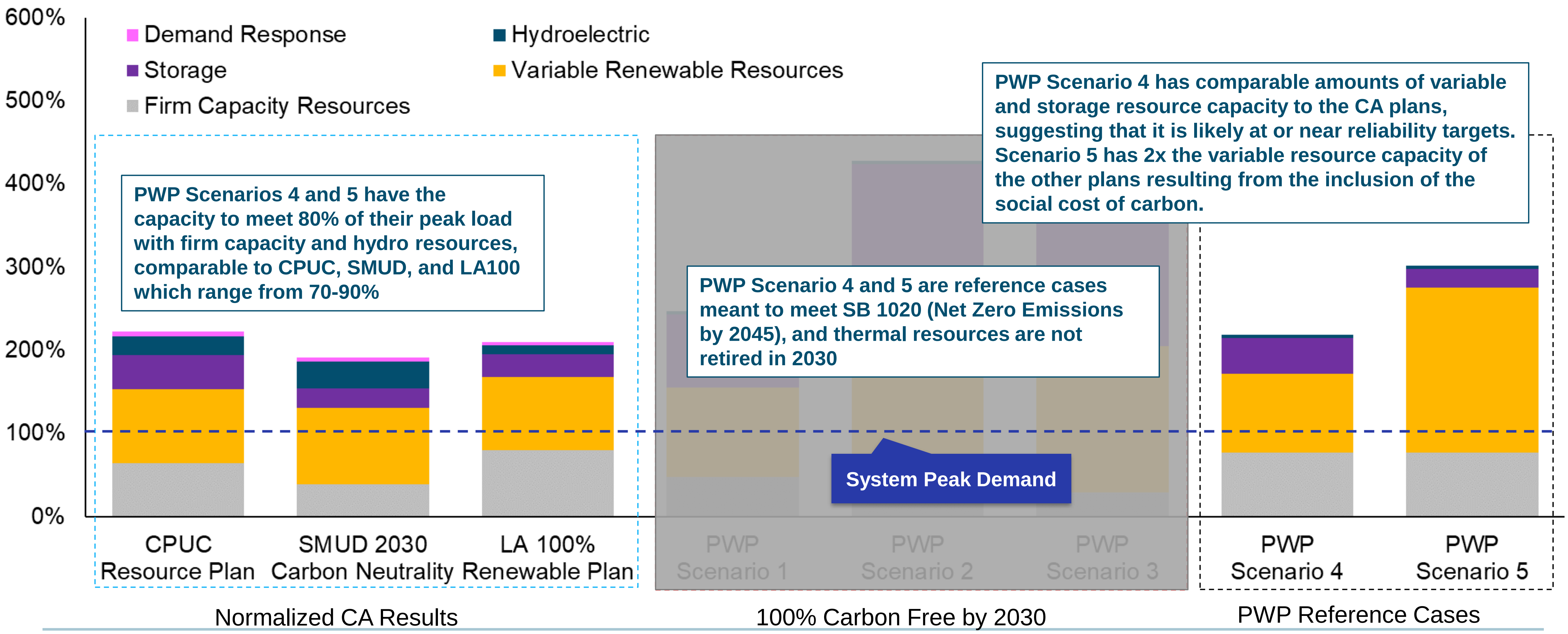
PWP IRP Benchmarking 2030 Results: 2 of 3

Nameplate Capacity Percent of System Peak Demand 2030



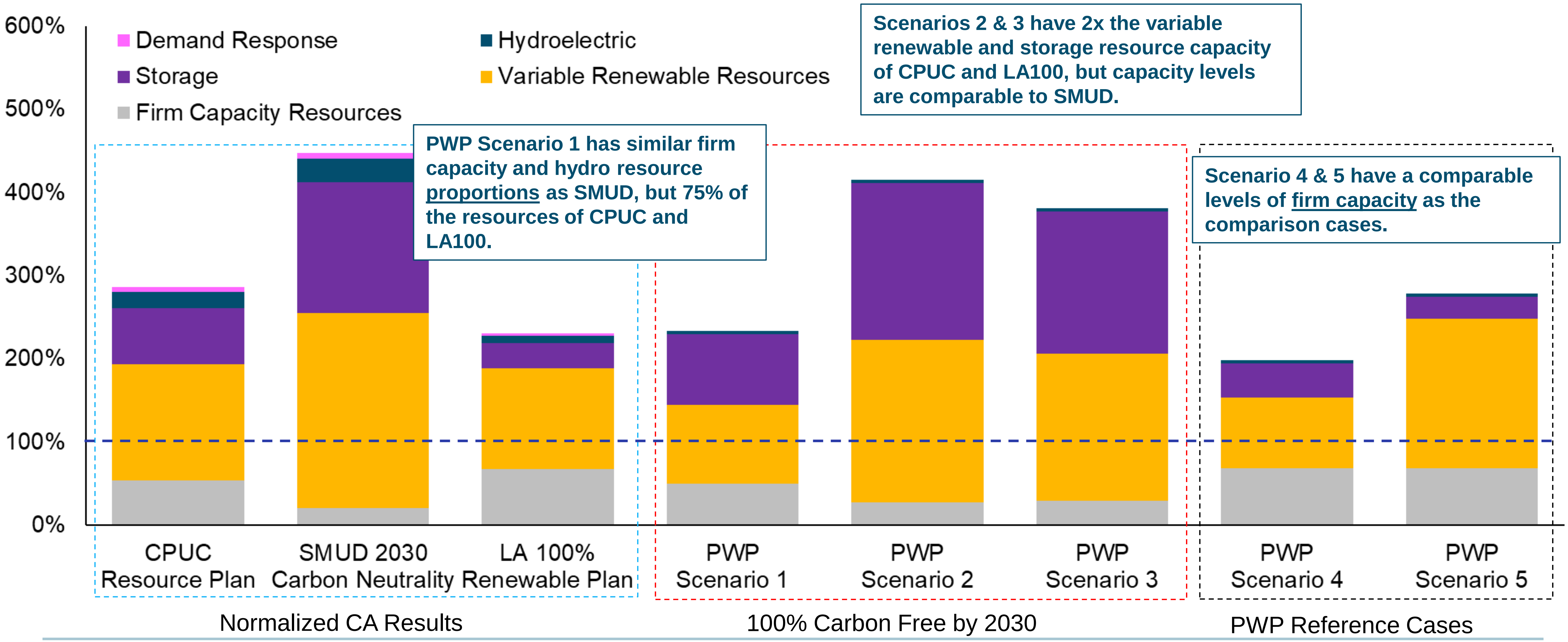
PWP IRP Benchmarking 2030 Results: 3 of 3

Nameplate Capacity Percent of System Peak Demand 2030



PWP IRP Benchmarking 2040 Results

Nameplate Capacity Percent of System Peak Demand 2040



PWP IRP Benchmarking: 2030 and Beyond Resource Mix

In Mix
Not in Mix

Resources	PWP IRP[1]	CPUC IRP	SMUD 2030 Carbon Neutrality	LA 100% Renewable Plan
Fuel Cells	In Mix	Not in Mix	Not in Mix	Not in Mix
Hydrogen Combustion	Not in Mix	Not in Mix	Not in Mix	In Mix
Offshore Wind	Not in Mix	In Mix	Not in Mix	Not in Mix
Gas with CCS	Not in Mix	Not in Mix	In Mix	Not in Mix
Gas	Not in Mix	In Mix	In Mix	In Mix
Pumped Storage	Not in Mix	In Mix	In Mix	In Mix
Demand Response (DR)[2]	Not in Mix	In Mix	In Mix	In Mix
Nuclear	In Mix	In Mix	Not in Mix	In Mix
Biogas	Not in Mix	In Mix	In Mix	Not in Mix
Wind	In Mix	In Mix	In Mix	In Mix
Solar	In Mix	In Mix	In Mix	In Mix
Hydro	In Mix	In Mix	In Mix	In Mix
Battery	In Mix	In Mix	In Mix	In Mix
Geothermal	In Mix	In Mix	In Mix	In Mix

The only dispatchable firm capacity resource option PWP considers is fuel cells, while LA, CPUC and SMUD include a mix of existing and new gas, gas w/ CCS, and hydrogen combustion for dispatchable firm capacity.

Only PWP's IRP does not consider new or existing gas resources as a firm capacity resources from 2030 on

Balancing resources such as pumped storage and DR, which are considered by LA, CPUC and SMUD, are not included in PWP's IRP Mix in Scenarios 1-3.[3]

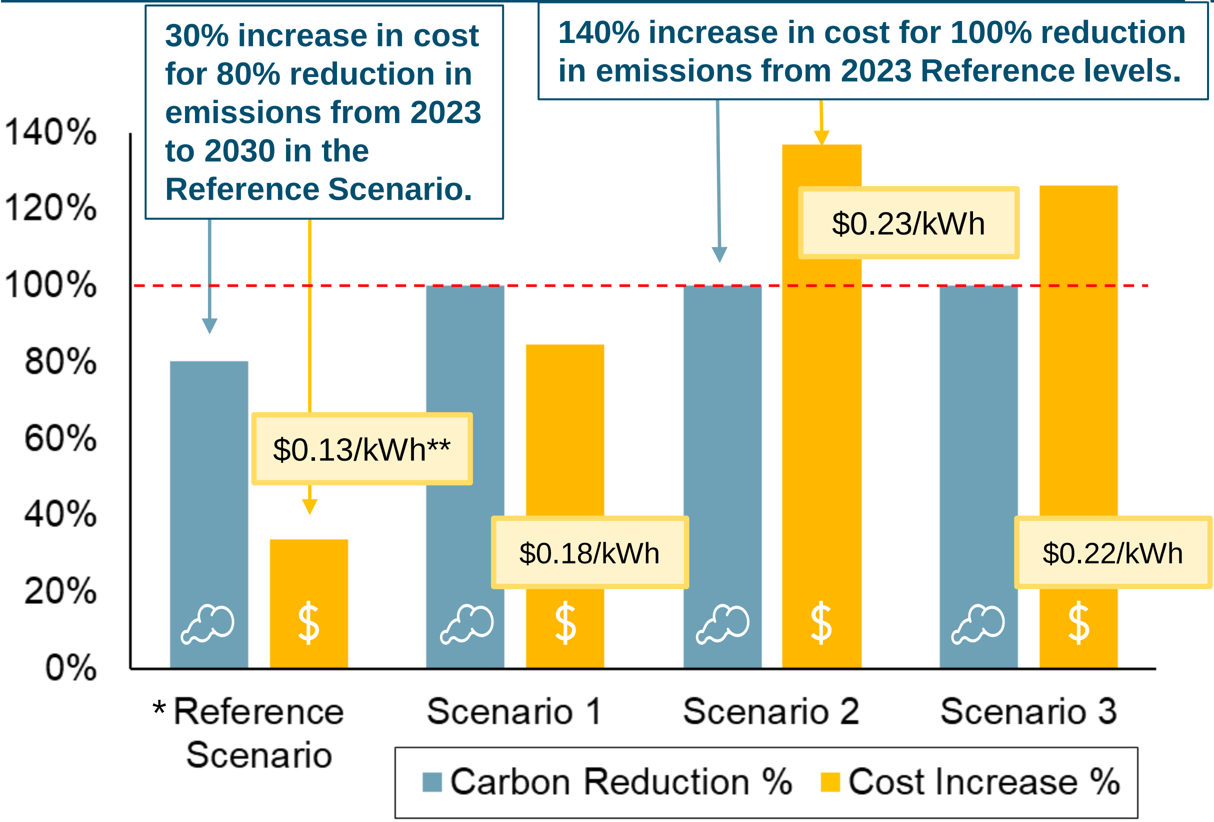
1. Only carbon-free scenarios 1, 2, & 3 considered here.
2. PWP load forecast includes 1 MW of DR resources by 2030.
3. PWP included an emerging technologies scenario that estimated additional DR potential; however, this DR capacity was not added to scenarios 1, 2 & 3.

PWP IRP Benchmarking: Key Takeaways

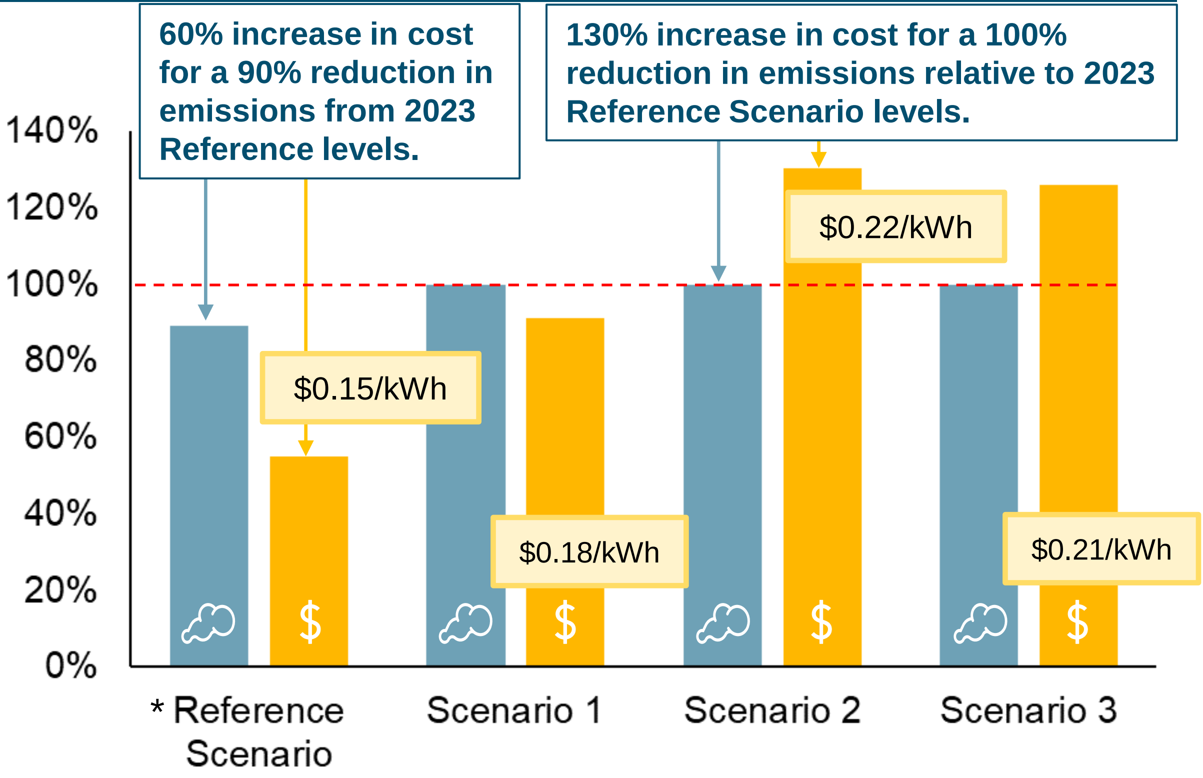
- **PWP's IRP aligns with ambitious decarbonization plans in terms of scalable clean energy and storage resources; however, differences are evident in the firm capacity options considered.**
  - Of the benchmarked plans, PWP was the only system that considered fuel cell additions and does not consider gas resources after 2030.
- **Constraints on firm capacity options (i.e., thermal resources) in carbon-free scenarios result in higher variable renewable resources and storage additions than the benchmarked scenarios.**
  - These additional variable renewables will have declining firm contributions with future system saturation, which may not be captured with the current reliability modeling approach.
- **CPUC, SMUD, and LA100 rely on existing thermal resources to provide firm capacity through 2030, moving to renewable fuels or CCS in the mid-term, and hydrogen combustion in the long-term.**
  - PWP's IRP gas resources are retired by 2030 in Carbon-Free scenarios, requiring significant additions of fuel cells and battery storage to meet firm capacity needs.
- **Benchmarking exercise helps validate PWP IRP methodology as 2040 reference scenario results align well with deep decarbonization trends.**
  - PWP's reference scenarios are well aligned with the common trends of firm capacity, scalable low-cost clean energy resources, and balancing resources of deep decarbonization plans.

PWP IRP Scenario Results: Carbon Abatement Costs

2030: Cost & Emissions Comparison to 2023 Reference Levels



2040: Cost & Emissions Comparison to 2023 Reference Levels



- **The additional cost to remove the remaining system carbon emissions after achieving 80% or 90% carbon reductions is significantly higher than the cost to get to those reduction levels**
- **This is consistent across scenarios but exacerbated in 2 & 3 where firm capacity limits are applied**

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**Refers to Scenario 4*

***Costs include base energy rate and IRP scenario revenue requirement normalized by load for scenario. Cost does not include any stranded assets*

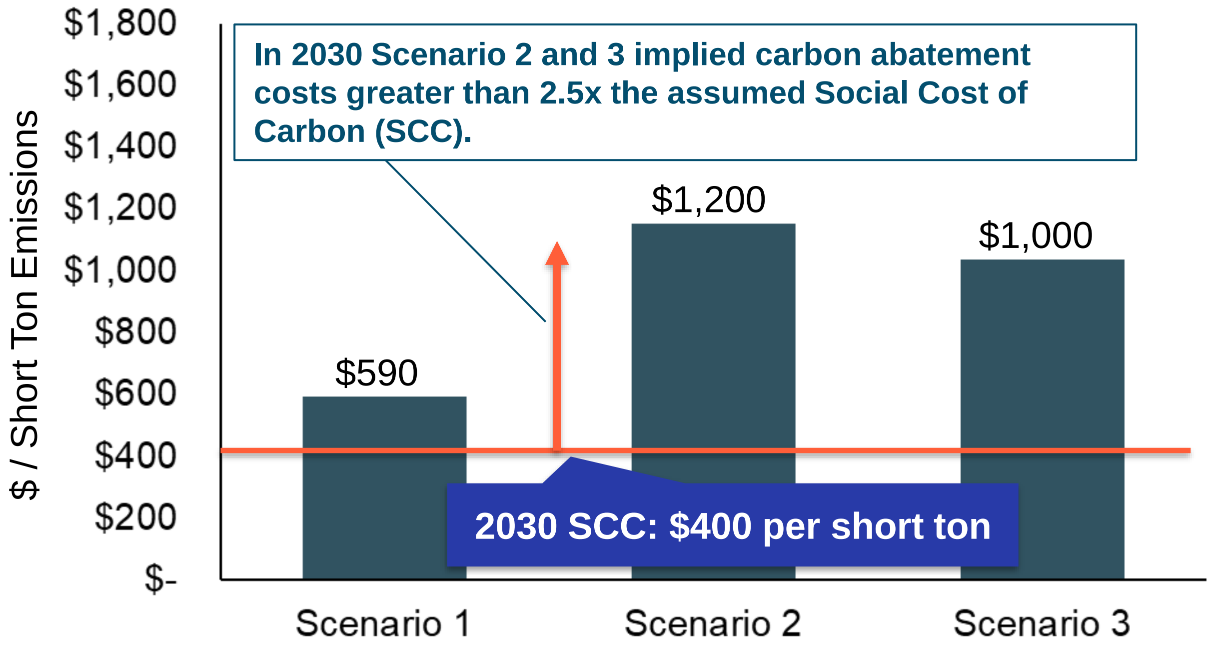
PWP IRP Scenario Results:
SCC and Implied Carbon Abatement Cost Comparison

The **Implied Cost of Carbon Abatement ($/ton)** for a given scenario measures the cost to achieve additional emissions reductions, relative to a reference case, on a per ton basis

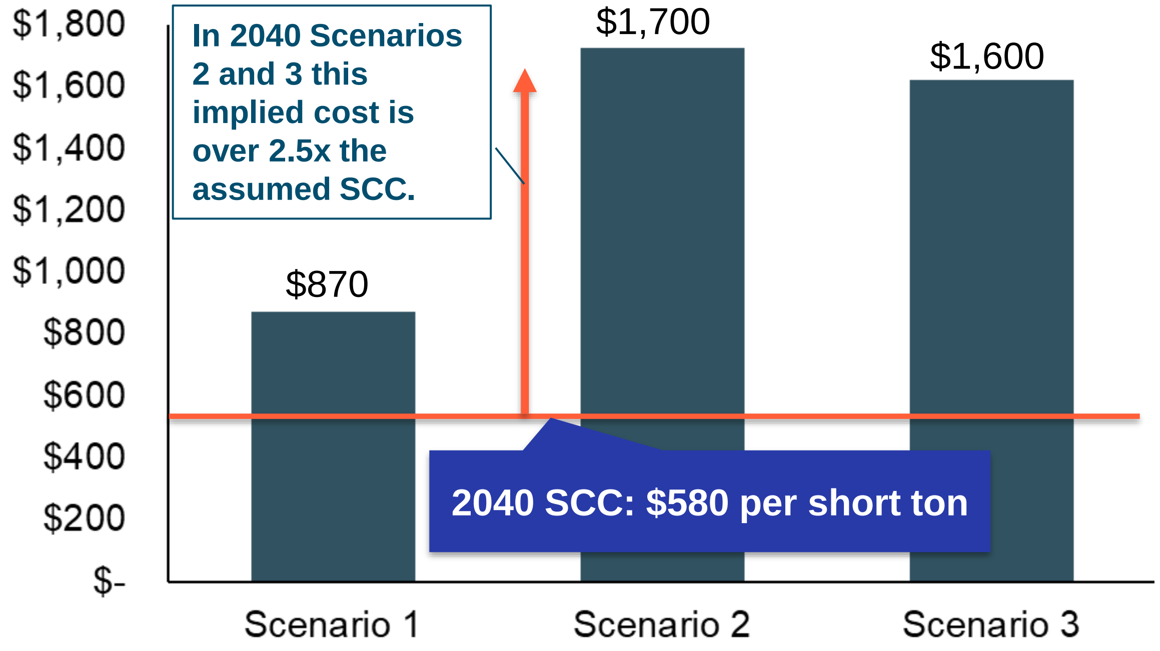
Calculation:

$$\$/\text{ton} = \frac{\Delta\ cost}{\Delta\ emissions}$$

2030: Implied Cost of Carbon Abatement



2040: Implied Cost of Carbon Abatement



+ **Implied cost of carbon abatement is higher than the assumed social cost of carbon chosen in Scenario 5, reaching 2x the costs in scenarios 2 and 3 in 2030.**

Thank You

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