ATTACHMENT 2

Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel Meeting #1

June 5, 2024

Nick Schlag, Partner
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Managing Consultant

Energy+Environmental Economics

Agenda

- Kickoff – David (10 min)
- Introductions – All (10 min)
- Study Scope Overview – Nick (25 min)
- Questions & Comments – All (15 min)

E3 Project Team

Project Leadership Team

Nick Schlag
Partner
Project Lead

Nathan Lee
Sr. Managing Consultant
Project Manager

Michaela Levine
Managing Consultant
Project Manager

Additional Subject Matter Experts

Eric Cutter
Partner
Distribution Planning

Lakshmi Alagappan
Partner
Transmission Planning

Mike Sontag
Associate Director
DR & Flexible Loads

Steering Committee

Amber Mahone
Managing Partner

Arne Olson
Senior Partner

Aaron Burdick
Director

Dyami Andrews, Managing Consultant
Maddie MacMillan, Consultant
Jack Moore, Senior Director
Emily Peterson, Senior Managing Consultant
Vignesh Venugopal, Senior Managing Consultant
Jun Zhang, Senior Managing Consultant

Mandy Kim, Consultant
Brendan Mahoney, Senior Consultant
Cameron Morelli, Consultant
Melissa Rodas, Consultant
Parker Wild, Consultant
Angineh Zohrabian, Managing Consultant

Ruoshui Li, Senior Consultant
Caitlin McMahon, Consultant
Jimmy Nelson, Director
Sam Schrieber, Managing Consultant
Chen Zhang, Managing Consultant

Context for the Need for an Optimized Strategic Plan

- **In January 2023, Pasadena City Council passed Resolution 9977, setting ambitious goals for the city amidst a climate emergency**
- **Goal to source all electricity from carbon-free sources by 2030 far exceeds requirements of California state policy**
  - Establishes City of Pasadena as a leader on climate change in a state with already aggressive policy goals
  - Requires a head-on confrontation with a series of technical challenges well-established in literature regarding the transition to a carbon-free electricity system

A RESOLUTION OF THE CITY COUNCIL OF THE CITY OF PASADENA, CALIFORNIA DECLARING A CLIMATE EMERGENCY AND SETTING A GOAL TO SOURCE 100% OF PASADENA'S ELECTRICITY FROM CARBON FREE SOURCES BY 2030

Section 3. The City Council hereby sets a policy goal to source 100% of Pasadena's electricity from carbon free sources by the end of 2030.

Section 4. The City Council hereby directs the City Manager to utilize the 2023 IRP process to plan multiple approaches to transition to the goal described in Section 3 and to optimize affordability, rate equity, stability, and reliability of electricity while achieving this goal.

Development of a Proposed Scope of Work for the Optimized Plan

- **City Council's approval of IRP was accompanied by a directive to develop an Optimized Strategic Plan:**

  "City Manager's Office to engage 3rd party consultant with expertise in green energy to advise in development of optimized plan. Optimized plan development to be completed within six months and presented to the Municipal Services Committee."

- **E3 began working with PWP and the City Manager's Office to develop a proposed scope in January 2024**

- **Proposed scope of work represents a cohesive and comprehensive framework built on rigorous technical analysis to inform an optimized plan**

Recommended studies to support Optimized Strategic Plan as discussed with Municipal Services Committee, February 26, 2024

Recommended Studies

Pasadena Water and Power

- Distributed Energy Resources and Demand Response
- Study options for Glenarm conversion or replacement
- Transmission and Distribution System
- Low-income and Disadvantaged Communities Support Community Solar Program
- New and Emerging Technology Evaluation
- Market Potential Study

8 PASADENA

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

Questions/Issues/Challenges Specific to Pasadena

Issue	Implications/Questions
Glenarm's importance for local reliability	Due to import limits and potential contingencies, maintaining sufficient generating capacity within the PWP system is necessary to ensure reliability across all hours
Limited interconnection to CAISO	Timing of planned upgrade at Goodrich receiving station has significant potential impacts on sequencing of other elements of plan
Aging T&D infrastructure	Replacement of undergrounded subtransmission lines staged prior to transformer upgrades at Goodrich
Limited land availability	Opportunities to add new generation resources within load pocket are limited
Lack of advanced metering infrastructure	Installation of smart meters necessary for implementation of any advanced demand response/load flexibility solutions

Defining an “Optimized Strategic Plan”

The Optimized Strategic Plan is…

…a roadmap that defines the key actions and future decision points that will best position PWP to achieve the city’s goal to source all electricity from carbon-free sources by 2031 while maintaining reliability and limiting cost impacts to customers

The Optimized Strategic Plan will…

…consider how new generation resources, investments in T&D infrastructure, and customer programs can facilitate transition to Pasadena’s carbon-free goal

What to Expect from an Optimized Strategic Plan

Infrastructure Needs

- New generation resources (types, general locations, timing)
- Existing generation resource retirements
- Transmission & distribution upgrades (including dependencies)

Customer Participation

- Projected future customer energy demands
- Distributed energy resources & virtual power plants (including solar, storage, demand response, flexible loads, vehicle charging)

Clean Energy Metrics

- Share of annual energy needs sourced from renewable energy
- Share of annual energy needs sourced from carbon-free energy
- Share of hourly energy needs sourced from carbon-free energy
- Reduction in carbon emissions relative to baseline (1990)

Cost Metrics

- Total incremental cost relative to Reference Case (state policy)
- Average system rate
- Relative customer bill impacts

Reliability

- Validation of key local reliability results
- Consistency with state regulatory requirements for resource adequacy

Overview of Study Plan

Where relevant and useful, the study plan will leverage findings and information from previous planning efforts (Integrated Resource Plan, Power Delivery Master Plan)

- **Preparatory Studies**
  - Distributed Solar & Storage Potential
  - Demand Response & Flex Load Potential
  - New & Emerging Technology
  - Transmission Expansion Options
- **Portfolio Development**
  - Glenarm Conversion & Replacement Analysis
  - Long-Term Capacity Expansion Studies
  - Production Simulation Studies
  - Distribution System Analysis
- **Optimized Strategic Plan**
  - Cost Impact Assessment
  - Final Report

Stakeholder & Community Outreach

Overview of Study Plan

Preparatory Studies → **Portfolio Development** → **Optimized Strategic Plan**

Preparatory Studies
- Distributed Solar & Storage Potential
- Demand Response & Flex Load Potential
- New & Emerging Technology
- Transmission Expansion Options

Portfolio Development
- Glenarm Conversion & … Expansion Studies
- Production Simulation Studies
- Distribution System Analysis

Optimized Strategic Plan
- Cost Impact …

Studies to characterize technical potential for local resource development in Pasadena service area with focus on demand-side solutions and distributed resources (solar, storage, DR, flex loads, electric vehicles)

Stakeholder & Community Outreach

Overview of Study Plan

Preparatory Studies → **Portfolio Development** → **Optimized Strategic Plan**

Preparatory Studies
- Distributed Solar & Storage Potential
- Demand Response & Flex Load Potential
- **New & Emerging Technology**
- **Transmission Expansion Options**

Portfolio Development
- Glenarm Conversion & Replacement Analysis
- Long-Term Capacity Expansion Studies
- Production

Optimized Strategic Plan
- Cost Impact Assessment
- Final Report

Studies to characterize supply-side resources and transmission solutions with a focus on options that can support local reliability needs (e.g. H2, long duration storage, Goodrich expansion)
Also includes external resource options

Stakeholder & Community Outreach

Overview of Study Plan

Preparatory Studies
- Distributed Solar & Storage Potential
- Demand Response & Flex Load Potential
- New & Emerging Technology
- Transmission Expansion Options

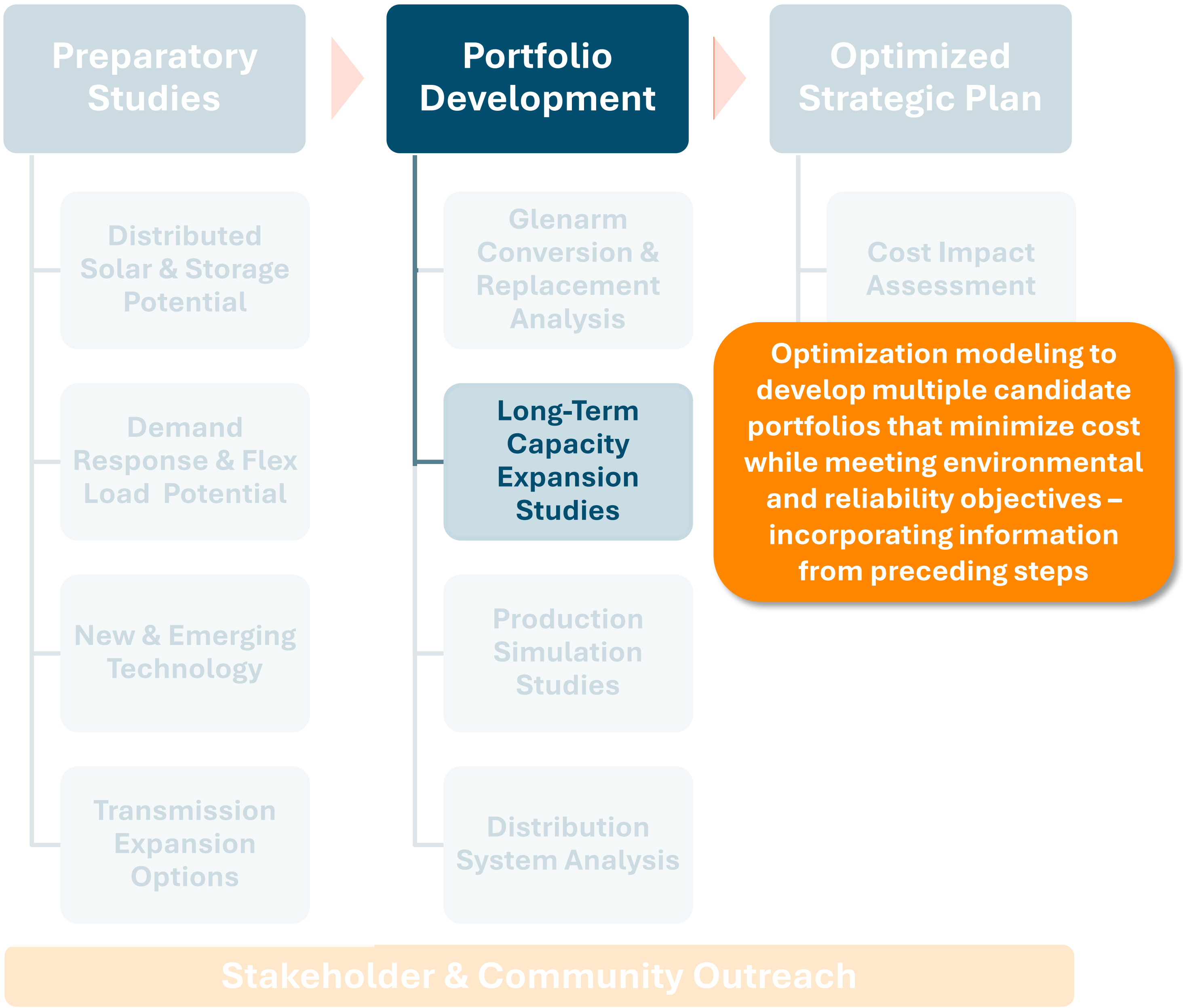
Portfolio Development
- Glenarm Conversion & Replacement Analysis
- Long-Term Capacity Expansion Studies
- Production Simulation Studies
- Distribution System Analysis

Optimized Strategic Plan
- Final Report

Analysis of options to convert or replace Glenarm while maintaining adequate supply of local resources & imports across all conditions – including peak loads/extreme weather and transmission contingencies

Stakeholder & Community Outreach

Overview of Study Plan



Overview of Study Plan

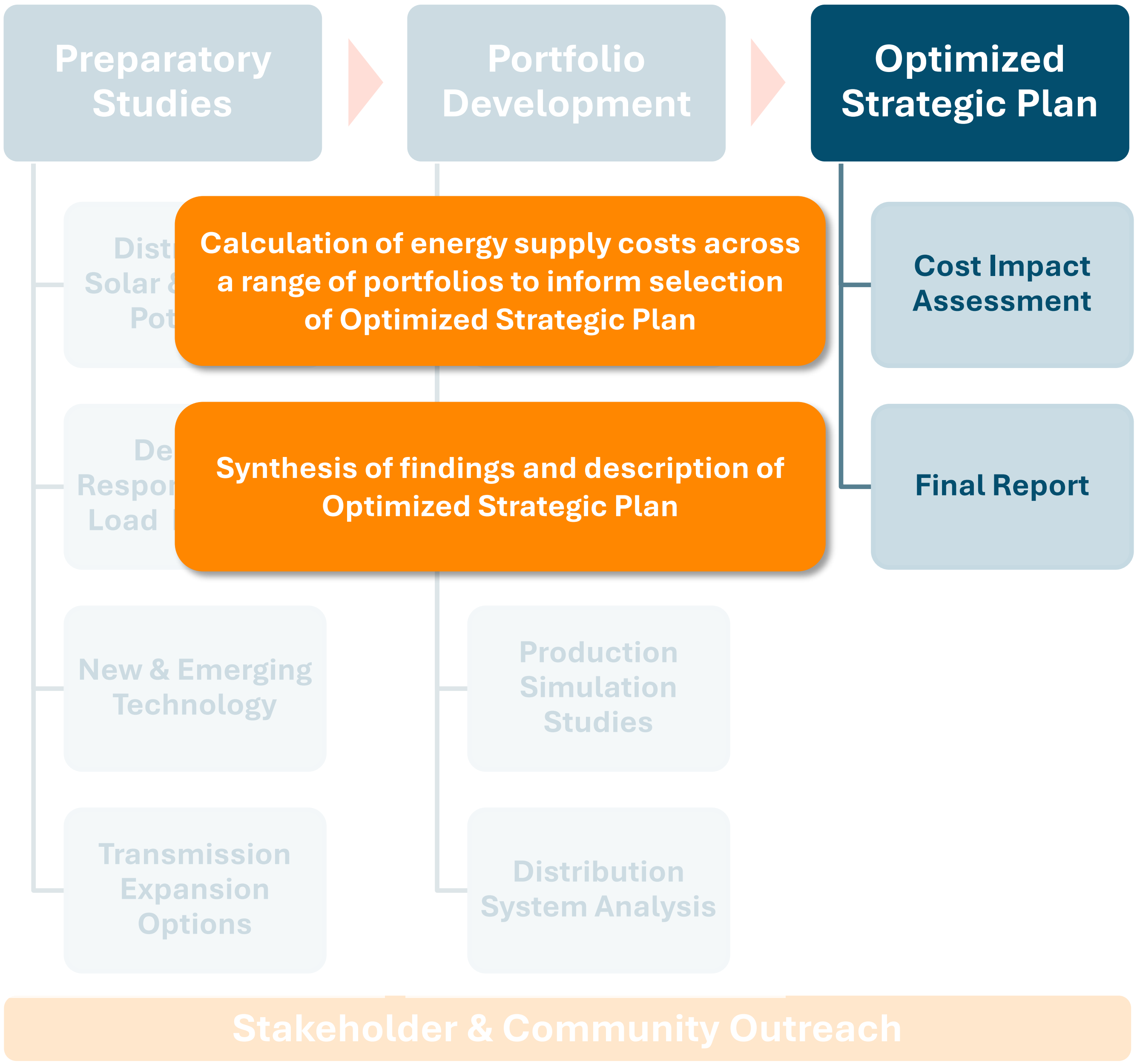
Preparatory Studies
- Distributed Solar & Storage Potential
- Demand Response & Flex Load Potential
- New & Emerging Technology
- Transmission Expansion Options

Portfolio Development
- Glenarm Conversion & Replacement Analysis
- Long-Term Capacity Expansion Studies
- **Production Simulation Studies** — Hourly dispatch simulation of portfolios to ensure operational reliability and evaluate operating costs
- **Distribution System Analysis** — Geospatial analysis of future substation loads to characterize distribution system impacts and identify options for targeted DERs

Optimized Strategic Plan
- Cost Impact Assessment
- Final Report

Stakeholder & Community Outreach

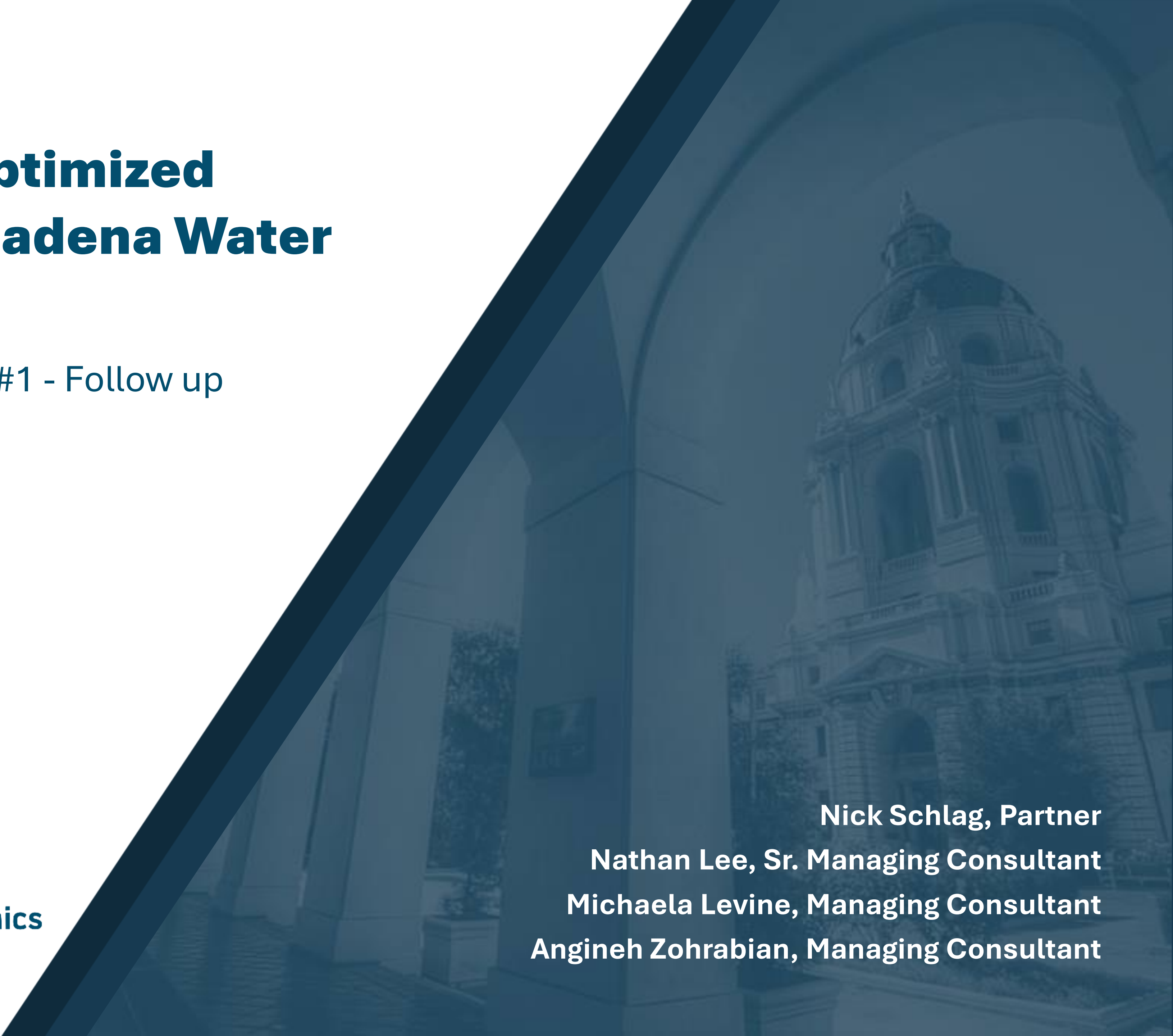
Overview of Study Plan



Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel Meeting #1 - Follow up

June 27, 2024



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Energy+Environmental Economics

Topics Covered

- **Follow-up questions from previous meeting**
- **Local solar + storage study**
  - Objectives
  - Technical potential methodology
  - Adoption Methodology
- **DR and flexible load study**
- **Emerging technology study**
  - Objectives
  - Data sources
  - Technologies considered

Follow-Up Questions: Study Overview

1. Fixing the Goodrich bottleneck that limits importation of electricity is a large infrastructure investment. On the other hand, DERs are comparatively more expensive than imported solar/storage, but provide resilience and reliability in the case there is an issue with Goodrich. Will this tradeoff be assessed in the studies and scenarios to be modeled?
2. Are there strategies PWP has considered and chosen not to pursue related to greening the energy supply? What are those and why not?

Follow-Up Questions: Distributed Solar + Storage Study

3. Your slides note the limited land available for DER. According to Project Sunroof[1] there is approximately 389 MW DC capacity in Pasadena on rooftops alone. What tools will you use to measure the available land for solar and storage?
4. The Project Sunroof methodology says explicitly that the estimate does *not* take into account of grid constraints: Will the OSP include simulations of the Pasadena grid under different PV adoption scenarios to have a more reliable estimate of solar potential? Such a simulation system will also be useful for determining the type and cost of grid investments that will be most impactful/efficient towards achieving the 2030 goal. It will also provide guidelines for, not just planning and deployment, but also for the efficient operation of the updated/new DER infrastructure once it is put in place.
5. Will you include parking lots, commercial rooftop, and PUSD properties in the analysis of available space for DER?
6. Will publicly-owned solar and storage on private residences (e.g. via PPA) be included as an option during the solar study?
7. Will the OSP consider the use of microgrids with neighborhood storage as a way to optimize supply and storage and also decrease demand?

1. https://sunroof.withgoogle.com/data-explorer/place/ChIJUQszONzCwoARSo_RGhZBKwU/)

Follow-Up Questions: Distributed Solar + Storage Study, cont’d

8. Is there a “safe” low hanging fruit goal for increasing rooftop solar (through a marketing campaign by the City, streamlining permitting and removing restrictions) that could be sought this year to begin increasing adoption in advance of the completion of the optimized plan?
9. Regarding question 8, what would be the cost of such a marketing campaign? Could the information be made available for outside organizations to spread for PWP? What permitting streamlining could be done? What restrictions would need to be removed?
10. In the IRP there was disagreement about how to estimate the cost of residential and community rooftop solar. The assumption was made that increases in the residential rooftop solar, beyond the historical increase, would be paid by PWP and passed on to ratepayers. How do you plan to do this?
11. What is/are PWP's current subsidy(ies) for non-utility-owned rooftop solar? If known and as applicable, please break out direct monetary and non-monetary subsidies (cash rebates, tax incentives, permitting exceptions) and indirect monetary subsidies (customer-avoided cost).
12. What is the current state of rebates/subsidies for residential rooftop solar? Commercial rooftop solar?

Follow-Up Questions: Distributed Solar + Storage Study, cont'd

13. Has or would PWP consider lease/electric power sharing with property owners as a way to incentivize solar installation? (If a property owner allows PWP to install solar on a rooftop, that property owner gets a discount on electric costs, for example and PWP gets the power generated.)
14. Regarding question 13, does PWP have experience with such? Does PWP have experience with or will the OSP provide cost estimates for the maintenance costs of such facilities on private property? What would the insurance model look like, and what would the cost for such (ex., City self-insured? A third-party private carrier policy for all such facilities? Requiring AI certificates for the homeowners/property-owners CGL insurance policies?)

Follow-Up Questions: New and Emerging Tech Study

15. Slide 6, under Blueprint for a Low Carbon Grid, includes Carbon Capture & Sequestration (CCS) as well as biogas, which are carbon neutral resources (as opposed to carbon free). Please verify that these will not be included in the Optimized Strategic Plan "that will best position PWP to achieve the city's goal to source all electricity from carbon-free sources by 2031."
16. Is linked neighborhood geothermal an available resource in Pasadena?

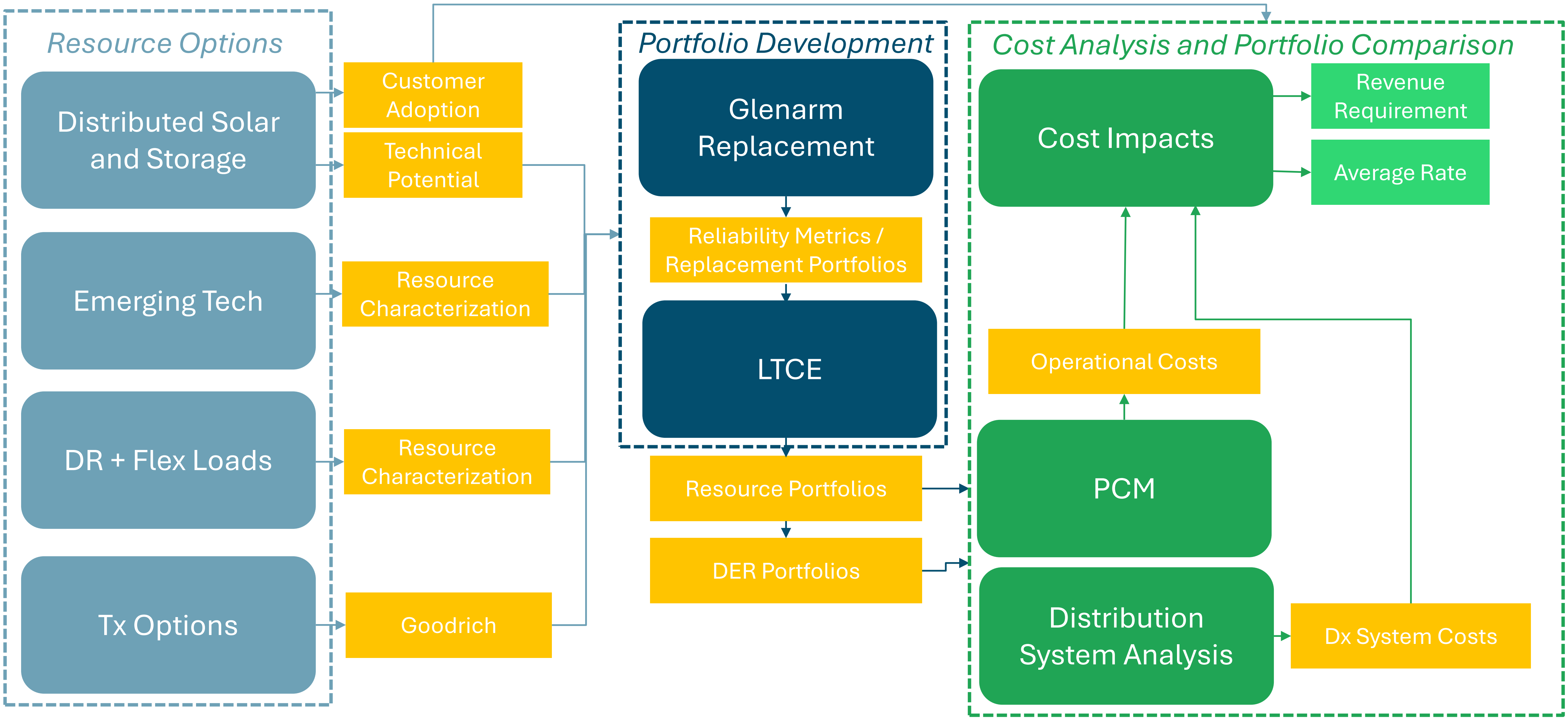
Follow-Up Questions: Demand Response and Flexible Load Study

17. For the Demand Response/flex load study, there are different ways of reducing demand, from voluntary requests, to TOU rates, to VPP and grid optimization, to mandatory management by PWP. Will each of these be considered in the study? Do all of these use the same kind of AMI?
18. What experience has PWP had with the performance of such programs? Also, will we look to the study for examples of the performance of such programs elsewhere?

Follow-Up Questions: Glenarm Replacement Studies

19. How will you discount the value of the Glenarm Plant for risks arising from plant shut downs, equipment defects, and maintenance costs? The General Electric GT-5 combined cycle turbine (which was installed in 2017) was shut down in November 2023 and remains in Texas for repair of a serious defect probably throughout the summer. The cost of the repairs has been increasing the longer the part stays in Texas. GE has been the subject of lawsuits over defective gas turbines although we don't know if the Pasadena GT-5 is related.
20. Regarding question 19, how will you apply similar discounts for other resources (e.g., rooftop solar, battery storage, and neighborhood geothermal)?
21. Regarding question 1 and Goodrich, how much is the currently anticipated large infrastructure investment? What is the anticipated reliability figure for Goodrich with the investment (e.g., 98%? 99%? 99.9999%)? Do we have similar reliability figures for generation or storage resources?
22. What are the regulatory/ISO restrictions we need to consider? Are there workarounds?
23. What is actually planned for the entire Glenarm site?

Detailed Illustration of Study Dependencies



Solar + Storage Study

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Scope of Local Solar & Storage Study

Questions addressed in Local Solar Storage Study:

1. What is technical potential for solar and storage within PWP service territory (rooftop, parking canopy, ground mount)?
2. What are cost and performance characteristics of potential solar and storage resources?
3. What levels of customer solar and storage adoption could occur under various rate designs and incentive structures?

Questions *not* addressed in Local Solar Storage Study:

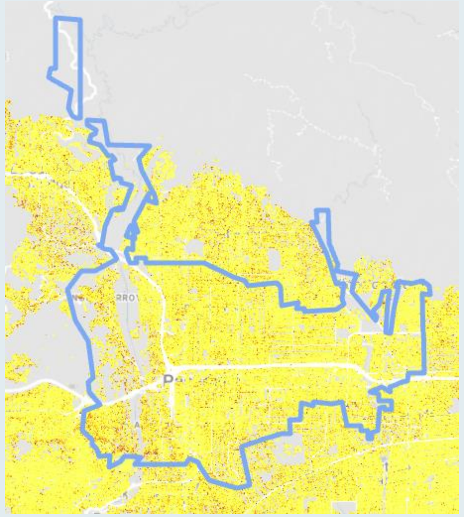
1. What is the value provided by solar and storage resources adopted by PWP customers?
2. What is total resource cost resulting from with different levels of customer solar adoption?
3. What bill impacts to non-participating customers will result from different levels of customer solar adoption?

Addressing these questions requires a complete view of the supply- and demand-side solutions that enable PWP to achieve its goals and will be part of the *Cost Impacts* study

Local Solar & Storage Technical Potential Methodology

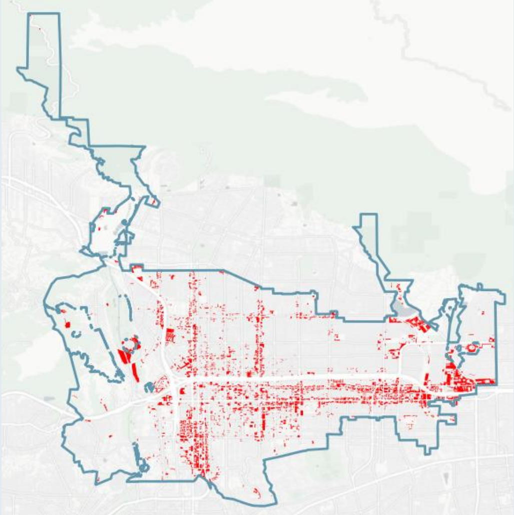
Rooftop Solar & Storage

Merge Google Sunroof database with PWP customer data and apply various screens to determine technical potential by segment.



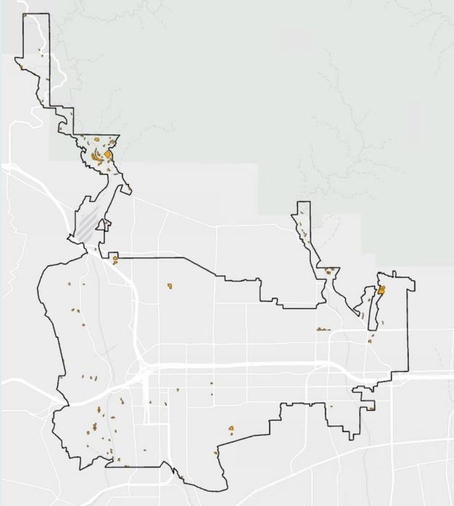
Parking Canopy Solar

Filter parking lots identified in OpenStreet maps for land use restrictions and building safety code.



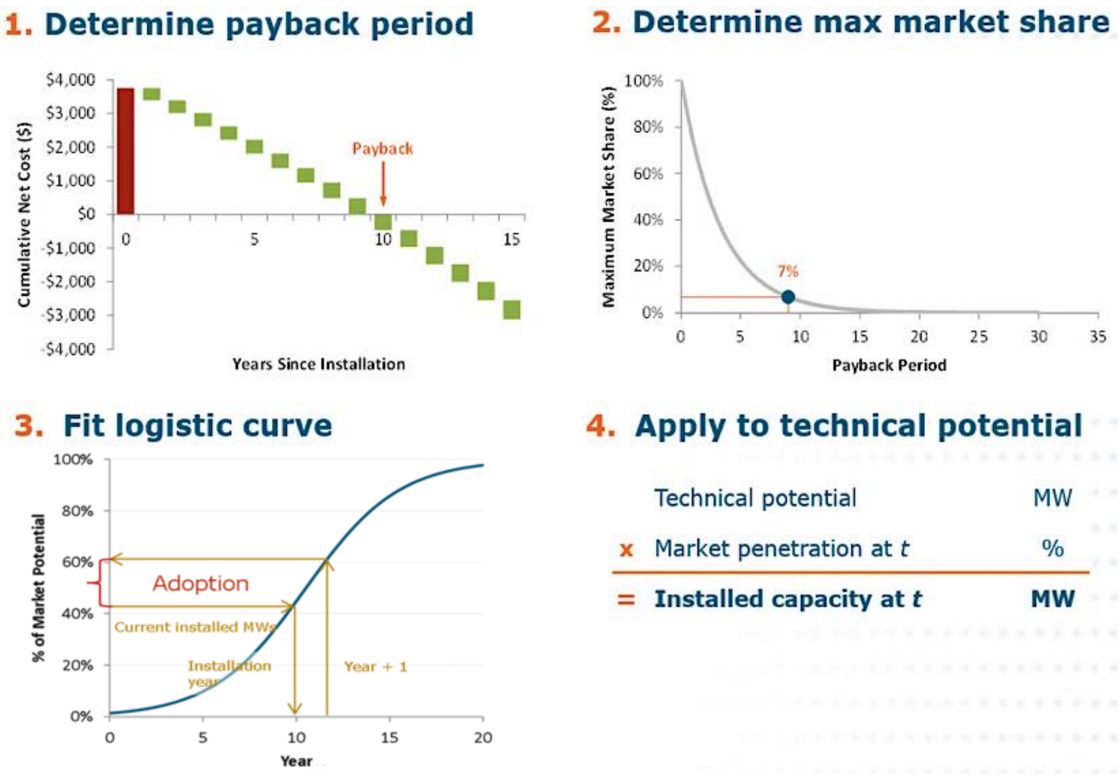
Ground Mount Solar

GIS-based screening of land use to exclude buildings, parks, roads, other impervious surfaces, and sloped terrain



Local Solar + Storage Adoption Methodology

+ **The local solar + storage adoption analysis will use a bass diffusion model framework**
  - Bass diffusion is an empirical market share model to determine the long-run market equilibrium of customer adoption.
  - The relationship between economic attractiveness and ***maximum market*** share is based on **payback periods** or **benefit-cost** ratios.
  - Logistic curves can be calibrated based on historical adoption rate and cost-effectiveness.
+ **Adoption will be modeled reflecting payback periods under several tariffs including:**
  - Net energy metering
  - Net billing
  - Buy-all / Sell-all
  - LCOE

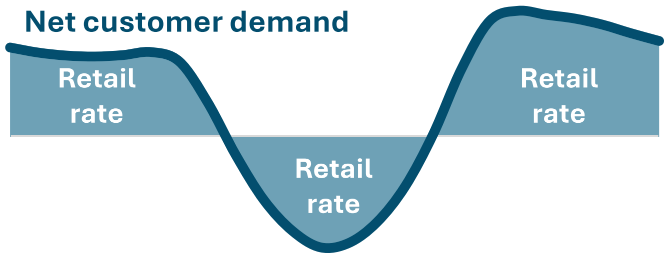


Options to Consider for Customer Solar & Storage Compensation

Option 1: Net Energy Metering

All generation (both self-consumption & exports) credited at customer retail rate (current design)

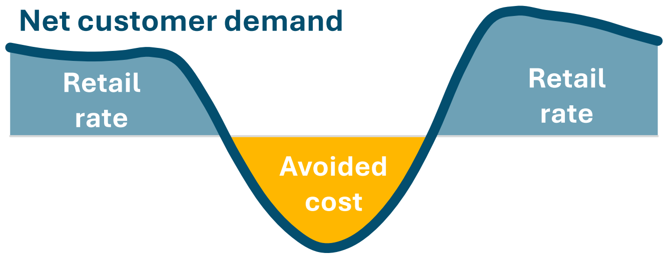
Time-dependent signal: no
Requires AMI: no



Option 2: Net Billing

Generation consumed by customer credited at full retail rate; generation exported to grid credited at utility avoided cost

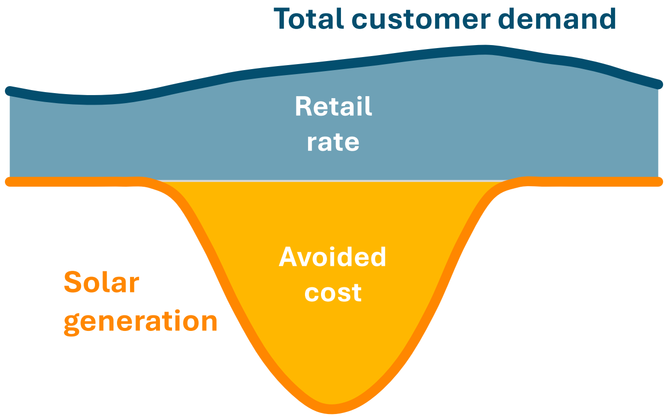
Time-dependent value: yes
Requires AMI: yes



Option 3: Buy-All/Sell-All

All generation (both self-consumption & exports) credited at utility avoided cost

Time-dependent value: yes
Requires AMI: yes



Consideration of broader changes to rate design (e.g. TOU rates) is beyond the scope of this study

DR and Flexible Loads Study

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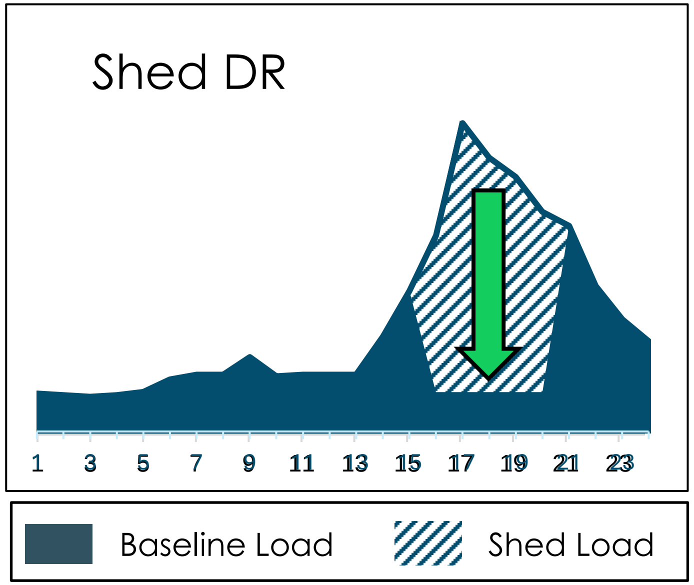
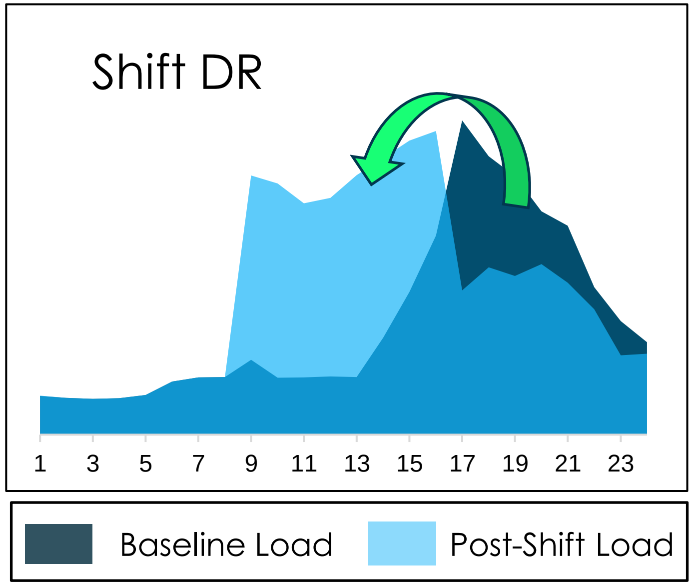
LBNL Potential Study Overview

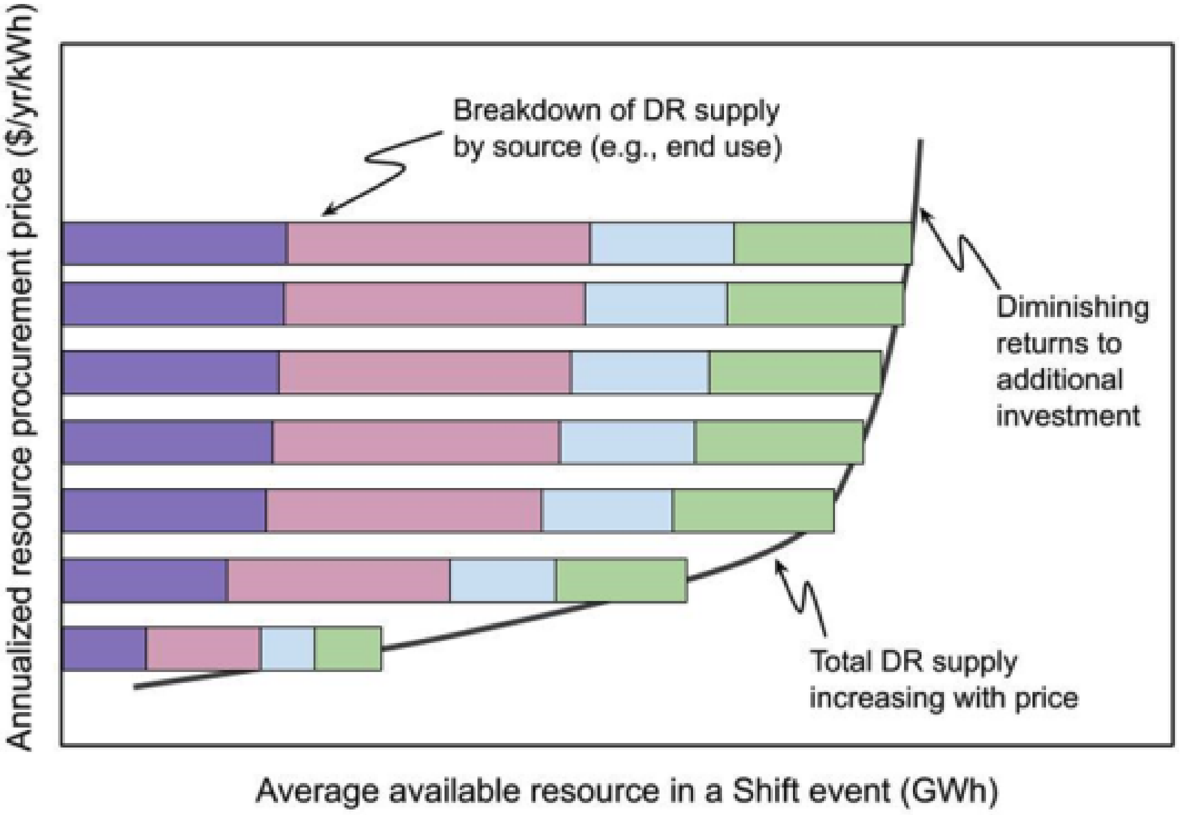
+ **LBNL produces supply curves for the achievable potential for shed and shift demand response curves characterizing the resource availability at a given cost.**
  - **Shed ("conventional") –** Loads that can be curtailed to provide capacity reductions
  - **Shift –** Loads that can be shifted between hours
+ **LBNL also characterized the shape DR resource in the latest phase of study.**
  - **Shape ("load-modifying")** - Reshaping customer load profiles for significant portions of the year through price responsiveness or behavioral campaigns.





Objective, Outputs, Methodology, and Uses

- **Objective: Assess cost and potential for demand response in PWP's service territory.**
- **Outputs:**
  - Shift and shed DR supply curves.
  - Options for managed vs unmanaged load shapes
- **Methodology:**
  - Scale Lawrence Berkeley National Laboratory's CA Demand Response Potential Study results from an SCE SubLap to PWP's service territory.
    - Leverage data from PWP on customer segmentation and end-use load studies for calibration.
    - Apply constraints to supply curve factoring in PWP's AMI deployment schedule and capacity to expand load flexibility programs.
  - Develop managed and unmanaged charging load profiles recommending alternative load scenarios for use in PWP using E3's RESHAPE-EV model.



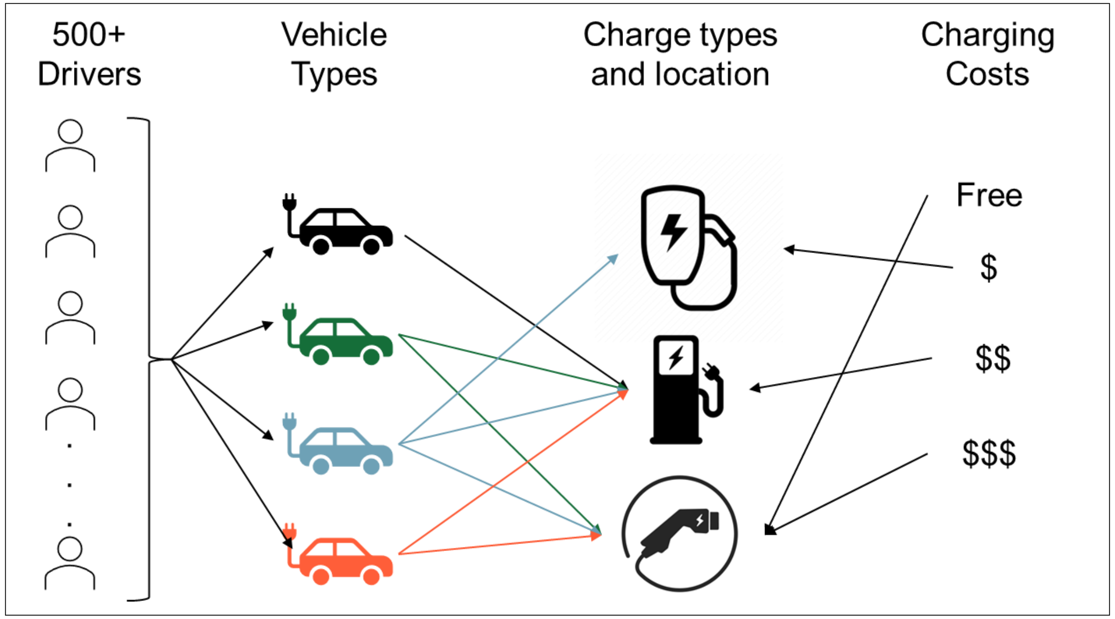
EV charging load shape modeling

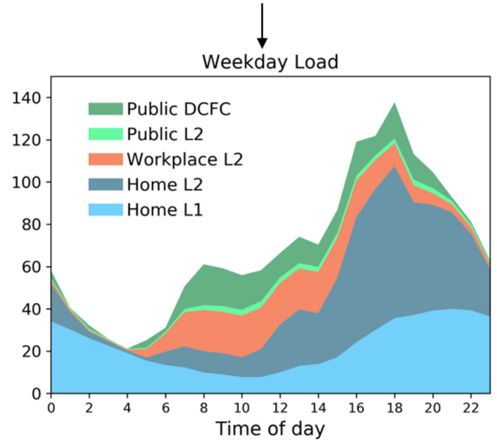
E3's RESHAPE-EV model

E3's RESHAPE-EV model generates diversified EV charging load shapes considering the driving pattern of thousands of drivers and characteristics of the driver population including charger access, vehicle types, and cost to charge vehicles in various locations.

E3's RESHAPE-EV model can be leveraged to model custom scenarios of EV charging load shapes:

- **Base or unmanaged charging load shapes are created based on drivers' travel needs and access to different charger types**
- **Managed charging load shapes are then developed by optimizing load in response to price signals, such as time-of-use rates, wholesale market prices, or utilities' avoided costs**
- **Managed charging can be passive, in response to time varying rates, or active with participation in demand response programs.**





New & Emerging Technologies Study

Energy+Environmental Economics

New & Emerging Technologies Study Purpose

+ **Primary purpose: identify a broad menu of supply-side resource options to consider in development of PWP's Optimized Strategic Plan**
  - Includes both resources commercially available today and "emerging" technologies not yet developed at scale
+ **Questions addressed in New & Emerging Technologies Study:**
  - What supply-side generation technologies may contribute to PWP's efforts to eliminate carbon from its power supply?
  - What are the risks and challenges associated with developing these resources over the next decade?
  - What reasonable range of cost and performance assumptions should be used to characterize resource options in further studies?

1. Identify Broad Set of New & Emerging Resource Options Consistent with Resolution 9977

- Renewable resources
- Energy storage (short, medium, long duration)
- Clean fuels (hydrogen, renewable natural gas)
- *(Demand-side resources, including solar, storage, DR, and flexible loads considered in other studies)*

2. Conduct Initial Assessment of Technology Suitability for PWP's Goals

- Commercial readiness & expected development timelines
- Land use intensity & technical potential limits, ability to develop locally
- Other development risks

3. Identify/Select Subset of Technologies for Further Study in OSP

4. Collect Cost, Performance, Potential Data Necessary to Represent Resources in Long-Term Capacity Expansion & Operational Models

- Capital & operating/maintenance costs
- Operational characteristics (e.g. hourly profiles, storage duration, round drip efficiency)

Proposed list of technologies to consider

Renewable	Short to Mid-Duration Storage (< 24 hrs)	Long Duration Storage (> 24 hrs)	Clean Fuels
• Utility-scale solar PV • Land-based wind (in- and out-of-state) • Floating offshore wind • Geothermal (conventional) • Geothermal (enhanced)	• Li battery storage • Flow battery • Flywheel storage • Pumped storage • Novel Pumped Hydro • Gravity-Based • Adiabatic Compressed Air Energy Storage (A-CAES) • Liquid Air (LAES) • Liquid CO2	• Sensible Heat • Latent Heat • Thermochemical heat • Aqueous Electrolyte Flow Batteries • Metal Anode Battery • Hybrid Flow Battery	• Renewable Natural Gas • Hydrogen Combustion • Hydrogen Fuel Cell

Notes:

By design and within the constraints of Resolution 9977, all gas-fueled and nuclear emerging technologies are excluded

Demand-side resources (local solar, storage, demand response, and load flexibility) considered separately in Local Solar & Storage and DR & Flexible Loads Studies

+ **Question 4: Any particular technology to add or remove from this list?**

Main data sources

+ **Main data sources for characterizing emerging technologies:**
  - DOE's 2023 and 2024 Commercialization reports
  - DOE's Technology Readiness Levels
  - DOE's Commercial Adoption Readiness Assessment Tool
  - CPUC IRP's Zero-Carbon Technology Assessment

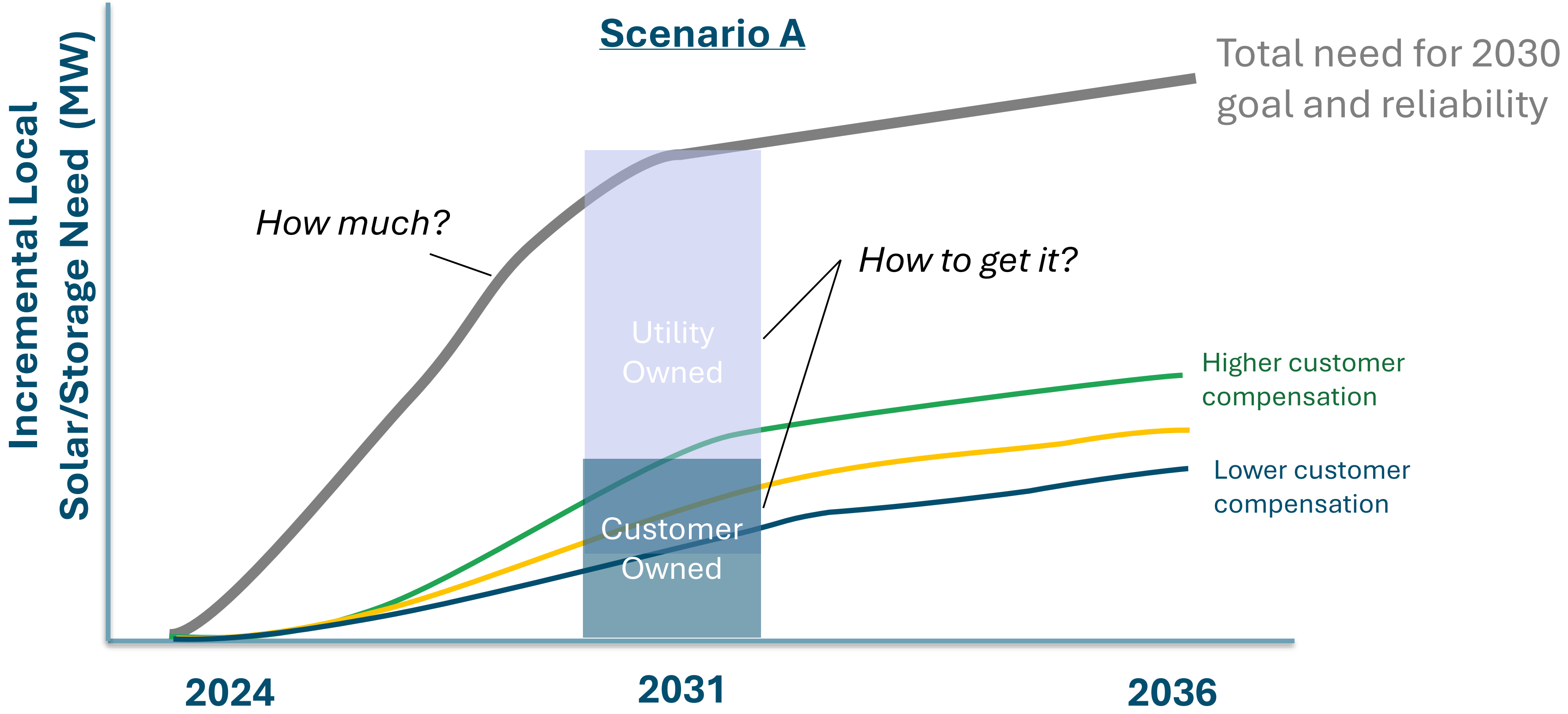
+ **Main data sources for cost, potential and performance:**
  - CPUC IRP Resource cost estimates
  - CEC/CPUC land-use screened renewable energy potential data
  - 2023 NREL Annual Technology Baseline (ATB) and upcoming 2024 NREL ATB
  - Lazard Cost data
  - CEC Long Duration Storage Reports
  - Prior E3 work

Appendix

Energy+Environmental Economics

How much solar and how to get it?

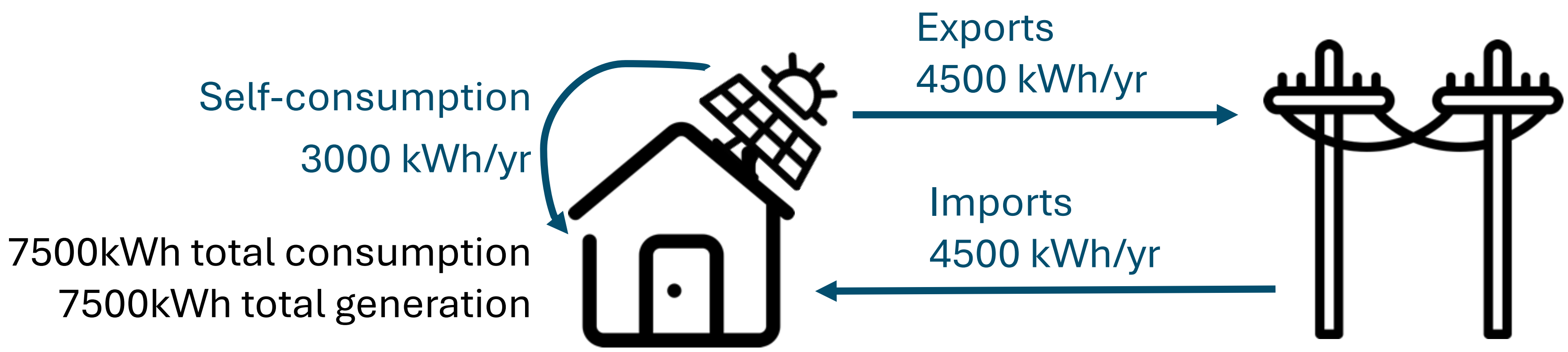
Local Solar + Storage Study



Cost Study

Customer Adoption Scenario	Total Resource Cost	Revenue Requirement	Rate Impact
Higher Compensation			
Lower Compensation			

Rooftop Solar Can Be Compensated by the Utility in Many Different Ways



Tariff	Self-consumption	Exports	Bill Savings	Cost Shift
Net Energy Metering (NEM)	All generation (both self-consumption and exports) credited at the customer's **import rate**		+++	+++
Net Billing (NEB)	Self-consumption credited at the **import rate**	Exports credited at a reduced **export rate**	++	++
Buy-All, Sell-All (BA, SA)	All generation (both self-consumption and exports) credited at a reduced **export rate**		+	+

Note: "Net Metering / NEM" is often used erroneously/ colloquially to describe all tariffs for crediting exports from customer-generators

Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel Meeting #3

July 17, 2024

Nick Schlag, Partner
Mike Sontag, Associate Director
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Managing Consultant

Energy+Environmental Economics

Agenda

<u>This meeting:</u>

- **Review of study plan and "synthesis" stage**
- **Technical studies methodology deep dives:**
  - Local Solar + Storage
  - Emerging Technology
  - Demand Response and Flexible Loads

<u>Potential topics for next meeting (tentative/draft):</u>

- ***Draft analysis results***
  - *Local Solar + Storage*
  - *Emerging Technology*
  - *Demand Response and Flexible Loads*
- ***Overview of Glenarm conversion/replacement scope***
- ***Discussion of core study scenarios***

Defining an "Optimized Strategic Plan"

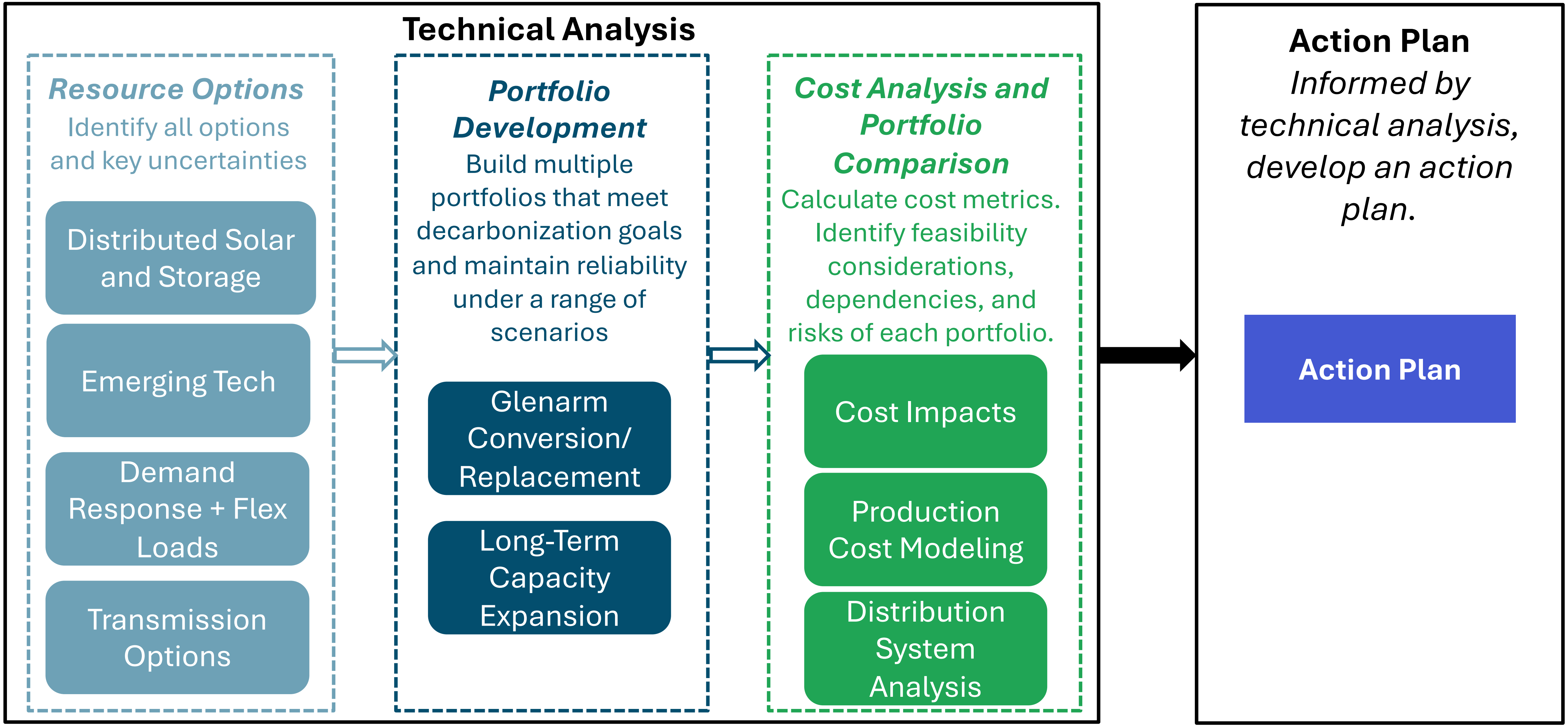
The Optimized Strategic Plan is…

…a roadmap that lays out the key steps and future decision points that will best position PWP to achieve its goal to source all electricity from carbon-free sources by the end of 2030 while maintaining reliability and limiting cost impacts to customers

The Optimized Strategic Plan will…

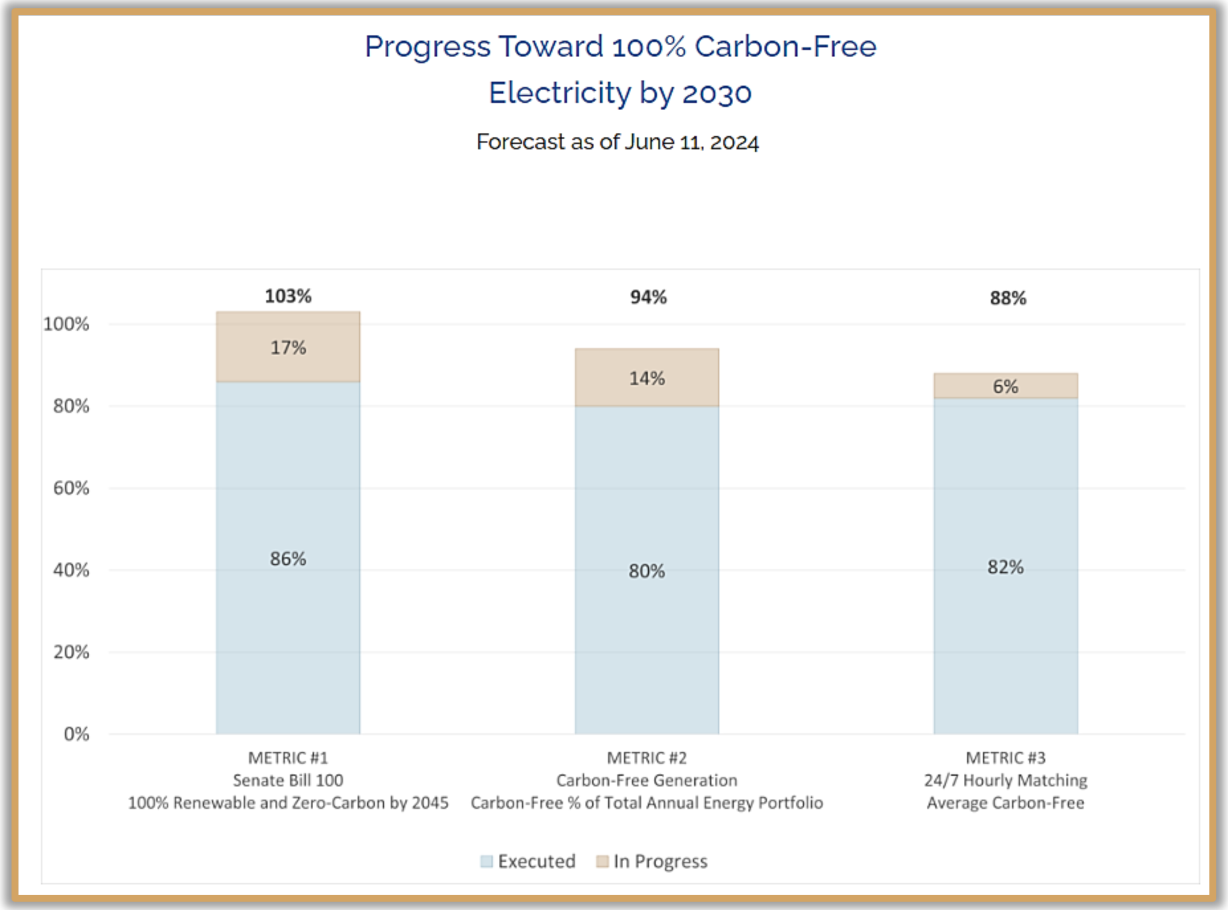
…consider how new generation resources, investments in T&D infrastructure, and customer programs can facilitate transition to Pasadena's carbon-free goal

Optimized Strategic Plan Study Workflow



Progress to Carbon-Free Electricity

Pasadena Water and Power



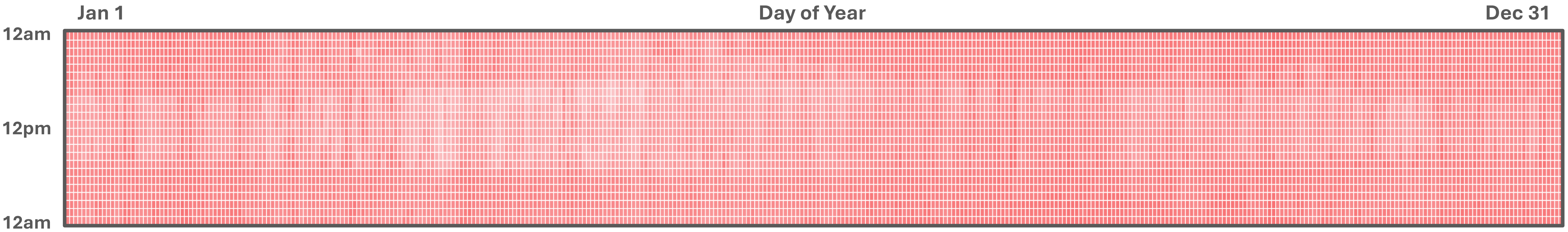
Decarbonization Progress Highlights

- Metric 1
  - PWP's progress to achieving State compliance goals
- Metric 2
  - The percentage of PWP's energy portfolio that is comprised of carbon-free resources
- Metric 3
  - The percentage of every hour that is served by carbon-free resources

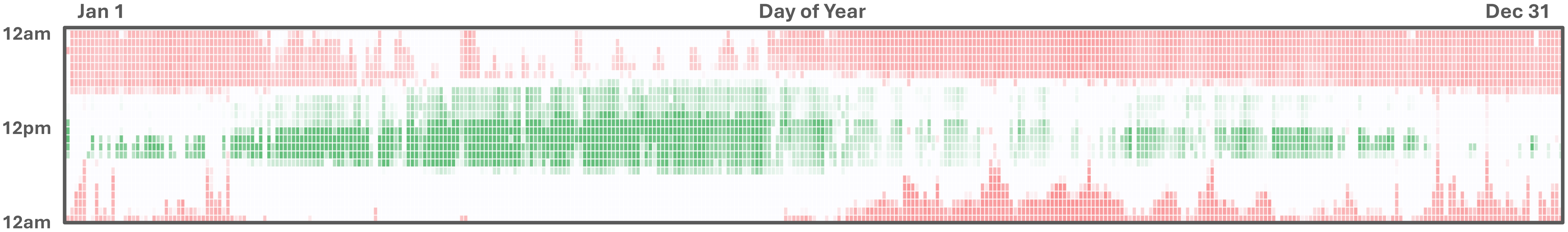
PASADENA

Balance of Carbon-Free Energy Resources based on Currently Executed Contracts

2025 Carbon-Free Electricity Supply — 24/7 Hourly Matching (“Metric 3”): 25%



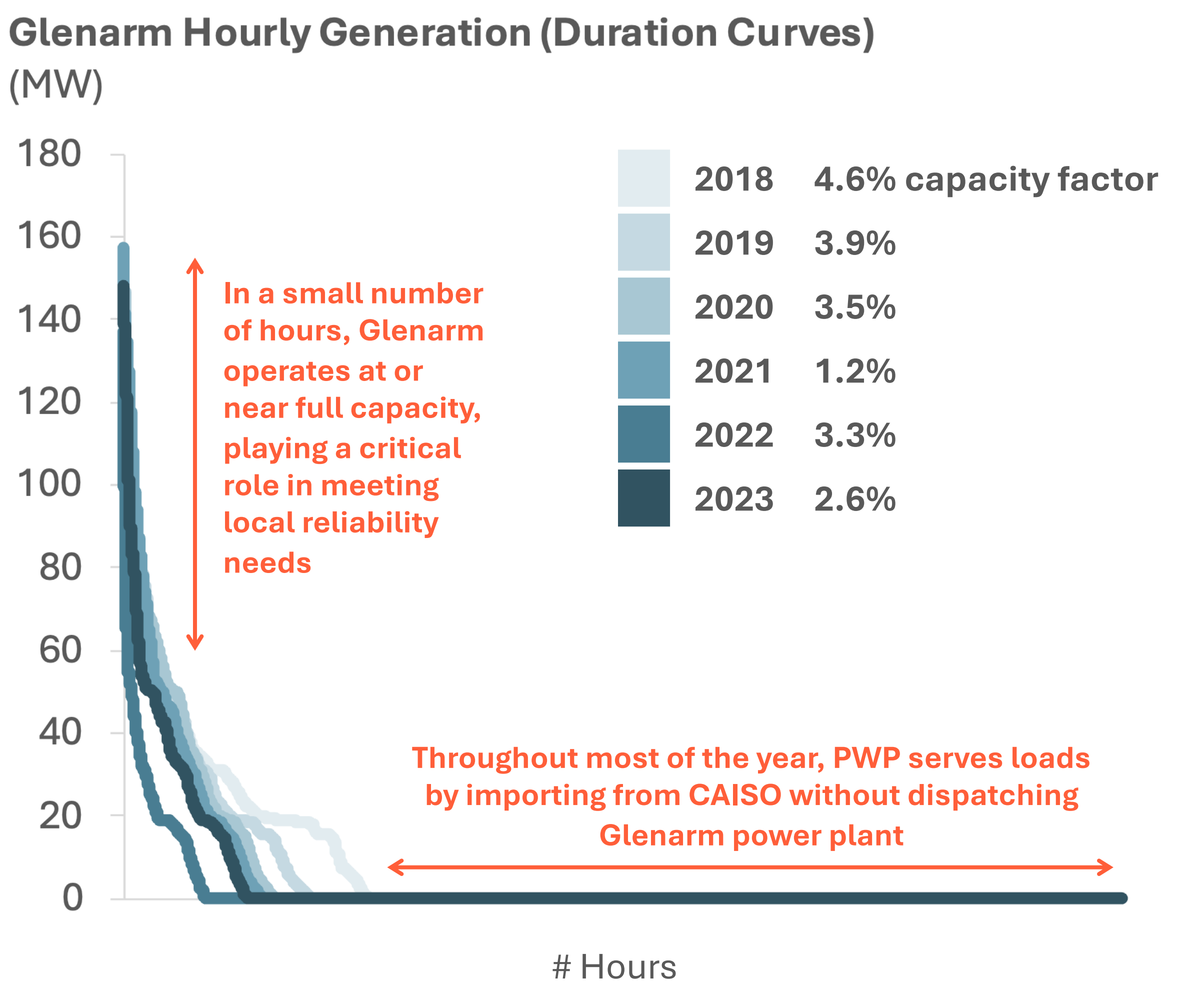
2030 Carbon-Free Electricity Supply (Executed Contracts Only) — 24/7 Hourly Matching (“Metric 3”): 83%



Hourly Carbon-Free Electricity vs. Hourly Load

0%	25%	50%	75%	100%	125%	150%	175%	200%

A Historical Perspective on the Role of Glenarm



- **Historical operational patterns of Glenarm Power Plant consistent with a resource whose primary purpose is supporting reliability:**
  - Low capacity factor, frequently not operated
  - Dispatched up to full capacity in a select number of hours per year
- **Conditions that currently require operations of Glenarm:**
  - Peak demand conditions (above import capability)
  - Transmission/distribution contingencies
  - High wholesale electricity prices in California Independent System Operator (CAISO)
  - CAISO resource deficiencies

A long-term reliability solution will require local resources that can operate reliably under very specific circumstances

Local Solar + Storage

Energy+Environmental Economics

Scope of Local Solar & Storage Study

+ Questions addressed in Local Solar Storage Study:

1. What is technical potential for solar and storage within PWP service territory (rooftop, parking canopy, ground mount)?
2. What are cost and performance characteristics of potential solar and storage resources?
3. What levels of customer solar and storage adoption could occur under various rate designs and incentive structures?

+ Questions *not* addressed in Local Solar Storage Study:

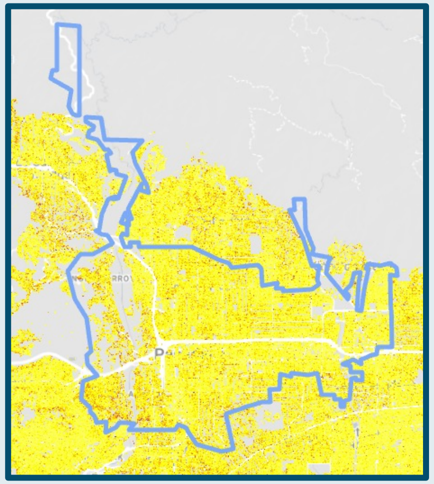
Addressing these questions requires a complete view of the supply- and demand-side solutions that enable PWP to achieve its goals and will be part of the *Cost Impacts* study

1. What is the value provided by solar and storage resources adopted by PWP customers?
2. What is total resource cost resulting from with different levels of customer solar adoption?
3. What bill impacts to non-participating customers will result from different levels of customer solar adoption?
4. The granular analysis of the distribution system needed to identify the ability of the distribution system to absorb more solar.

Local Solar & Storage Technical Potential Methodology

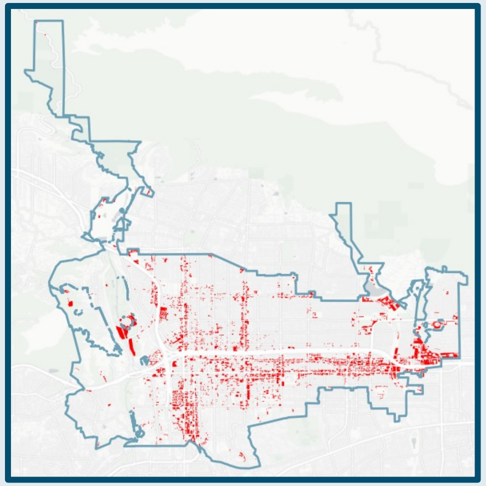
Rooftop Solar & Storage

Merge Google Sunroof database with PWP customer data and apply various screens to determine technical potential by segment.



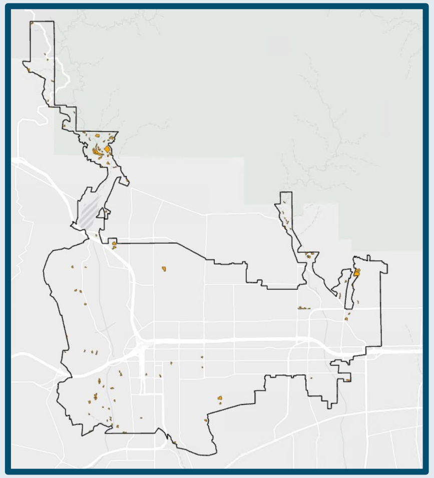
Parking Canopy Solar

Filter parking lots identified in OpenStreet maps for project viability.



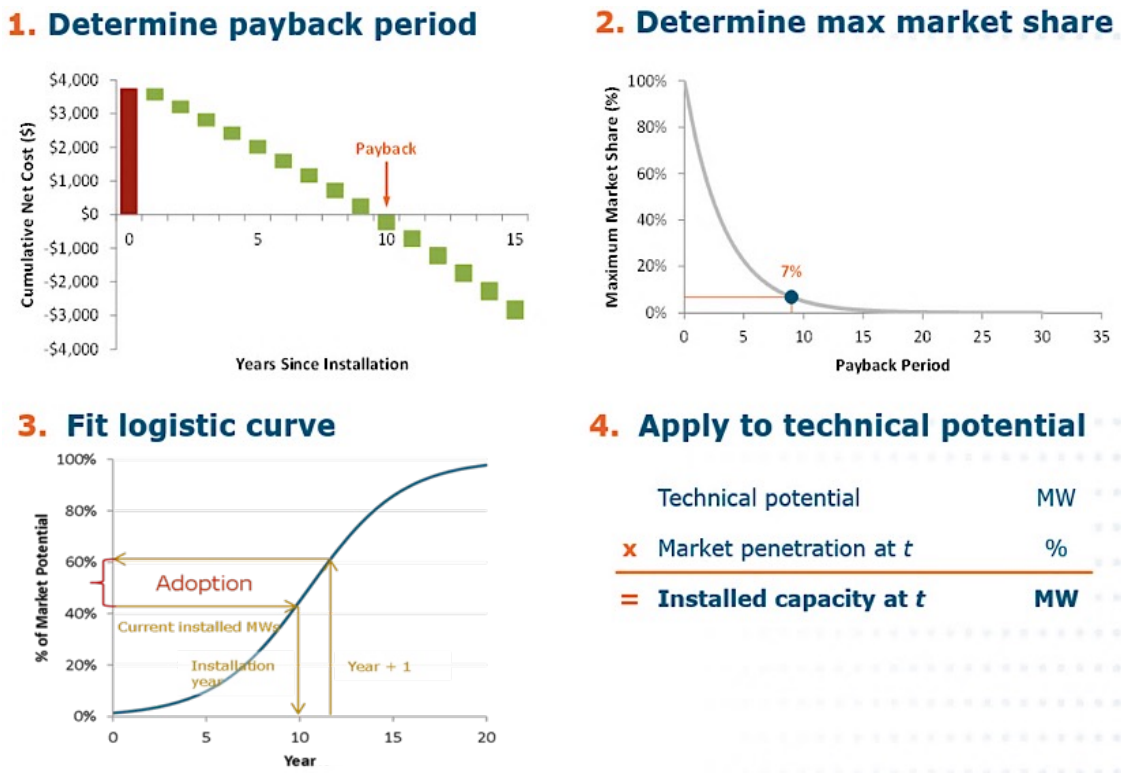
Ground Mount Solar

GIS-based screening of land use to exclude buildings, parks, roads, other impervious surfaces, and sloped terrain



Local Solar + Storage Customer Adoption Methodology

- **The local solar + storage adoption analysis will use a bass diffusion model framework**
  - Bass diffusion is an empirical market share model to determine the long-run market equilibrium of customer adoption.
  - The relationship between economic attractiveness and ***maximum market*** share is based on **payback periods** or **benefit-cost** ratios.
  - Logistic curves can be calibrated based on historical adoption rate and cost-effectiveness.
- **Adoption will be modeled reflecting payback periods under several tariffs. For example,**
  - Net Energy Metering (NEM)
  - Net billing
  - Buy-all / Sell-all

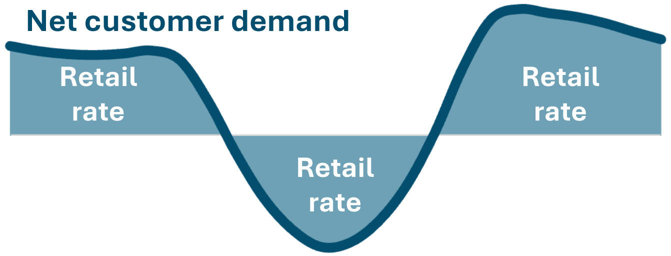


Designs for Customer Solar & Storage Compensation for OSP Analysis

Design 1: Net Energy Metering

All generation (both self-consumption & exports) credited at customer retail rate (current design)

Time-dependent signal: no
Requires AMI: no

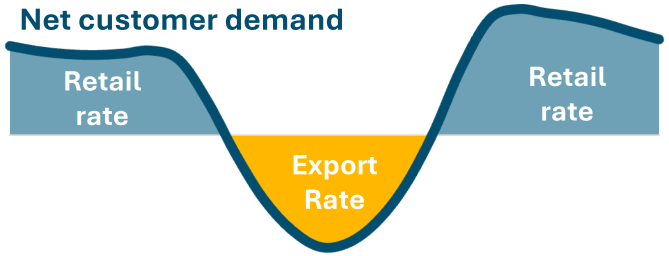


Does not incentivize pairing storage adoption with solar

Design 2: Net Billing

Generation consumed by customer credited at full retail rate; generation exported to grid credited at an export rate

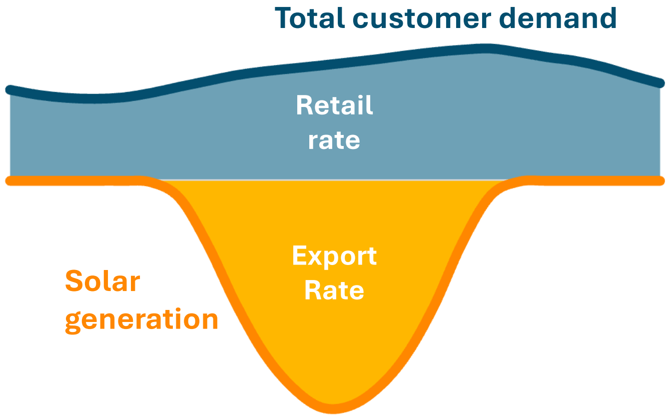
Time-dependent value: yes
Requires AMI: yes



Design 3: Buy-All/Sell-All

All generation (both self-consumption & exports) credited at an export rate

Time-dependent value: yes
Requires AMI: yes



Designs considered in OSP do not reflect full spectrum of options but are meant to capture a range of potential options

AMI = Advanced Metering Infrastructure

Demand Response and Flexible Loads

Energy+Environmental Economics

Objective, Motivation, Research Questions

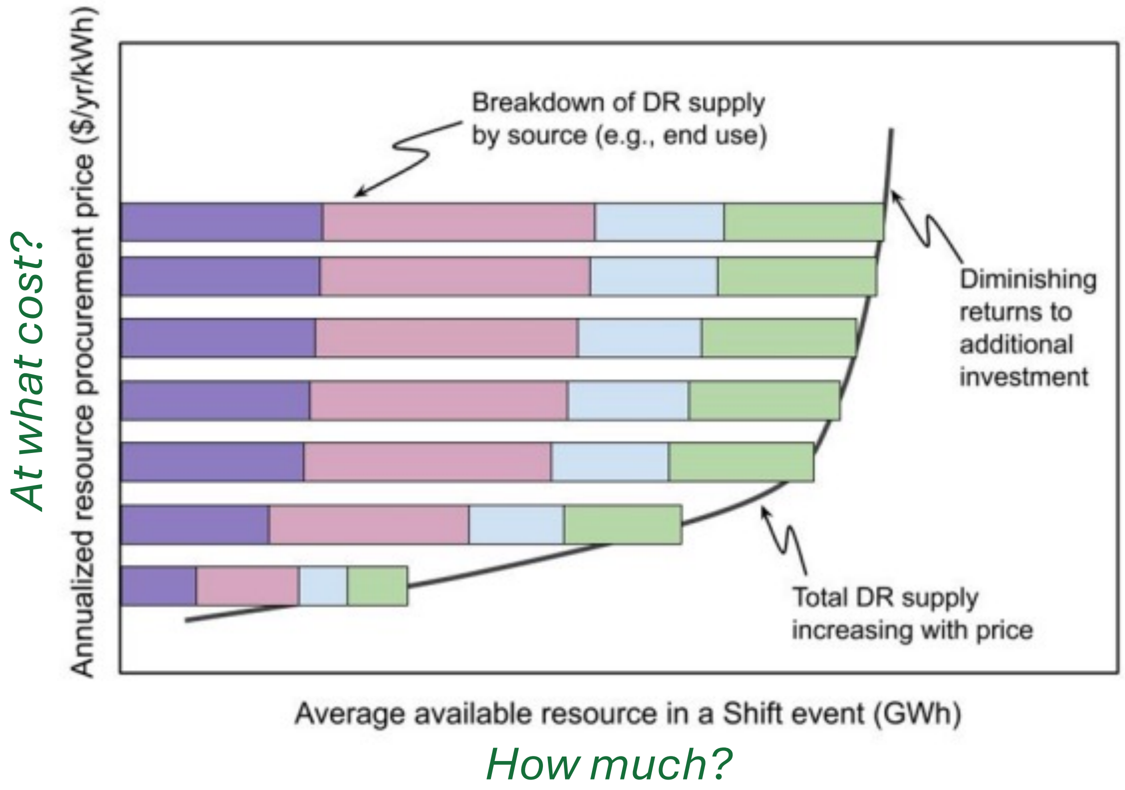
- **<u>Objective</u>: Assess cost and potential for demand response in PWP's service territory.**
- **<u>Motivation</u>: Given constraints on PWP to leverage utility-scale resources due to limited import capability and in-zone resource availability, demand response is one of the zero-carbon demand-side resources that can contribute to meeting PWP's capacity needs for maintaining reliability.**

Questions answered in this study:

1. How much demand response potential is available from PWP customers?
2. What are the costs of demand response?
3. How can PWP leverage managed electric vehicle (EV) charging to reduce grid impacts of electrification?

Questions not answered in this study:

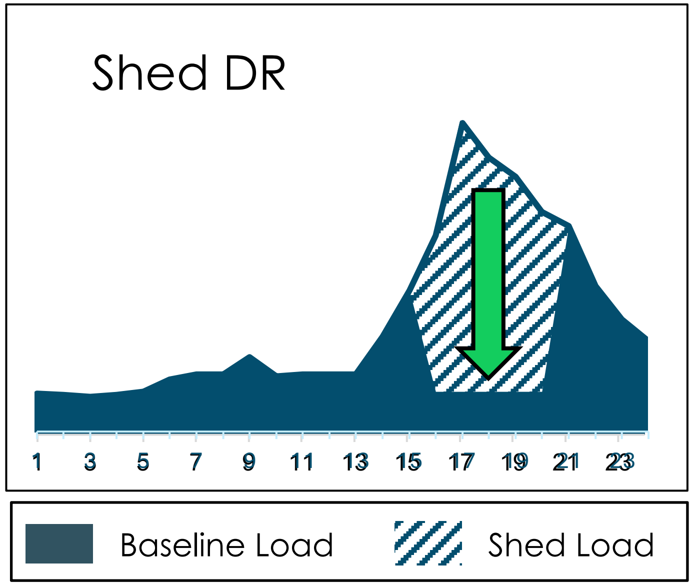
1. How should PWP design programs and tariffs to procure demand response?

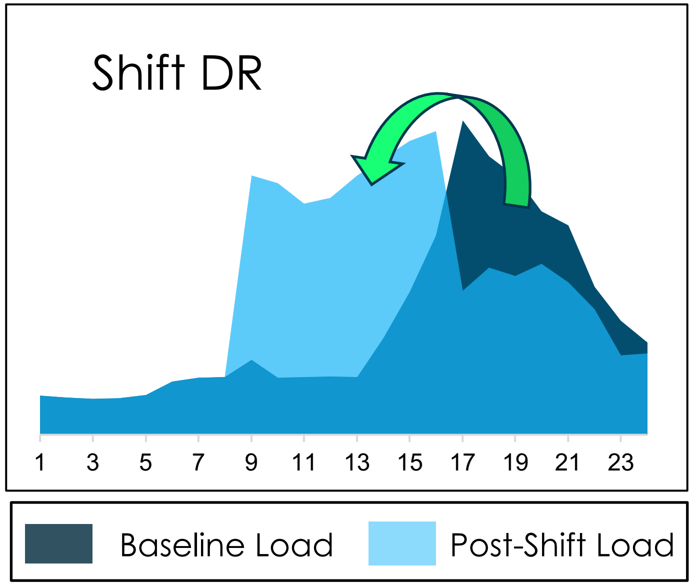


LBNL (2024), Figure 15, https://eta-publications.lbl.gov/sites/default/files/phase_4_dr_potential_study_final_2024-05-21.pdf

LBNL Potential Study Overview

+ **LBNL produces supply curves for the achievable potential for shed and shift demand response curves characterizing the resource availability at a given cost.**
  - **Shed ("conventional")** – Loads that can be curtailed to provide capacity reductions
  - **Shift** – Loads that can be shifted between hours
+ **LBNL also characterized the shape DR resource in the latest phase of study.**
  - **Shape ("load-modifying")** - Reshaping customer load profiles for significant portions of the year through price responsiveness or behavioral campaigns.

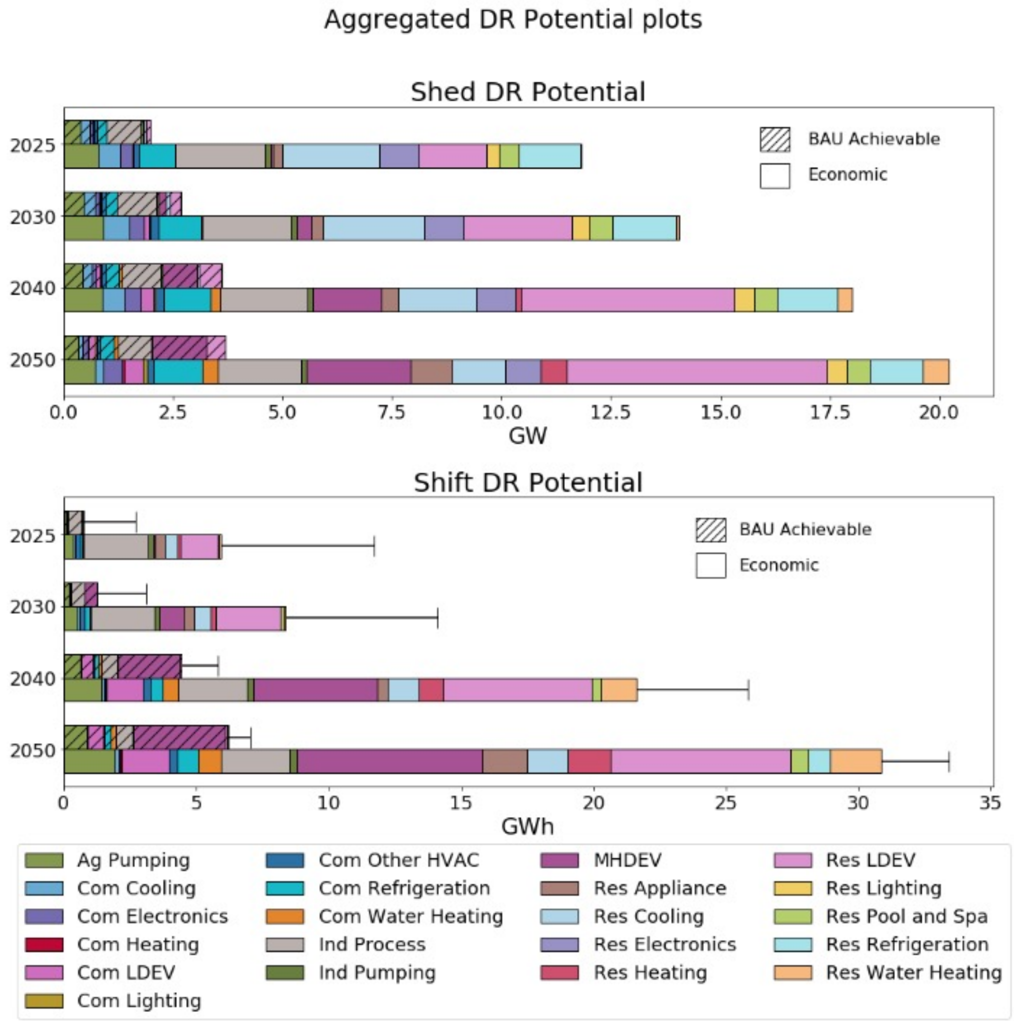




Key findings LBNL's DR Potential Study Phase 4

Based on the Investor Owned Utilities' customer base and flexibility needs

- **Driven by electrification and shifting periods of system need:**
  - Light-Duty Vehicles (LDVs), Medium and Heavy-Duty Vehicles (MHDVs), and residential water heating are emerging as end uses with large potential.
  - Space cooling DR potential is declining in the long-term (2040+).
  - Refrigeration, industrial process loads, and agricultural pumping are consistent sources of DR.
- **Dynamic price signals can capture a large portion (40-50%) of the technical potential for demand response.**
- **DR enabling technologies will be crucial for capturing the DR resource.**



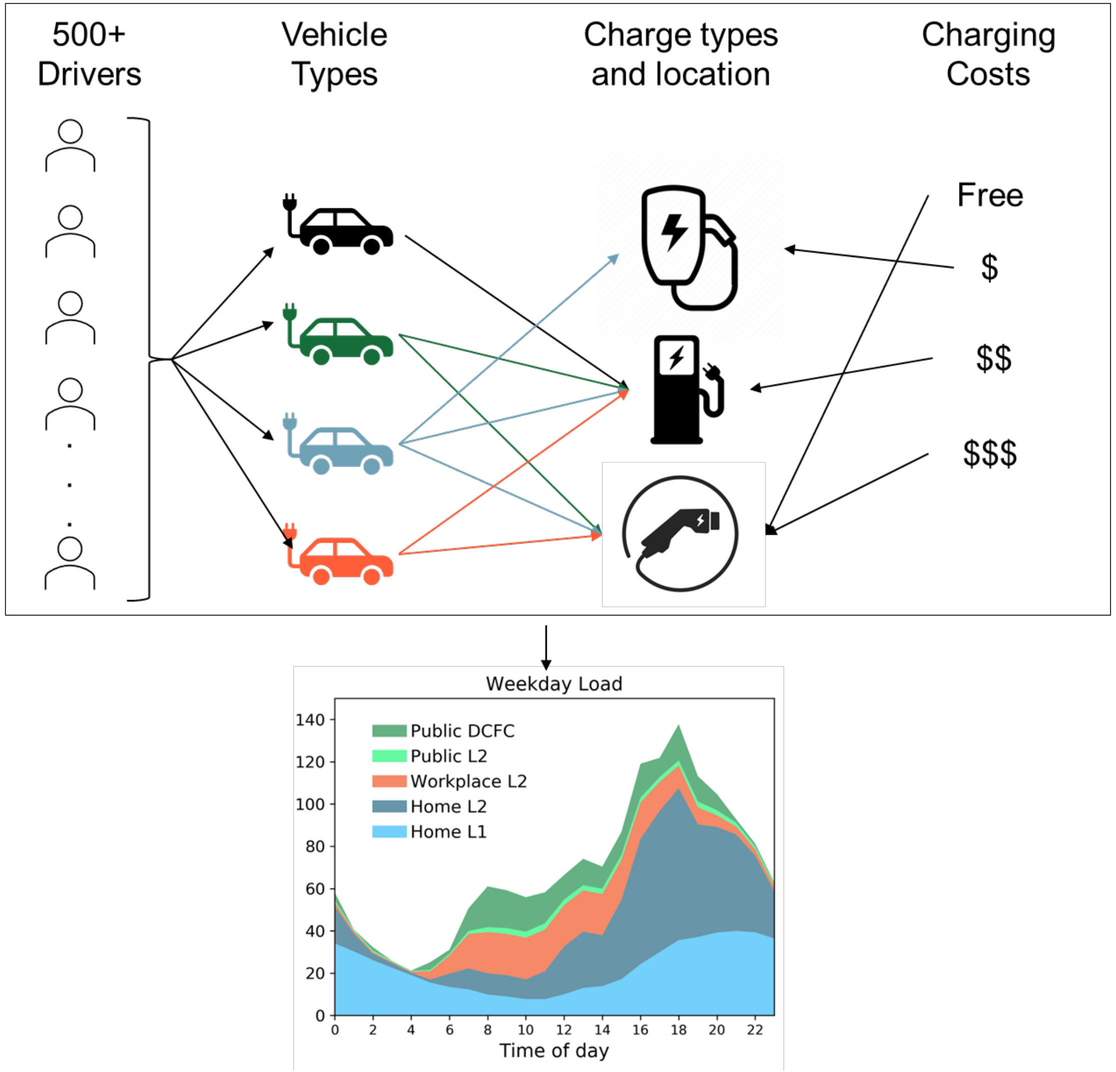
EV charging load shape modeling

E3's RESHAPE-EV model

E3's RESHAPE-EV model generates diversified EV charging load shapes considering the driving pattern of thousands of drivers and characteristics of the driver population including charger access, vehicle types, and cost to charge vehicles in various locations.

E3's RESHAPE-EV model can be leveraged to model custom scenarios of EV charging load shapes:

- **Base or unmanaged charging load shapes are created based on drivers' travel needs and access to different charger types**
- **Managed charging load shapes are then developed by optimizing load in response to price signals, such as time-of-use rates, wholesale market prices, or utilities' avoided costs**
- **Managed charging can be passive, in response to time varying rates, or active with participation in demand response programs.**



New & Emerging Technologies Study

Energy+Environmental Economics

New & Emerging Technologies Study Purpose

- **Primary purpose: identify a broad menu of supply-side resource options to consider in development of PWP's Optimized Strategic Plan**
  - Includes both resources commercially available today and "emerging" technologies not yet developed at scale
- **Questions addressed in New & Emerging Technologies Study:**
  - What supply-side generation technologies may support PWP's efforts to eliminate carbon from its power supply?
  - What are the risks and challenges associated with developing these resources over the next decade?
  - What reasonable range of cost and performance assumptions should be used to characterize resource options for subsequent OSP studies?

1. Identify Broad Set of New & Emerging Resource Options Consistent with Resolution 9977

- Renewable resources
- Energy storage (short, medium, long duration)
- Clean fuels (hydrogen, renewable natural gas)
- *(Demand-side resources, including solar, storage, DR, and flexible loads considered in other studies)*

2. Conduct Initial Assessment of Technology Suitability for PWP's Goals

- Commercial readiness & expected development timelines
- Land use intensity & potential siting/locational constraints
- Other development risks

3. Identify/Select Subset of Technologies for Further Study in OSP

4. Collect Cost, Performance, Potential Data Necessary to Represent Resources in Long-Term Capacity Expansion & Operational Models

- Capital & operating/maintenance costs
- Operational characteristics (e.g. hourly profiles, storage duration, round trip efficiency)

Technologies for consideration in the "New & Emerging Technologies Study"

+ **New & Emerging Technologies study will include a comprehensive review of supply-side generating technologies that may play a role in meeting the City's goals**
+ **Based on results of review, a subset of these technologies will be further considered in technical analysis**

Renewable	Short to Mid-Duration Storage (< 24 hrs)	Long Duration Storage (> 24 hrs)	Clean Firm Fuels
• Utility-scale solar PV • Land-based wind (in- and out-of-state) • Floating offshore wind • Geothermal (conventional) • Geothermal (enhanced)	• Lithium ion battery • Flow battery • Pumped storage • Gravity-based • Compressed Air Energy Storage (CAES) • Liquid Air (LAES)	• Sensible heat • Latent heat • Thermochemical heat • Aqueous flow battery • Metal anode battery • Hybrid flow battery	• Hydrogen combustion • Hydrogen fuel cell • Renewable natural gas • Nuclear small modular reactors

Notes:

By design and within the constraints of Resolution 9977, natural gas-fueled technologies are not considered

Demand-side resources (local solar, storage, demand response, and load flexibility) considered separately in **Local Solar & Storage** and **DR & Flexible Loads Studies**

Question: any additional technologies that should be considered?

Main data sources

- **Main data sources for characterizing emerging technologies:**
  - DOE's 2023 and 2024 Commercialization reports
  - DOE's Technology Readiness Levels
  - DOE's Commercial Adoption Readiness Assessment Tool
  - CPUC IRP's Zero-Carbon Technology Assessment

- **Main data sources for cost, potential and performance:**
  - CPUC IRP Resource cost estimates
  - CEC/CPUC land-use screened renewable energy potential data
  - 2023 NREL Annual Technology Baseline (ATB) and upcoming 2024 NREL ATB
  - Lazard Cost data
  - CEC Long Duration Storage Reports
  - Prior E3 work

Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel Meeting #4

August 22, 2024

Nick Schlag, Partner
Mike Sontag, Associate Director
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Managing Consultant

Energy+Environmental Economics

Agenda

This meeting:

- Optimized Strategic Plan progress update
- Key highlights from Preparatory Studies (ongoing)
  - Local Solar and Storage Technical Potential
  - New & Emerging Technologies
- Portfolio design proposal and discussion
- Next steps

Upcoming meetings:

- Follow-up results from preparatory studies
- Additional assumptions developed for OSP portfolio development studies
- Overview of scopes for Glenarm Conversion & Replacement and Long-Term Capacity Expansion studies

Optimized Strategic Plan Study Workflow

Technical Analysis

Resource Options

Identify all options and key uncertainties

- Distributed Solar and Storage
- Emerging Tech
- Demand Response + Flex Loads
- Transmission Options

Portfolio Development

Build multiple portfolios that meet decarbonization goals and maintain reliability under a range of scenarios

- Glenarm Conversion/ Replacement
- Long-Term Capacity Expansion

Cost Analysis and Portfolio Comparison

Calculate cost metrics. Identify feasibility considerations, dependencies, and risks of each portfolio.

- Cost Impacts
- Production Cost Modeling
- Distribution System Analysis

Action Plan

Informed by technical analysis, develop an action plan.

- Action Plan

Status Updates: Optimized Strategic Plan Supporting Studies

Active Workstreams

Local Solar & Storage

- Draft geospatial analysis of technical potential complete (ground mount, parking canopy, rooftop)
- Adoption modeling beginning soon

Demand Response & Flexible Loads

- Downscaling methodology to adapt LBNL DR supply curves developed
- Awaiting data inputs from LBNL

New & Emerging Technologies

- Review of emerging technology characteristics and risk factors complete
- Currently developing cost and performance assumptions for portfolio modeling

On Deck

Transmission Options

Glenarm Conversion & Replacement

- Compiling inputs and assumptions, reviewing proposed scope of analysis with PWP

Long-Term Capacity Expansion

- Reviewing data provided by PWP, compiling additional inputs and assumptions needed for modeling

Not yet started

Production Simulation

Distribution System Impacts

Cost Impacts

Progress Updates: Local Solar & Storage Study

Energy+Environmental Economics

Scope of Local Solar & Storage Study

Questions addressed in Local Solar Storage Study:

Today's focus

1. What is technical potential for solar and storage within PWP service territory (rooftop, parking canopy, ground mount)?
2. What are cost and performance characteristics of potential solar and storage resources?
3. What levels of customer solar and storage adoption could occur under various rate designs and incentive structures?

Questions addressed in future studies of the Optimized Strategic Plan:

Addressing these questions requires a complete view of the supply- and demand-side solutions that enable PWP to achieve its goals and will be part of the *Cost Impacts* study

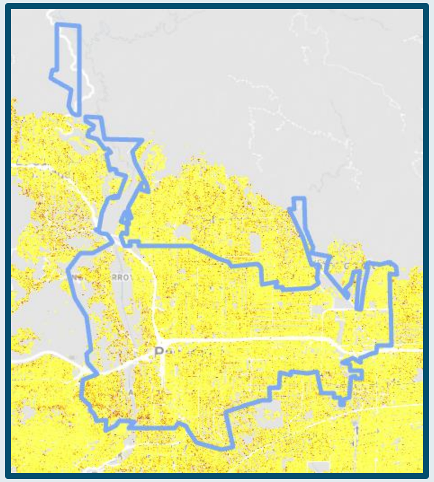
1. What is the value provided by solar and storage resources adopted by PWP customers?
2. What is total resource cost resulting from with different levels of customer solar adoption?
3. What bill impacts to non-participating customers will result from different levels of customer solar adoption?
4. What is the capacity of the distribution system to absorb more solar and what is the cost to integrate more solar onto the distribution system?

Local Solar & Storage Technical Potential Methodology

Technical Potential: The total amount of solar capacity available for development based on physical constraints such as available land or developable roof area. Does not consider economic viability or consumer willingness to adopt.

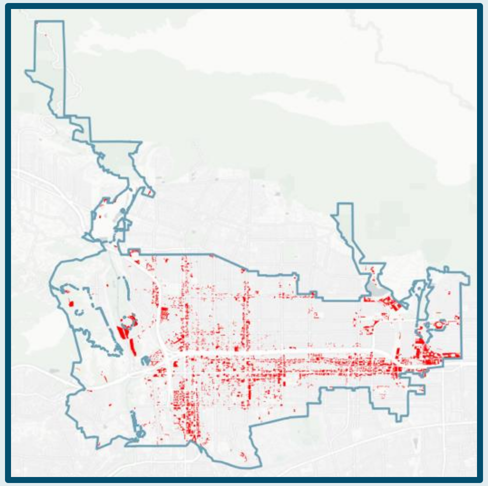
Rooftop Solar & Storage

Merge Google Sunroof database with PWP customer data and apply various screens to determine technical potential by segment.



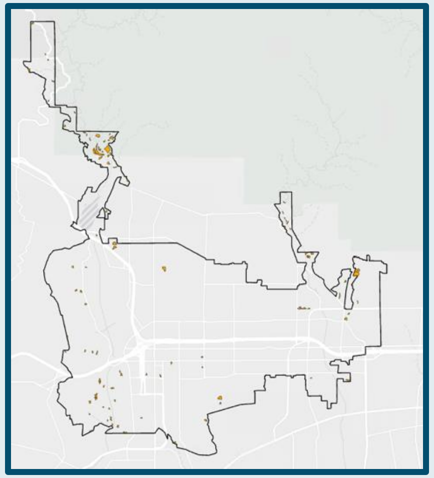
Parking Canopy Solar

Filter parking lots identified in OpenStreet maps for land use restrictions and building safety code.

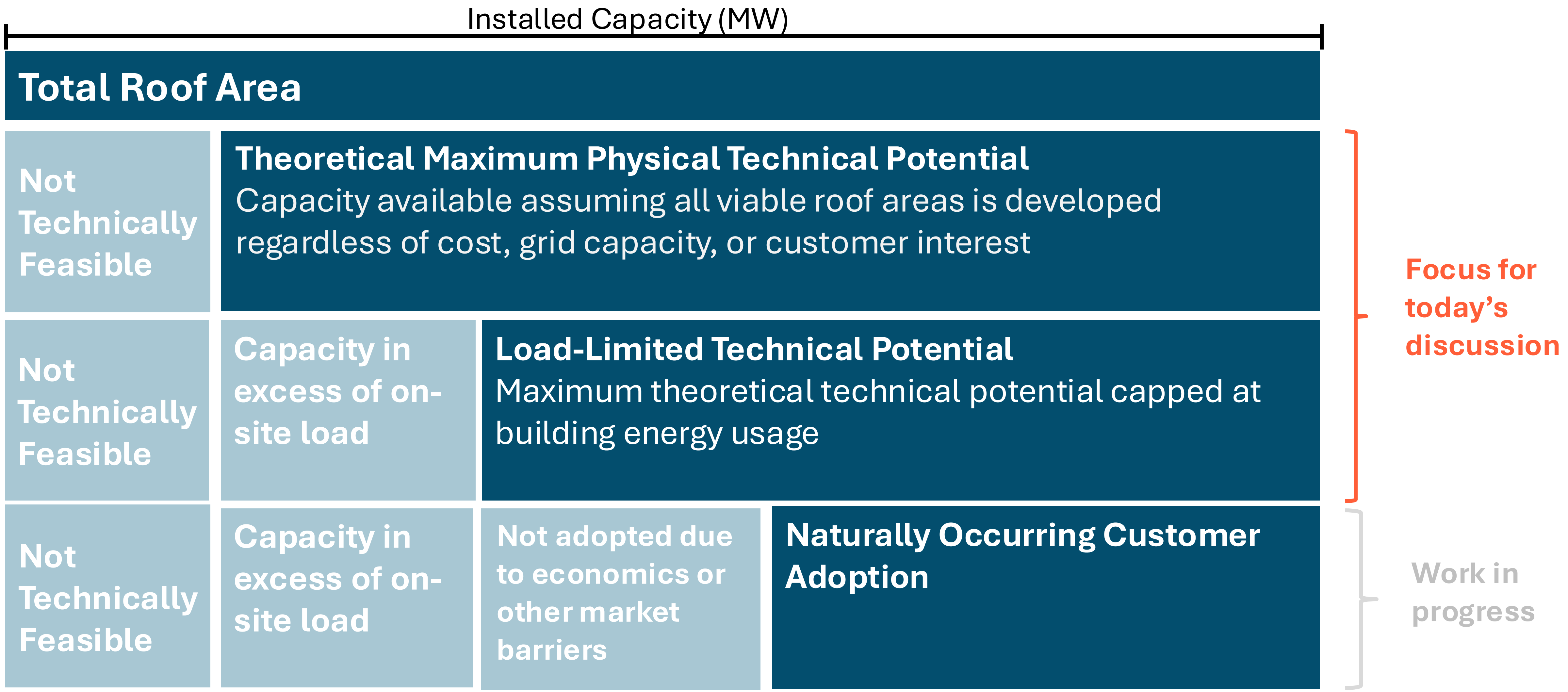


Ground Mount Solar

GIS-based screening of land use to exclude buildings, parks, roads, other impervious surfaces, and sloped terrain



Additional Context for Rooftop Solar Technical Potential Definition

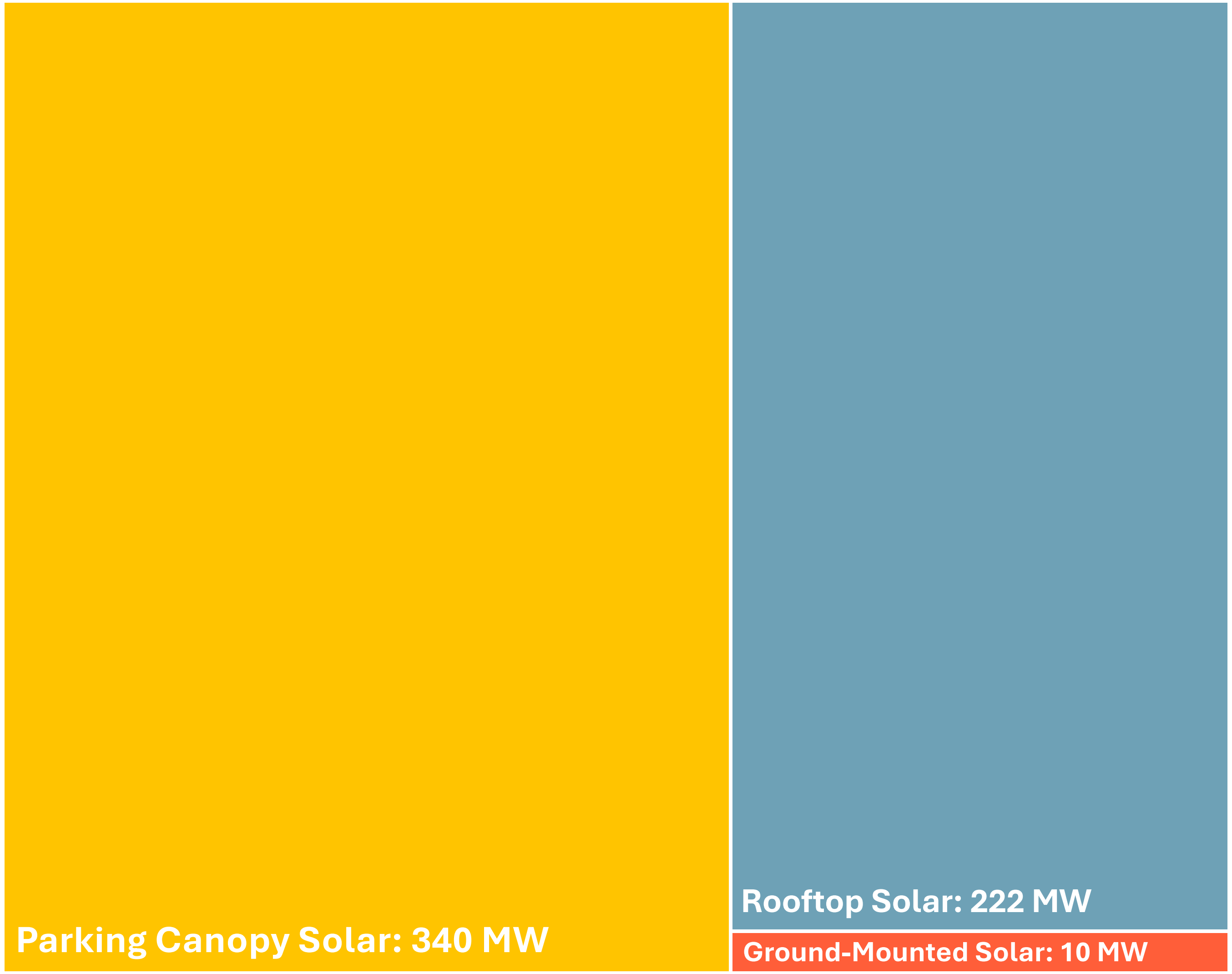


Solar Technical Potential within Pasadena Water and Power

Rooftop, Parking Canopy, and Ground-Mounted Solar

+ **Despite land constraints, technical potential for local solar within Pasadena footprint is significant:**
  - **Rooftop: 222 MW***
  - **Parking Canopy: 340 MW***
  - **Ground-Mounted: 10 MW***
+ **Key insight: the amount of local solar included in the OSP will be primarily determined by the needs of the grid and economics rather than by constraints on available space**

**These values represent the maximum capacity available for development in a given region and do not consider the economic or market viability, historical landmark status, or other physical conditions that may make installation cost prohibitive.*

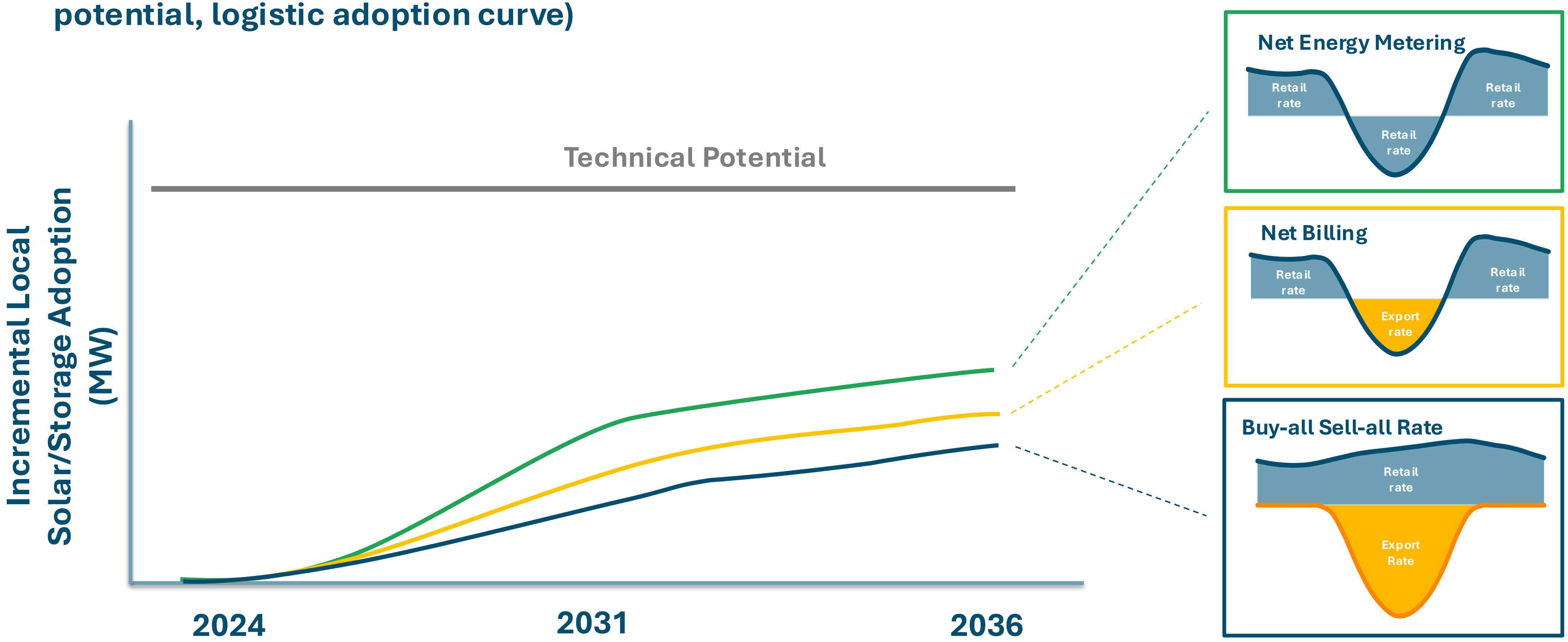


Rooftop Solar Technical Potential Screens

Total roof area in Pasadena: 1.5 GW	
+ Aspects facing north excluded	968 MW
+ Setback factor applied to perimeter of each aspect (3 ft for residential, 6 ft for commercial)	586 MW
+ Aspects with contiguous area < 13 m^2 or maximum pitch > 60° excluded	555 MW
+ Aspects with capacity factor <75% of unshaded potential excluded	413 MW
Total physical technical potential in Pasadena: 413 MW	
+ Systems sized to 100% of annual load	222 MW of load-limited technical potential

Solar and Storage Study Next Steps

- Finalize storage technical potential
- Solar and Storage adoption modeling based on 3 rate scenarios (function of payback period, tech potential, logistic adoption curve)



Non-Economic Factors Influencing Solar Adoption

Literature on the impact of marketing on solar adoption is mostly qualitative in nature and based on case studies of specific programs or campaigns conducted by varying entities.

- **Branding, reliability, and customer testimonials build trust and credibility.** [1,2,3,4,5]
- **Community engagement, partnerships, and word of mouth increase adoption.** [8,9,15,16]
- **Neighbor adoption and non-residential installations can increase residential adoption.** [6, 7, 8, 9,10]
- **Consumer motivations and predispositions are key factors that drive interest in solar adoption.** [11,12]
- **Educational content reduces barriers to solar adoption.** [8,9]
- **Different forms of advertising have varying impacts based on audience and customer tolerance for frequency of messaging.** [13,14]
- **Streamlining permitting reduces bottlenecks to adoption.**

Sources:

1: Wang, Zhang, Li, 2018, "Policy simulation for promoting residential PV considering anecdotal information exchanges based on social network modelling"
2: Shakeel, Yousaf, Irfan, Rajala, 2023, "Solar PV adoption at household level"
3: Tsantopoulos, Arabatzis, Tampakis, 2014, "Public attitudes towards photovoltaic developments: Case study"
4: Abdullah, Zhou, Shah, Jebran, Ali, 2017, "Acceptance and willingness to pay for solar home system: Survey evidence"
5: Gardner, 2024, "Mastering Solar Marketing Strategies"
6: Shakeel, Juntunen, Rajala, 2024, "Business models for enhanced solar photovoltaic (PV) adoption: Transforming customer interaction and engagement practices"
7: Shakeel, Rajala, 2022, "Transforming Energy Marketing Practices for Enhanced Solar PV Adoption"
8: Bioenergy Consult, 2023, "Solar Marketing Strategy For Solar Companies"
9: M Studio Agency, 2024, "Illuminating Success: Best Practices in Solar Energy Marketing"
10: NREL 2024, "Commercial-Scale Solar PV Increases Local Residential Solar Adoption"
11: Wolske, Todd, Rossol, McCall, Sigrin, 2018, "Accelerating demand for residential solar photovoltaics"
12: Wolske, 2020, "Profiles of high-income and low-income rooftop solar adopters in the United States"
13: Kumar, Ramachandran, Kumar, 2021, "Influence of new-age technologies on marketing"
14: NREL, 2024 "Winter 2024 Solar Industry Update"
15: Yale, 2019, "An Evidence-Based Guide for Accelerating the Adoption of Residential Solar"
16: Bollinger, Gillingham, Lamp, Tsvetanov, 2023, "Promotion Campaign Duration and Word-of-Mouth in Solar Adoption"

Progress Updates: New & Emerging Technologies Study

Energy+Environmental Economics

New & Emerging Technologies Study Purpose

- **Primary purpose: identify a broad menu of supply-side resource options to consider in development of PWP's Optimized Strategic Plan**
  - Includes both resources commercially available today and "emerging" technologies not yet developed at scale
- **Questions addressed in New & Emerging Technologies Study:**
  - What supply-side generation technologies may contribute to PWP's efforts to eliminate carbon from its power supply?
  - What are the risks and challenges associated with developing these resources over the next decade?
  - What reasonable range of cost and performance assumptions should be used to characterize resource options in further studies?

1. Identify Broad Set of New & Emerging Resource Options Consistent with Resolution 9977 — Complete

- Renewable resources
- Energy storage (short, medium, long duration)
- Clean fuels (hydrogen, renewable natural gas)
- *(Demand-side resources, including solar, storage, DR, and flexible loads considered in other studies)*

2. Conduct Initial Assessment of Technology Suitability for PWP's Goals — Draft Complete

- Commercial readiness & expected development timelines
- Land use intensity & potential siting/locational constraints
- Other development risks

3. Identify/Select Subset of Technologies for Further Study in OSP — Draft Complete

4. Collect Cost, Performance, Potential Data Necessary to Represent Resources in Long-Term Capacity Expansion & Operational Models — In Progress

- Capital & operating/maintenance costs
- Operational characteristics (e.g. hourly profiles, storage duration, round trip efficiency)

Technologies Reviewed in the New & Emerging Technologies Study

- **New & Emerging Technologies study will include a comprehensive review of supply-side generating technologies that may play a role in meeting the City's goals**
- **Based on results of review, a subset of these technologies will be further considered in technical analysis**

Renewable	Short to Mid-Duration Storage (<= 24 hrs)	Long Duration Storage (> 24 hrs)	Clean Firm Fuels
• Utility-scale solar PV • Land-based wind (in- and out-of-state) • Floating offshore wind • Geothermal (conventional) • Geothermal (enhanced) • Concentrated solar power	• Lithium ion battery • Flywheel • Flow battery • Pumped storage • Gravity-based • Compressed Air Energy Storage (CAES) • Liquid Air (LAES)	• Sensible heat • Latent heat • Thermochemical heat • Aqueous flow battery • Metal anode battery • Hybrid flow battery	• Green hydrogen combustion • Green hydrogen fuel cell • Renewable natural gas • Nuclear small modular reactors

Notes:

By design and within the constraints of Resolution 9977, natural gas-fueled technologies are not considered

Demand-side resources (local solar, storage, demand response, and load flexibility) considered separately in **Local Solar & Storage** and **DR & Flexible Loads Studies**

Proposed List of Technologies to Include in OSP Portfolio Development

+ **New & Emerging Technologies study reviews a comprehensive set of supply-side generating technologies that may play a role in meeting the City's goals**
+ **Based on results of review, the following subset of these technologies are considered in techno-economic analysis**

Renewable	Short to Mid-Duration Storage (<= 24 hrs)	Long Duration Storage (> 24 hrs)	Clean Firm Fuels
• Utility-scale solar PV • Land-based wind (in- and out-of-state) • Floating offshore wind • Geothermal (conventional) • Geothermal (enhanced) • Concentrated solar power	• Lithium ion battery • Flywheel • Flow battery • Pumped storage • Gravity-based • Compressed Air Energy Storage (CAES) • Liquid Air (LAES) • **10-hr duration archetype storage**	• Sensible heat • Latent heat • Thermochemical heat • Aqueous flow battery • Metal anode battery • Hybrid flow battery • **100-hr duration archetype storage**	• Green hydrogen combustion • Green hydrogen fuel cell • Renewable natural gas • Nuclear small modular reactors

Notes:

By design and within the constraints of Resolution 9977, natural gas-fueled technologies are not considered

Demand-side resources (local solar, storage, demand response, and load flexibility) considered separately in **Local Solar & Storage** and **DR & Flexible Loads Studies**

Key Highlights from Long Duration Energy Storage (LDES) Technology Review

+ **There are a significant number of long-duration storage technologies currently in R&D stages of development**
  - Multiple studies indicate that technical capabilities of LDES resources are well-suited to contributing to decarbonized portfolios, particularly reliability challenges
  - Inflation Reduction Act has acted as an additional catalyst spurring interest in this sector
+ **Most LDES technologies have not yet reached full market readiness; many indications that this level of technological maturity will not occur until mid 2030s:**
  - Requirements for 8-hour storage in CPUC Mid-Term Reliability decision largely satisfied by procurement of lithium-ion storage
  - Multiple utilities currently pursuing pilots of LDES technologies at a small scale (~5-10 MW)
  - DOE Pathways to Commercial Liftoff establishes an optimistic roadmap to commercialize LDES technologies by 2030
  - CPUC's PD for AB 1373 (as of 7/19/2024) issued LDES need for 1 GW 12+ hr, and 1 GW multi-day storage after 2031
+ **Rapidly evolving technology landscape means that care should be taken not to be overly prescriptive in selecting LDES in resource planning**

Key Risks & Uncertainties

Commercial readiness: most emerging long-duration storage technologies have not been demonstrated at grid scale; multiple utilities are working on small pilots; lack of commercial readiness results in both *development* and *operational* risks

Land use: longer duration storage technologies are typically less energy dense and require larger footprints

Cost: lack of technological maturity translates to greater uncertainty around cost; early movers likely to pay higher costs to develop first-of-a-kind projects

Key Highlights from Hydrogen Technology Review

- **Interest in hydrogen as an energy carrier – especially in California – has grown considerably in the past several years**
  - Generous incentives for green hydrogen (produced via electrolysis fueled by renewable energy) established by Inflation Reduction Act
  - Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) currently has over $12 billion in funding – including $1.2 billion in federal funding from DOE – to catalyze development of hydrogen production, transport, and storage infrastructure
- **In the electricity sector, hydrogen is a "clean firm" resource option that provides a long-duration storage service while displacing natural gas from peaking power plants**
  - Current generation technologies allow for blending up to 50% by volume, but most turbine manufacturers are planning for 100% capability by 2030
  - Many utilities (including LADWP and GWP) have developed plans that include full conversion to hydrogen fuels by mid 2030s
- **Scale and timing of fuel needs in electric sector will require development of infrastructure to transport and store hydrogen**
  - While trucking & on-site storage may be suitable for pilot projects to demonstrate capabilities, dedicated pipelines are likely required for combustion of hydrogen in peaking power plants
  - Implication: the viability of relying on hydrogen at scale will also require the presence of a broader network for hydrogen distribution within the LA Basin

Key Risks & Uncertainties

Commercial readiness: 100% hydrogen combustion turbines are yet to be demonstrated; multiple utilities include hydrogen in their plans in mid to late 2030s

Fuel supply: Hydrogen fuel supply for power generation may largely depends on hydrogen expansion for other sectors of the economy such as transportation

Cost: Hydrogen storage and transport costs are uncertain and largely depend on the scale and site; hydrogen production costs are expected to go down in 2030s when demand for hydrogen scales and IRA incentives are still available

Initial Scoping of Portfolio Development

Energy+Environmental Economics

Role of Portfolio Analysis in Development of the Optimized Strategic Plan

- **OSP supporting studies focus on development and analysis of <u>“portfolios”</u>: unique combinations of resources to meet PWP future needs**
- **Goal of developing and analyzing multiple portfolios is not to select a single one as the Optimized Strategic Plan, but to synthesize learnings across all cases to inform creation of an OSP**

Multiple Portfolios Developed and Analyzed

Varying technology sets

Varying milestones

Results of Technical Analysis Synthesized

Common themes across portfolios

Relative cost impacts

“Least regrets” actions

Key risks & uncertainties

Path dependencies, tools to preserve optionality

Optimized Strategic Plan Created

“…a roadmap that lays out the key steps and future decision points that will best position PWP to achieve its goal to source all electricity from carbon-free sources by the end of 2030 while maintaining reliability and limiting cost impacts to customers”

Initial Learnings and Implications from Preparatory Studies

Local Solar & Storage Study

- Potential for ground-mounted solar within Pasadena city limits is severely limited by constraints on land availability
- Technical potential for rooftop and parking canopy solar is significant, comparable in magnitude to levels of local solar studied in 2023 IRP
- High technical potential for rooftop/parking canopy solar means that **levels of solar and storage will be based on grid needs and economics**, not limited by availability of space

New & Emerging Technologies Study

- Wind, solar, and battery storage are today widely available as carbon-free resource options despite upward cost pressures in the wake of COVID-19
- Emerging longer-duration storage technologies are unlikely to reach commercial maturity before early 2030s
- Deploying hydrogen for peaking capacity is technically feasible but will require technological advancements and significant new infrastructure development

Demand Response & Flexible Loads Study

- New sources of load flexibility, enabled by Advanced Metering Infrastructure (AMI), can allow customers to shift consumption from peak/net peak periods to periods of higher resource availability (typically solar hours)
- Managed charging of electric vehicles can limit the need for incremental generation and distribution capacity, while increasing the utilization factor of the grid

Transmission Options Study

- Significant investments in PWP's subtransmission system are necessary to replace aging infrastructure in the near term
- Replacement of transformers at Goodrich will allow for increased import capability but is unlikely to occur before mid 2030s
- Opportunities to expand import capability beyond current plans still being explored

Strawman Portfolio Proposal Informed by Initial Learnings from Preparatory Studies

	Technology Sets	A State Policy	B Glenarm Limited Use	C Carbon-Free Owned & Contracted Resources	D 24x7 Carbon Free
1	Mature Technologies Only	1A	1B	1C	1D
2	Mature Technologies + Hydrogen			2C	2D
3	Mature Technologies + Long Duration Storage			3C	3D
		Portfolio compliant with SB100 requirements — *Metric 1 = 100%*	*Local resources added to reduce frequency of Glenarm operations*	*Glenarm converted/replaced* — *Metric 2 = 100%*	*Glenarm converted/replaced* — *Unspecified purchases eliminated* — *Metric 3 = 100%*

Increasing stringency of clean energy requirements →

Summary of Portfolio Assumptions

	New Resource Options			
Portfolio	Available by 2030	By 2035	Glenarm Transition	Unspecified Purchases
1A	Li-ion		Retained	Offset by unspecified sales
1B	Li-ion		Retained (limited use)*	Offset by unspecified sales
1C	Li-ion		Replaced by 2030	Offset by unspecified sales
1D	Li-ion		Replaced by 2030	Eliminated by 2030
2C	Li-ion		H_2 Converted to H_2 by 2031	Offset by unspecified sales
2D	Li-ion		H_2 Converted to H_2 by 2031	Eliminated by 2030
3C	Li-ion	LDES	Replaced by 2035*	Offset by unspecified sales
3D	Li-ion	LDES	Replaced by 2035*	Eliminated by 2035

** In portfolios where Glenarm operations continue beyond 2030, renewable natural gas considered as an option*

Solar · Wind · Geothermal · Load Flexibility · Li-ion Short Duration Storage · LDES Long Duration Storage · TMG Expansion · Glenarm

Detailed Portfolio Assumptions & Inheritance Tree

Portfolio	Key Assumptions
1A	• All statutory clean energy requirements (e.g. SB100) met or exceeded • CAISO resource adequacy requirements satisfied
1B	• All requirements of **Portfolio 1A** • Additional local solar, storage, and DSM resources added to reduce frequency of Glenarm operations • *(Optional) Renewable natural gas purchased to support limited operations of Glenarm*
1C	• All requirements/assumptions of **Portfolio 1A** • Additional local solar, storage, and DSM resources added fully replace Glenarm capabilities by end of 2030
1D	• All requirements of **Portfolio 1C** • Additional renewables & storage resources added to eliminate reliance on unspecified market purchases
2C	• All requirements/assumptions of **Portfolio 1A** • Glenarm Power Plant is converted to operate using hydrogen fuel by end of 2030
2D	• All requirements/assumptions of **Portfolio 2C** • Additional renewables & storage resources added to eliminate reliance on unspecified market purchases
3C	• All requirements/assumptions of **Portfolio 1A** • Glenarm Power Plant is replaced by a combination of local solar, battery storage, DSM, and emerging LDES technologies • Timing of Glenarm replacement portfolio coincides with upgrades to transformers at Goodrich • *(Optional) Renewable natural gas used as a bridge fuel to allow limited operations at Glenarm until replacement is possible*
3D	• All requirements/assumptions of **Portfolio 3C** • Additional renewables & storage resources added to eliminate reliance on unspecified market purchases

Thank You

Nick Schlag, nick@ethree.com

Mike Sontag, michael@ethree.com

Michaela Levine, michaela.levine@ethree.com

Energy+Environmental Economics

Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel Meeting #5

September 18, 2024

Energy+Environmental Economics

Nick Schlag, Partner
Mike Sontag, Associate Director
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Managing Consultant

Agenda

- **Optimized Strategic Plan progress update**
- **Portfolio development scope**
  - Glenarm Conversion and Replacement Scope and Methodology
  - Long-Term Capacity Expansion Modeling Scope and Methodology
- **Next steps**

Primary objective for today: *Build shared understanding of tools and modeling approaches used in Portfolio Development phase to allow deeper technical conversations in future meetings*

Status Updates: Optimized Strategic Plan Supporting Studies

Active Workstreams

Local Solar & Storage
- Draft geospatial analysis of technical potential complete (ground mount, parking canopy, rooftop)
- Customer adoption modeling under multiple rate structures currently in progress

Demand Response & Flexible Loads
- Electric vehicle charging profiles (managed vs. unmanaged) developed
- Downscaling Lawerence Berkeley National Laboratory (LBNL) Demand Response (DR) supply curves

New & Emerging Technologies
- Review of emerging technology characteristics and risk factors complete
- Cost and performance assumptions for portfolio modeling currently under review by PWP

Glenarm Conversion & Replacement
- Preliminary modeling underway

Long-Term Capacity Expansion
- Reviewing data provided by PWP, compiling additional inputs and assumptions needed for modeling

On Deck

Transmission Options

Not yet started

Production Simulation

Distribution System Impacts

Cost Impacts

Optimized Strategic Plan: Study Workflow

Technical Analysis

Phase 1
Preparatory Studies
Identify and characterize all potential resource options

- Distributed Solar and Storage (in progress)
- New & Emerging Tech (in progress)
- Demand Response + Flex Loads (in progress)
- Transmission Options (on deck)

Phase 2
Portfolio Development
Use detailed power system modeling to construct multiple portfolios that meet clean energy goals and maintain reliability

- Glenarm Conversion/ Replacement (on deck)
- Long-Term Capacity Expansion (on deck)

Phase 3
Impact Assessment
Calculate cost metrics; identify feasibility concerns, dependencies, and risks of each portfolio

- Cost Impacts
- Production Cost Modeling
- Distribution System Analysis

Synthesis

Result
Optimized Strategic Plan
Informed by technical analysis, develop an action plan.

- Action Plan/ Final Report

Summary of Portfolio Assumptions

Presented to MSC & EAC, September 10, 2024

Technology Set	Portfolio	New Resource Options: Available by 2030	New Resource Options: By 2035	Glenarm Transition	Unspecified Purchases
Mature Tech Only	State Policy	Li-ion		Retained	⇄ Offs
	Accelerated DERs	Li-ion		Retained (limited use)*	⇄
	Carbon-Free Owned/Contracted	Li-ion		⊘ Replaced by end of 2030	⇄
	Carbon-Free 24x7	Li-ion		⊘ Replaced by end of 2030	⊘
Mature Tech + H_2	Carbon-Free Owned/Contracted	Li-ion		Converted to H_2 by end of 2030	⇄
	Carbon-Free 24x7	Li-ion		Converted to H_2 by end of 2030	⊘
Mature Tech + LDES	Carbon-Free Owned/Contracted	Li-ion	LDES	⊘ Replaced by 2035*	⇄
	Carbon-Free 24x7	Li-ion	LDES	⊘ Replaced by 2035*	⊘

Legend: Solar PV, Wind, Geothermal, Flexible Loads, Li-ion Battery, Transmission Expansion, LDES Long Duration Storage

Portfolios Developed Through a Two-Step Process

1 **Identify resources needed to ensure local reliability**

Glenarm Conversion and Replacement

1A. Evaluate infrastructure investments and options for converting Glenarm to hydrogen gas.

1B. Identify multiple portfolios of local resources that that could replace Glenarm while providing a similar levels of reliability.

2 **Identify additional resources needed to meet PWP system needs, the goals of Res. 9977, and resource adequacy requirements.**

Long-Term Capacity Expansion

2. Identify resources needed in addition to those found in step 1.

Each portfolio will be optimized for least cost independently. Portfolio costs will be compared in the Cost Impacts study.

Technical Analysis Plan for Portfolio Development

Phase 1: Resource Options

- Distributed Solar and Storage
- New & Emerging Tech
- Demand Response + Flex Loads
- Transmission Options

Local solar & storage potential →

Supply-side resource characteristics →

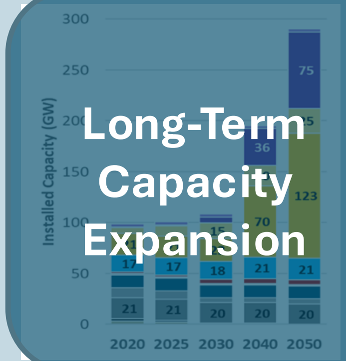
Supply curves for load management →

Options for transmission expansion →

Phase 2: Portfolio Development

Glenarm Conversion and Replacement

Stochastic simulations of system conditions accounting for load and renewable variability, generator and transmission outages across 1000 "draws," each representing a plausible calendar year of conditions



Long-Term Capacity Expansion

Co-optimization of new resource investments and system operations to minimize costs while meeting clean energy targets and reliability requirements

Portfolio 1 →

Portfolio 2 →

… →

Portfolio *n* →

Phase 3: Impact Assessments

- Production Cost Modeling
- Distribution System Analysis
- Cost Impacts Evaluation

Glenarm Conversion and Replacement Scope and Methodology

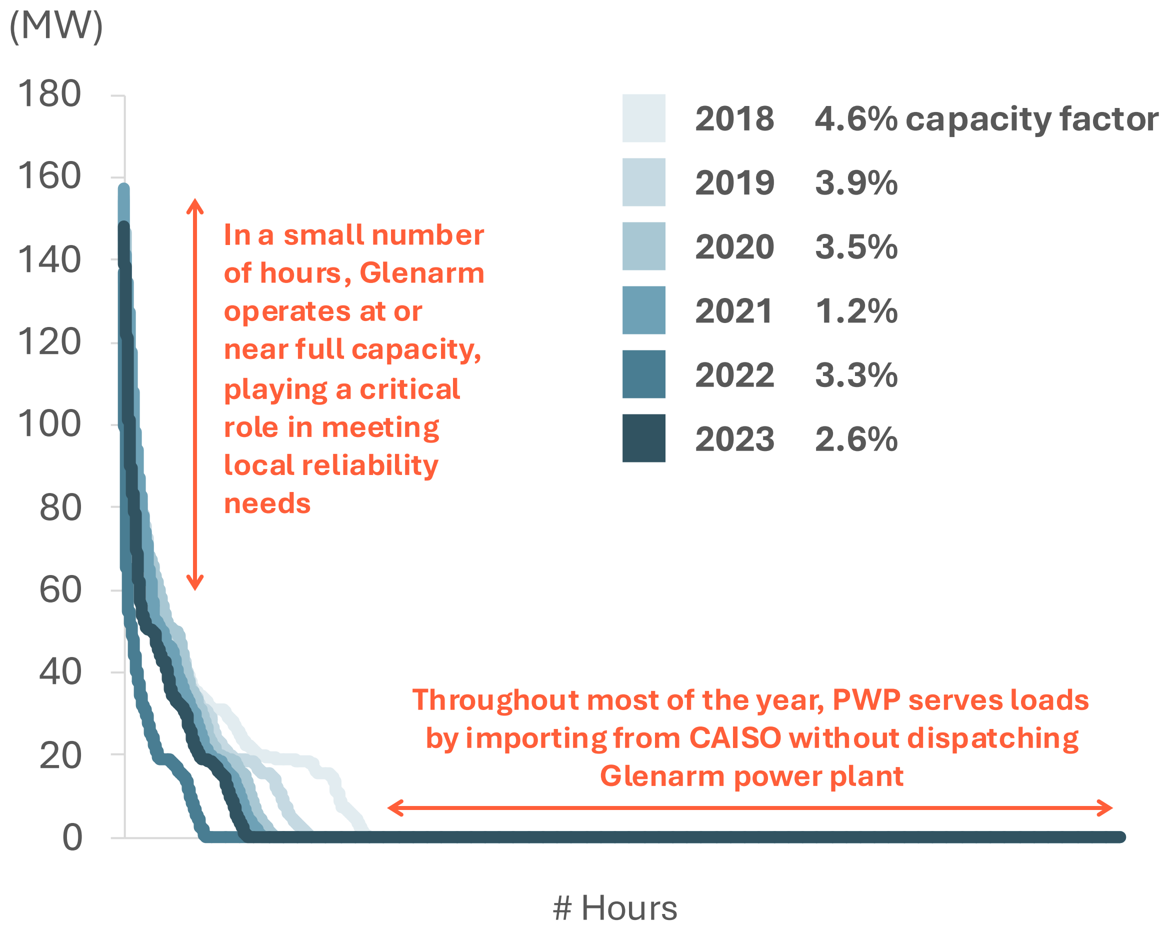
Energy+Environmental Economics

Scope of Glenarm Conversion & Replacement Study

- **ena's Glenarm Power Plant is a 200 MW peaking facility comprising five units fueled by natural gas**
- **While operations of Glenarm are limited (<5% annual capacity factor), the power plant plays a crucial role in maintaining local reliability**
- **PWP's goals of carbon-free supply requires a long-term transition plan for Glenarm that either:**
  1. Results in continued operations in a limited fashion using a carbon-free fuel
  2. Provides for the replacement of Glenarm with a portfolio of local resources resulting in comparable levels of local reliability
- **This study is not a master plan for the Glenarm site. Rather, it focuses on a potential resource portfolios to convert or replace the power supply provided by Glenarm.**

Step	Approach
Options for Hydrogen Conversion	Assess infrastructure investments needed to convert Glenarm to H2, including pilot project and milestones
Development of Replacement Portfolios	Use loss-of-load-probability modeling to identify alternative generation portfolios that yield similar levels of reliability within PWP system
Review of Regulatory Considerations	Review requirements associated with PWP's participation in CAISO market

A Historical Perspective on the Role of Glenarm



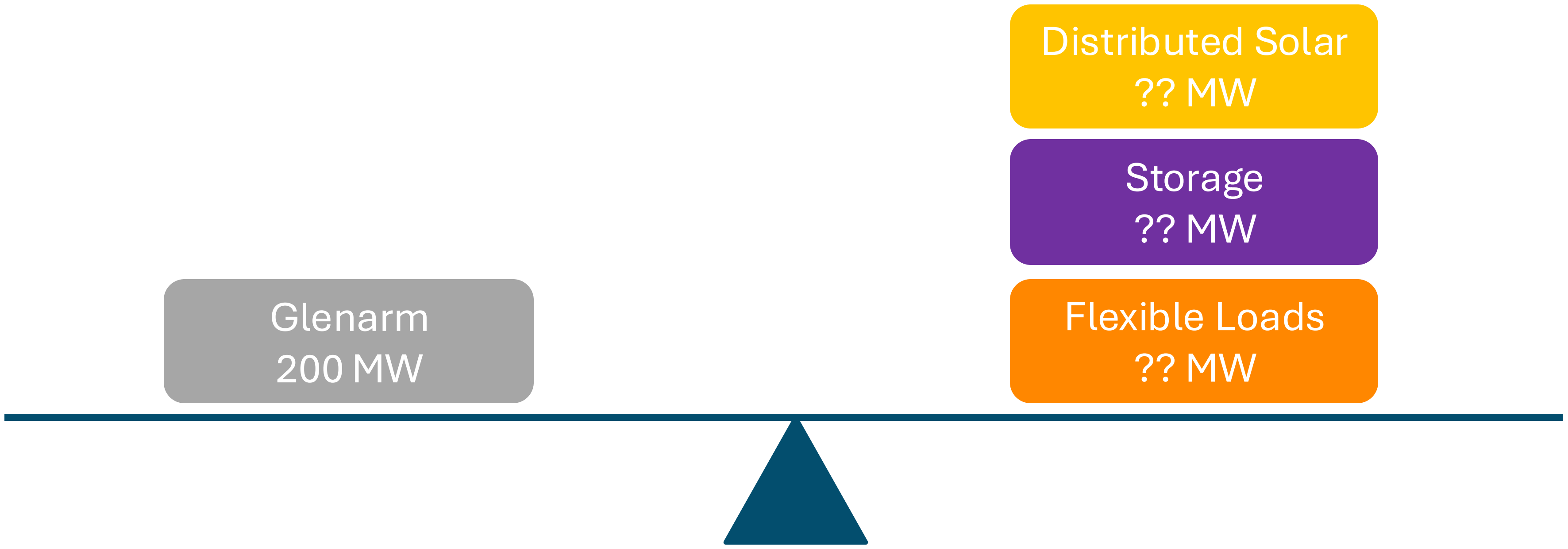
+ **Historical operational patterns of Glenarm Power Plant consistent with a resource whose primary purpose is supporting reliability:**
  - Low capacity factor, frequently not operated
  - Dispatched up to full capacity in a select number of hours per year
+ **Conditions that currently require operations of Glenarm:**
  - Peak demand conditions (above import capability)
  - Transmission/distribution contingencies
  - High wholesale electricity prices in California Independent System Operator (CAISO)
  - CAISO resource deficiencies

A long-term reliability solution will require local resources that can operate reliably under very specific circumstances

$$Capacity\ Factor\ [\%] = \frac{Annual\ Generation\ [MWh/yr]}{Nameplate\ Capacity\ [MW] * 8760\ hrs/year}$$

Goal of Glenarm Replacement Study

The goal of the Glenarm Replacement analysis is to identify combinations of local resources that can contribute an equivalent amount to system reliability as Glenarm currently does.

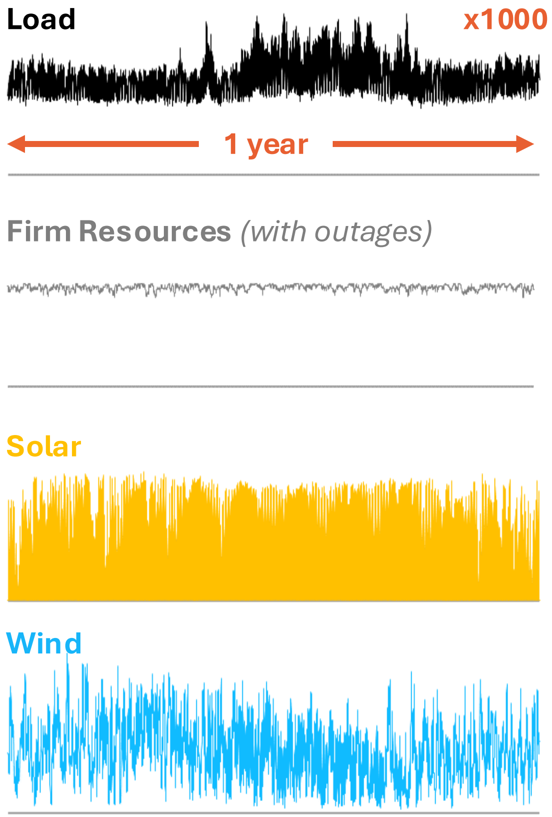


System Reliability Contribution

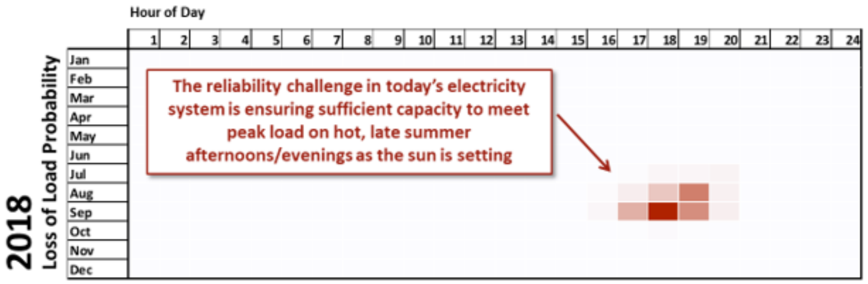
E3's RECAP: Loss of Load Probability Modeling

- E3's Re
  Planning (RECAP) model is a probabilistic method to consider system reliability across a wide range of load and weather conditions
- Monte Carlo simulations consider system operations across a range of conditions
  - Broad range of loads & renewables
  - Randomly simulated plant outages
  - Dispatch of use-limited resources
- Primary results are probability-weighted statistics of loss of load frequency, duration, and magnitude – but can also be used to derive Planning Reserve Margin (PRM) requirements and ELCCs of different resources

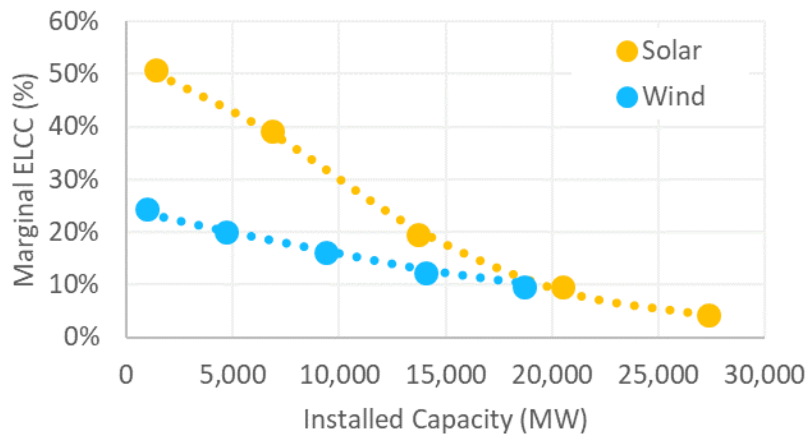
Monte Carlo simulation of loads, renewable profiles, and generator outages used to simulate 1,000 years of plausible system conditions



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



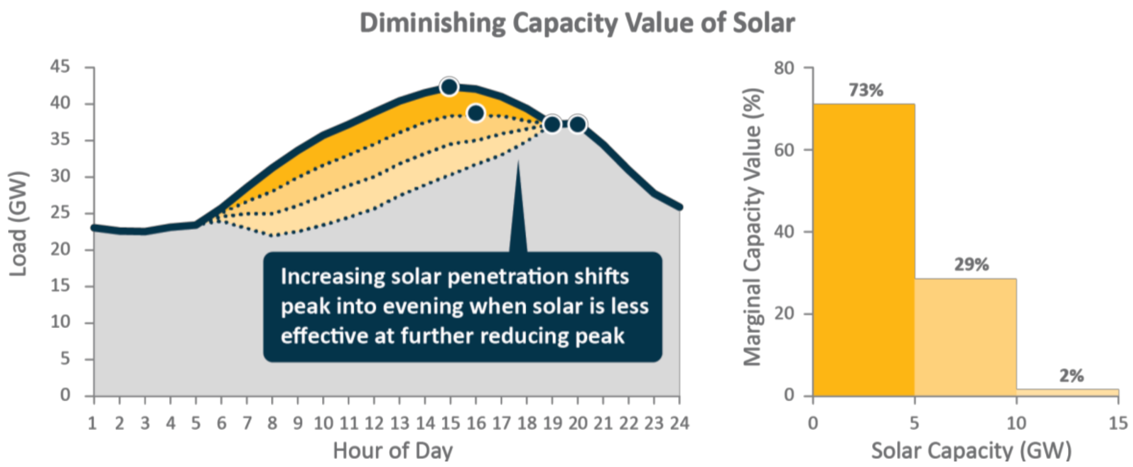
Effective load carrying capability (ELCC) for a wide range of types of resources evaluated

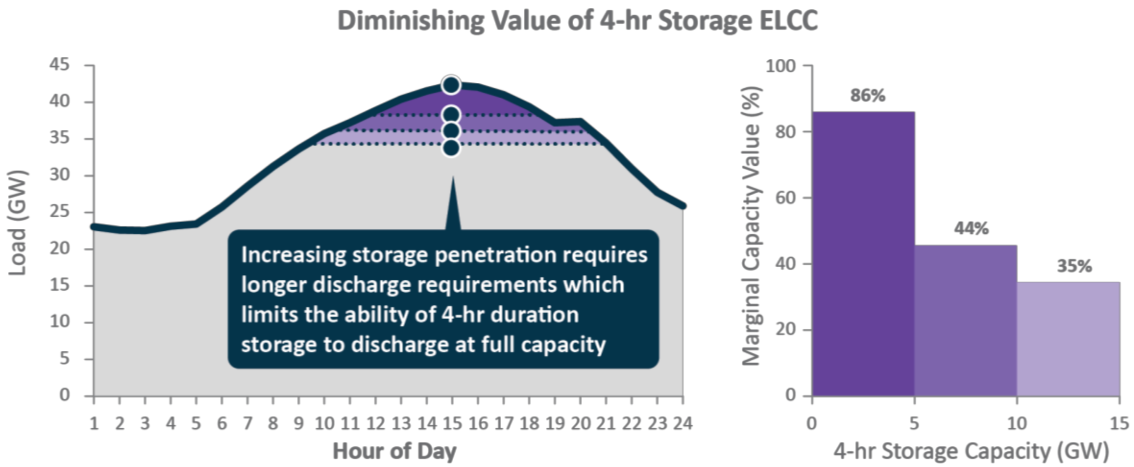


Example RECAP result from *Long-Run Resource Adequacy under Deep Decarbonization Pathways for California* (Calpine, 2019)

Why do we need hourly simulations and probabilistic models to construct replacement portfolios?

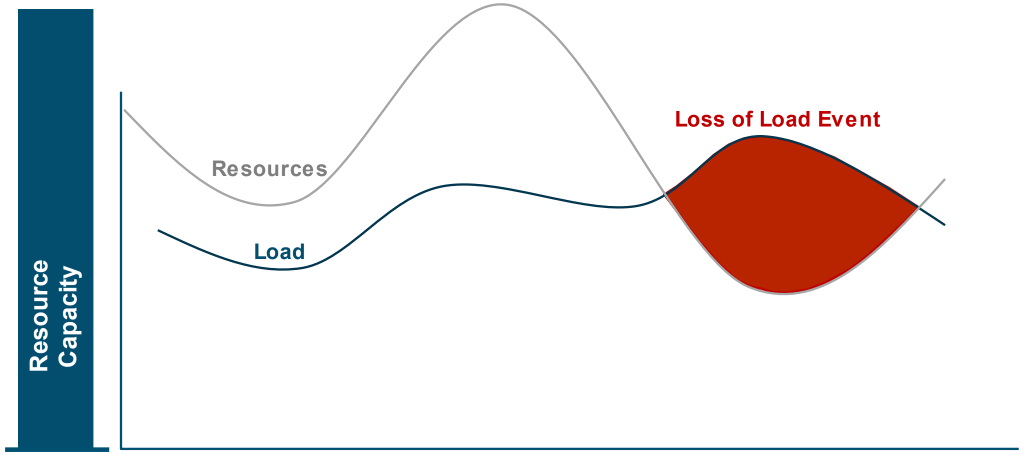
- Distributed solar and storage, which will play large roles in Glenarm replacement portfolios, have limitations as variable and energy limited resources that need to captured in determining their ability to contribute to system reliability.
- These limitations include:
  - **Resource availability**: RECAP accounts for the probability that periods of low solar output will coincide with high load.
  - **Saturation effects:** At increasing penetrations, variable and energy-limited resources experience declining marginal capacity value.
    - **Variable resources:** reliability risks shift towards "net peak" when resource availability is lower
    - **Energy-limited resources:** reliability risk extends across greater number of hours, requiring additional duration





Evaluating Reliability with Different Metrics

+ **System reliability can be measured in different ways, such as the resource adequacy of a power system, but generally based on characteristics of loss-of-load events that the system may encounter, in terms of:**
  - Frequency
  - Duration
  - Magnitude



+ **Target reliability metrics are not standard across the industry and are often not rigorously justified**
  - For example, “1-day-in-10-year" Loss-of-Load Expectation (LOLE) is often used but this metric does not capture the duration or magnitude of individual events

+ **PWP n’t d, e, two commonly-us “d s” -of-load events**
  - LOLE: Loss-of-Load Expectation (days/year) - Average number of days with loss of load
  - EUE: Expected Unserved Energy (MWh/year) - Average quantity of unserved energy

Standard Reliability Metric Definitions

+ Reliability metrics measure outages in terms of frequency, magnitude, and duration.

- No single metric captures all three dimensions of loss-of-load events.

+ Target reliability metrics are not standard across the industry

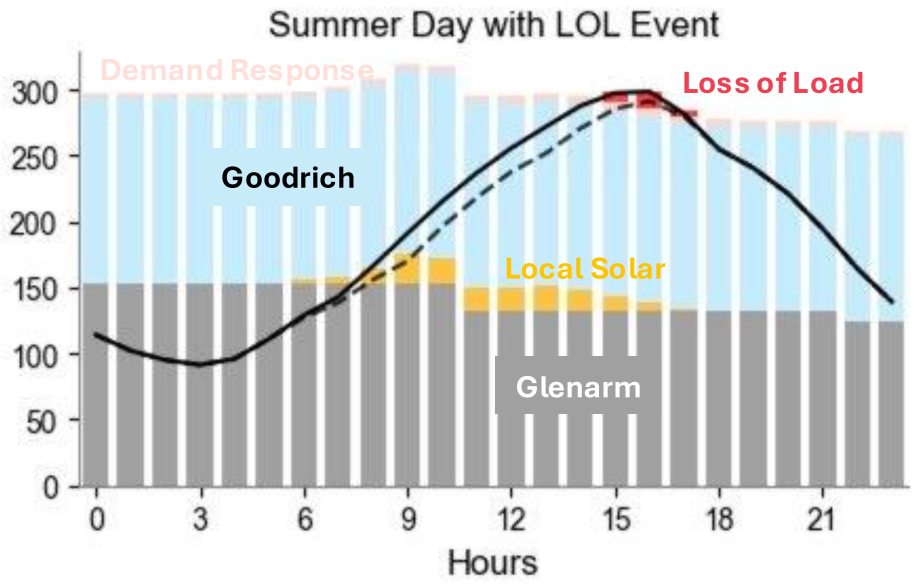
- LOLE has historically been the most commonly used in setting standards, though increasing interest in alternative metrics (particularly EUE)

Reliability Metric	Units	Definition
Loss-of-Load Expectation (LOLE)	days/year	Average number of days with loss of load (at least once during the day) due to system demand exceeding available generation capacity
Expected Unserved Energy (EUE)	MWh/year	Average quantity of unserved energy (MWh) over a year due to system demand exceeding available generation capacity
Loss-of-Load Probability (LOLP)	%	Probability of system demand exceeding available generation capacity over a given time period (e.g., season, year)
Loss-of-Load Hours (LOLH)	hours/year	Average number of hours per year where system demand exceeded available generation capacity
Loss-of-Load Events (LOLEV)	events/year	Average number of events (of any duration or magnitude) during which system demand exceeded available generation capacity

Representation of PWP Existing System in RECAP

+ **Representation of PWP system in RECAP generally includes three components:**
  1. **PWP retail energy demand**
     – Capturing hourly demand patterns throughout the year across a range of different weather conditions
  2. **Import capability from CAISO**
     – 280 MW under normal operating conditions
     – Reduced to 140 MW in the event of a transformer outage/maintenance at TM Goodrich
  3. **Glenarm availability**
     – Five units totaling 198 MW of capacity
     – Each unit susceptible to independent forced outages based on probabilities provided by PWP
+ **Simulations repeated across hundreds of "draws," eac sample of load and outages**

In any hour that PWP retail energy demand exceeds import capability from CAISO plus availability of Glenarm, a "reliability event" occurs

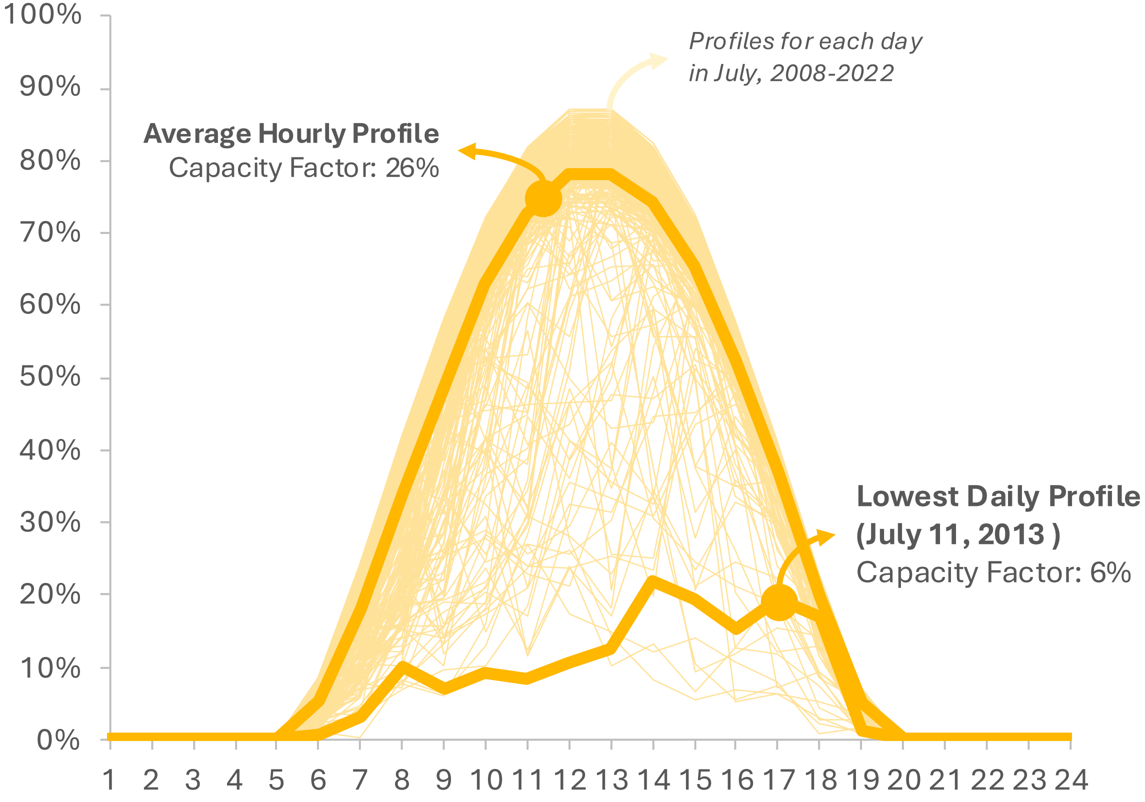


ILLUSTRATIVE

Representing a Wide Range of Solar Production Profiles

- **To capture a wide range of different potential weather conditions and corresponding solar production patterns, simulated profiles are REL's [System Advisor Model](#) and [National Solar Radiation Database](#)**
  - Historical period covered: 2006-2022
  - Chronological resolution: hourly
  - Spatial resolution: 4km
- **Incorporation of multiple weather years of solar profiles into LOLP modeling ensures low probability tail events – with potential impacts to reliability – are captured with representative probabilities**
  - Example: overcast days with low solar production

Pasadena Distributed Solar PV Hourly Profile, July
(% of maximum capacity)

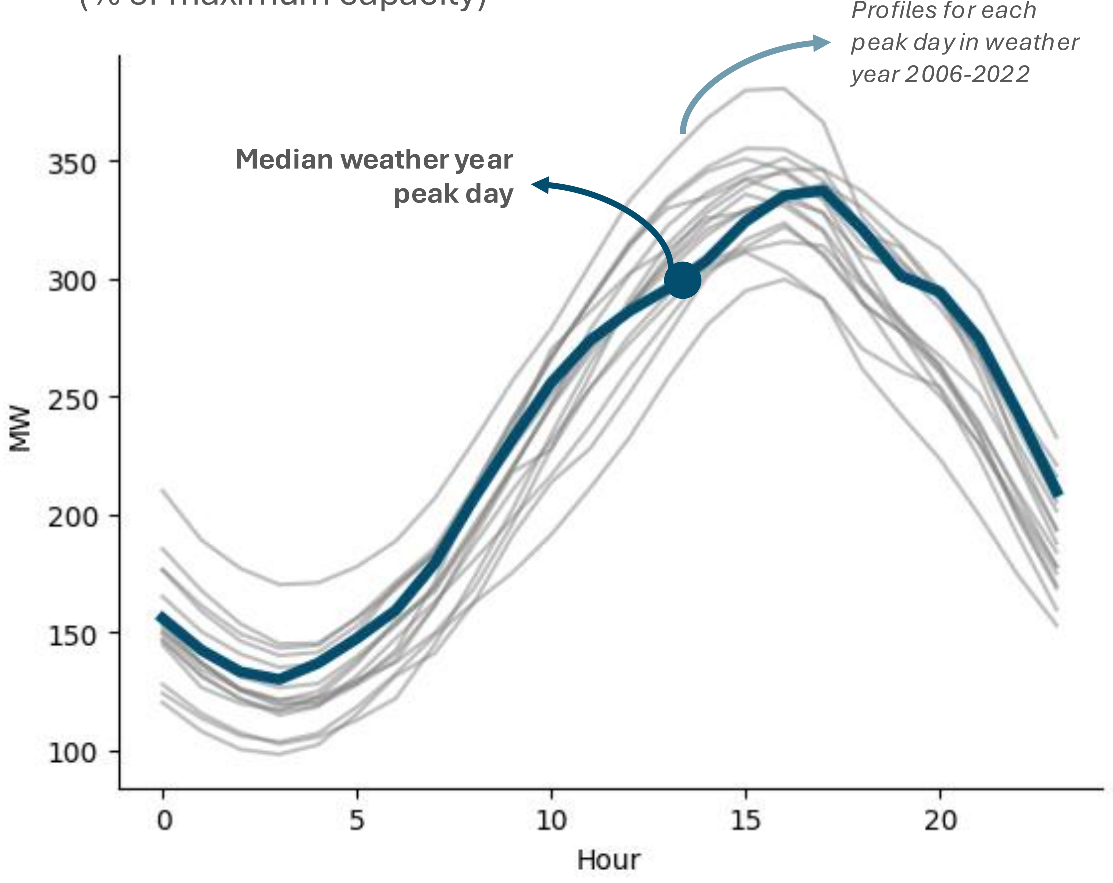


Based on profiles simulated at multiple locations and with multiple configurations throughout Pasadena using NREL's System Advisor model for the period 2006-2022

Representing a Wide Range of Load Conditions

+ **To capture uncertainties in demands, E3 models multiple years of base load profiles that reflect a broad range of weather conditions that Pasadena may experience.**
+ **E3 detrends historical load profiles for growth in BTM PV and energy efficiency to isolate the impacts of weather variability on load.**
  - Existing and incremental BTM PV is modeled as a resource.
  - Future energy efficiency is accounted for in scaling up load profiles to a future year forecast.
+ **Loads are scaled up to future years (e.g. 2030) to PWP's median energy and peak demand forecast.**
  - E3 models transportation electrification load growth using and end-use specific load shape.

Pasadena peak day in 2024 across weather year conditions
(% of maximum capacity)



Process for Developing Alternative “Replacement” Portfolios

1

Evaluate local reliability of current PWP system (2024)

Calculate reliability metrics (EUE and LOLE) to establish reliability baseline

Include simulations of hourly load and outages at Glenarm and Goodrich

2

Remove Glenarm and rerun LOLP simulations in 2030

Frequency and magnitude of unserved energy events increases, particularly during peak periods and outages at Goodrich

3

Add portfolios of new resources to restore original level of reliability

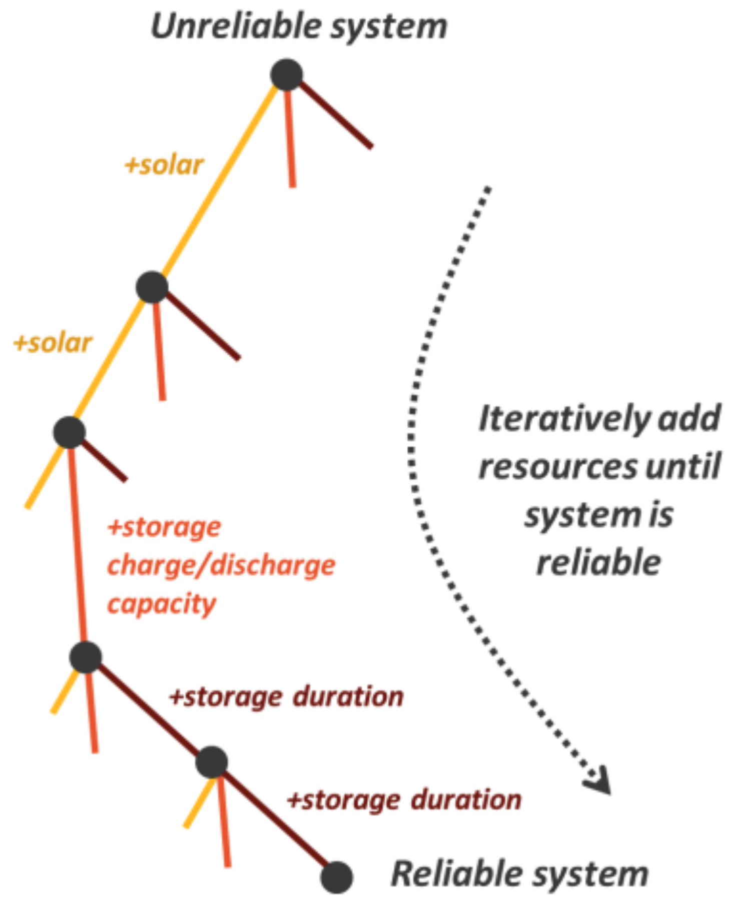
Add solar, storage, and flexible load resources until reliability is restored

Maintain same sampling of load and outage conditions as Step 1

Approach for Identifying a Replacement Portfolio

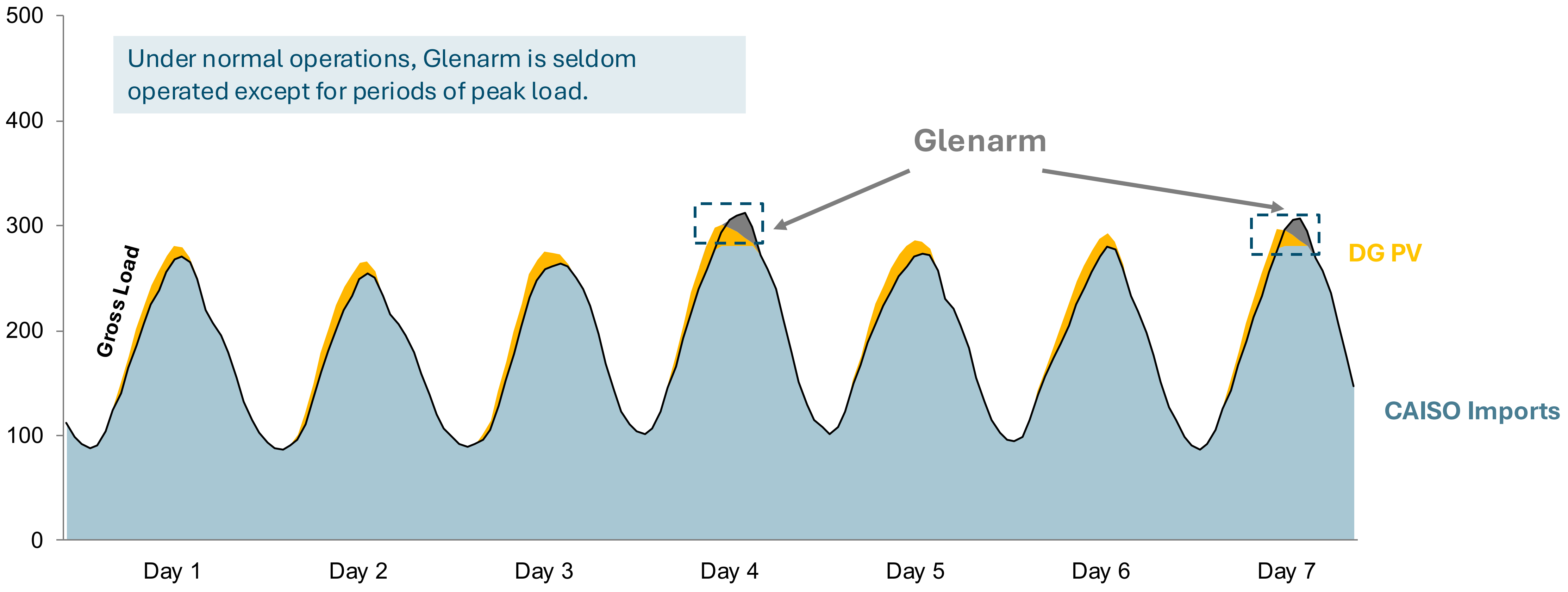
- m, “s h”: portfolios by iteratively identifies and adds least-cost resources until target reliability is reached
- **This tool will aim to add resources cost-effectively to a base portfolio to achieve the maximized reliability benefit**
  1. Smart search starts with a local portfolio that is insufficiently reliable relative to the target reliability;
  2. It then evaluates the incremental improvement to reliability that results from adding small, equal-cost increments of candidate resources;
  3. The resource that improves reliability the most is added to the portfolio, and the process is then repeated with the same set of resources until the portfolio is sufficiently reliable
- **We will run smart search with various combinations or resources that can be selected to bring reliability back to its baseline level.**

Illustrative Smart Search Process



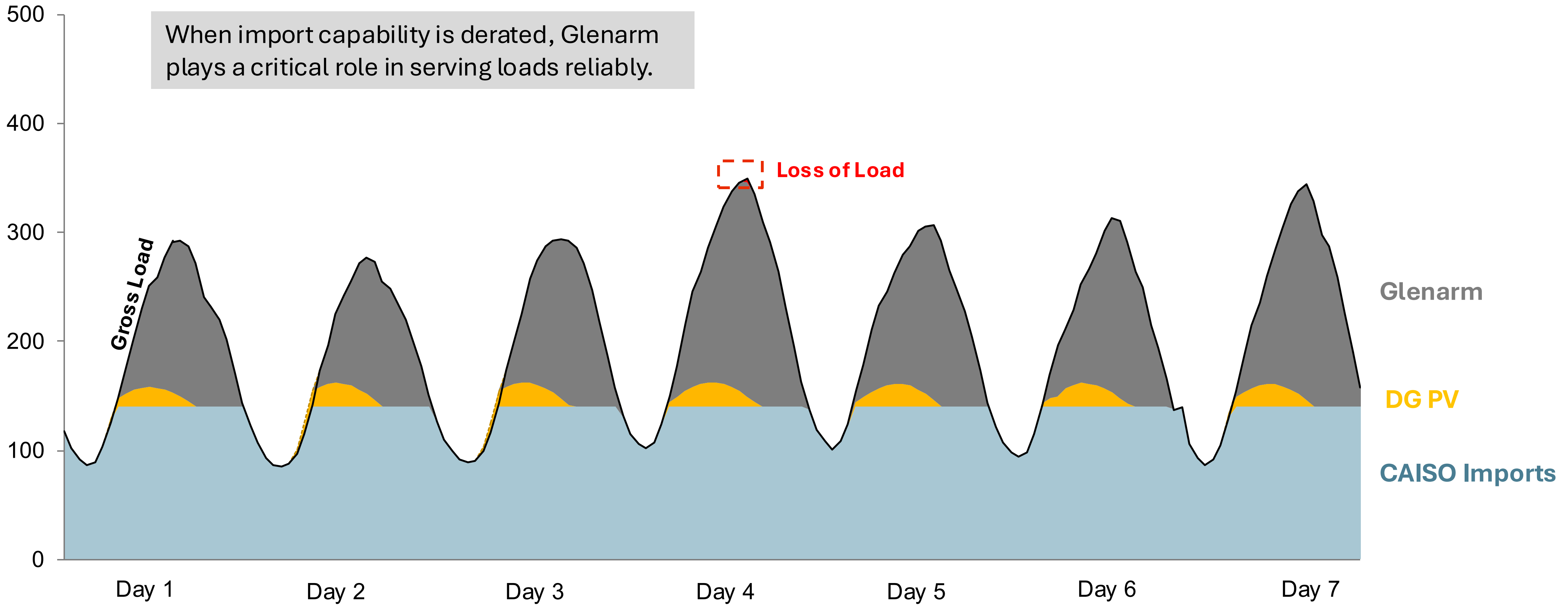
System Load-Resource Balance, 2031

System Dispatch during high load week
Base system with Full Import Capability (280 MW)
(MW)

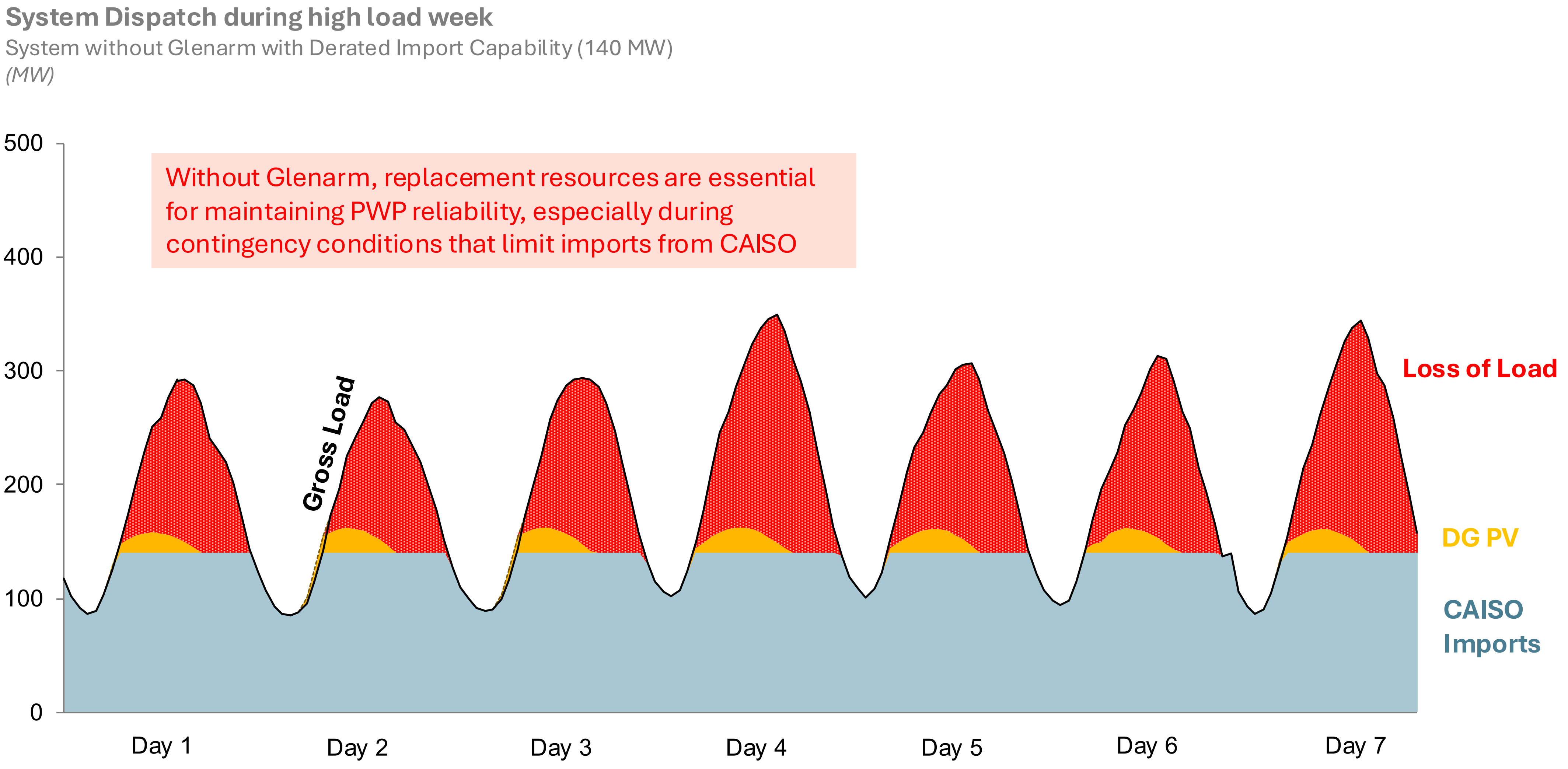


System Load-Resource Balance with TMG outage, 2031

System Dispatch during high load week
Base system with Derated Import Capability (140 MW)
(MW)



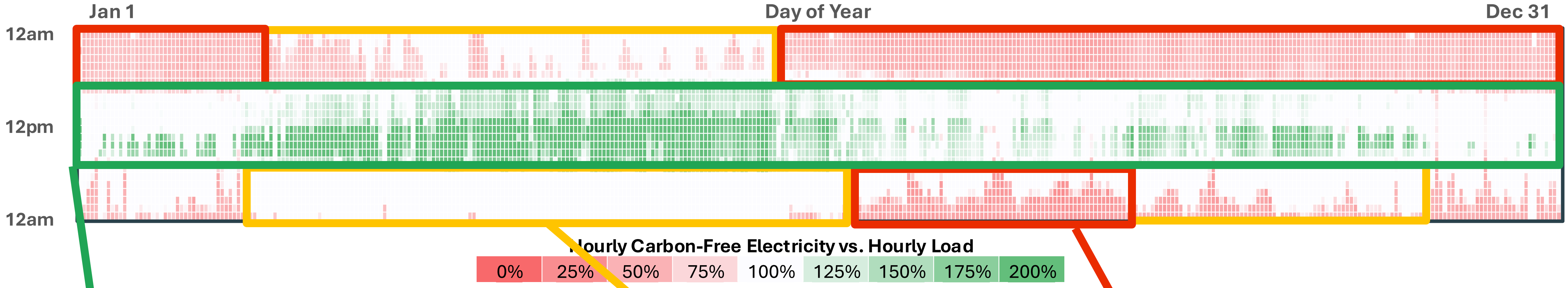
System Load-Resource Balance with Glenarm Retired, 2031



Beyond Goodrich Contingency, Technical Challenge for Reliability Will Likely Center Around Non-Solar Hours

Abundant solar generation during the day helps meet gross system peak, but significant levels of energy storage and load shifting will be needed to deliver that energy to other times of the day and year, and provide system capacity in all hours

2030 Carbon-Free Electricity Supply, as a proxy for Difficulty of Supplying Carbon-Free *Capacity*



Midday hours can leverage abundant solar (both distributed and utility scale) to fulfill capacity requirements at relatively low difficulty

Evenings and some mornings in shoulder seasons can leverage shorter duration battery storage

Peak summer evening/nights and eventually winter mornings will place the most strain on local reliability. Contingency events (ex. Goodrich going down), must also be considered

Next Steps: Combinations of Replacement Resources to Explore

- **Replacement portfolios are under development for:**
  - **Multiple technology sets** (corresponding to the portfolios)
  - **Multiple years** (to account for changes in load and eventual expansion of transmission limits)

- **Each replacement portfolio serves as the basis for a local resource reliability constraint in Long-Term Capacity Expansion study**

	Mature Technologies Only		Mature Technologies + LDES	
Resource Options	**2030**	**2035**	**2030**	**2035**
Distributed Solar	✓	✓	**	✓
Battery Storage (4hr)	✓	✓	**	✓
Mid Duration Storage (10hr)	*	*	**	✓
Long Duration Storage (100hr)	*	*	**	✓
Flexible Loads	✓	✓	**	✓
Demand Response	✓	✓	**	✓
Transmission Expansion	*	✓	**	✓

* Technology options not included in specified replacement analysis
** In the "Mature Technologies + LDES" portfolios, Glenarm is retained for emergency conditions through 2035

Long-Term Capacity Expansion (LTCE) Scope and Methodology

Energy+Environmental Economics

Development of Optimized Portfolios using Long-Term Capacity Expansion Modeling

+ **Long-term planning of optimized portfolios is a complex, multifaceted process that considers a horizon of 15 to 20 + years, for example**
+ **Long-term capacity expansion models use optimization to construct optimized portfolios that:**
  - Minimize an objective function (such as cost)
  - Meet reliability, policy, and any other applicable constraints (such as reliability, and/or carbon-free energy, among others)
  - Implicitly evaluate tradeoffs among a wide range of resource options to find appropriate balance

Objective

Minimize costs

Constraints

Achieve carbon-free energy

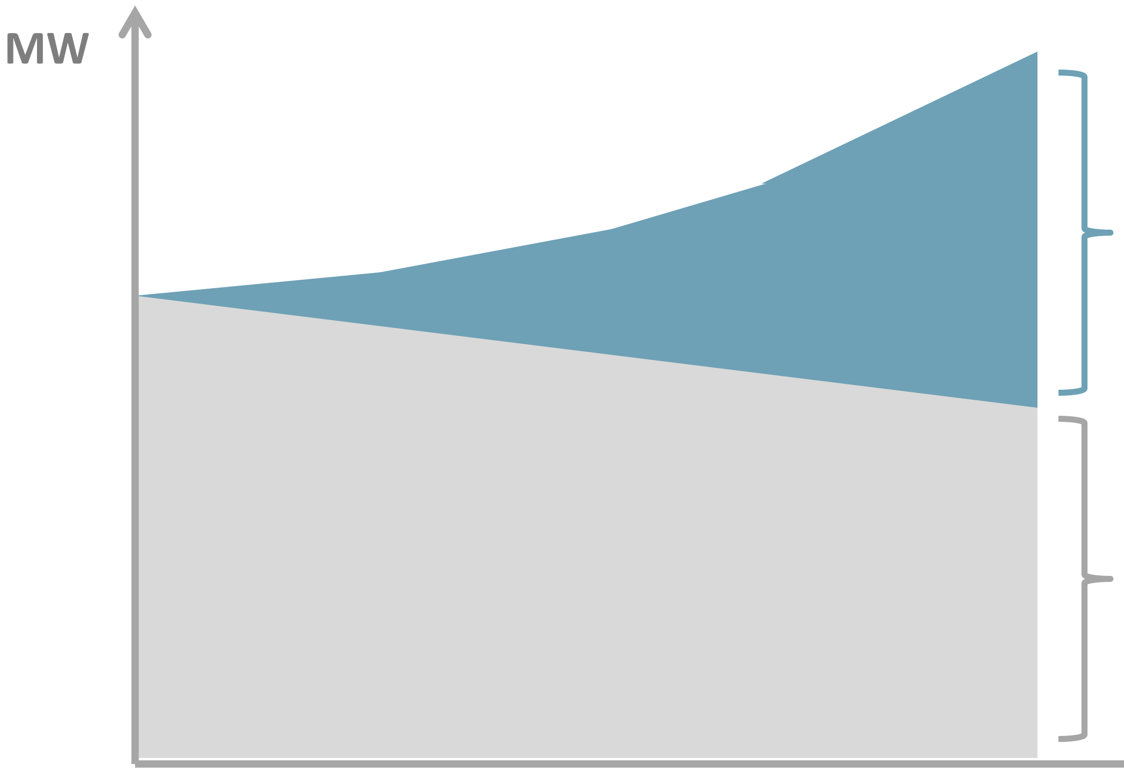
Ensure reliability

Resource options
(with unique characteristics)

Candidate Resource Options
Distributed Solar PV
Utility-Scale Solar PV
Wind (California)
Wind (Out of State)
Geothermal
Battery Storage (4hr)
Mid Duration Storage (10hr)
Long Duration Storage (100hr)
Demand Response
Load Flexibility
Green Hydrogen
Transmission

Capacity Expansion Optimizes Incremental Investments

+ **Fixed costs of new investments included in objective function**
+ **Embedded costs of existing infrastructure are treated as sunk costs**



Year

<u>**Selected Resources:**</u> New resource investments optimized by capacity expansion to minimize cost while meeting reliability and policy goals

<u>**Baseline Resources:**</u> Existing and planned resources assumed to remain in service through planned retirement; costs assumed to be sunk

Portfolios will vary in what resources can be selected based on technology set.

Long-term Capacity Expansion (LTCE) Model: PLEXOS

- **What is PLEXOS?**
  - A system simulation tool based on optimization
  - Allows us to represent complex energy systems to explore questions and inform decision making
- **Why do we use PLEXOS?**
  - Detailed unit-level representations of resources and their interactions with other resources and load
  - Can represent the evolution of policy and new technologies
  - Flexible tool that can help solve many real-world problems
- **What questions can PLEXOS help us answer?**
  - Optimal resource portfolio mix
  - Future system operations
  - And more!

PLEXOS

E3 will use PLEXOS, an industry standard LTCE model, which has functionality similar to EnCompass (used in 2023 IRP)

Capacity Expansion Formulation

Objective Function

+ Investment Costs
- New resources
- New transmission (optional)

+ Fixed Costs
- Renewables
- Energy storage
- Thermal

+ Variable Costs
- Variable O&M*
- Fuel Costs
- Market purchases

*Operation and Maintenance

Decisions

Investments ⇅ **System Operations**

Constraints

- Clean energy targets
- Resource adequacy requirements
- Resource Limits
- Operations
- Transmission

Key inputs and assumptions required for LTCE

Load Forecast	PWP baseload EV adoption forecast Energy efficiency
Baseline Resources	Glenarm and existing DER portfolio Owned & contracted renewable, storage, and thermal resources Renewable profiles, thermal operating parameters, storage round-trip efficiency
Candidate Resources	Capacity expansion resource options and availability, including DR resources Resource costs, fuel costs, and renewable profiles
Portfolio Constraints	CAISO Resource Adequacy (RA) requirement (applying forward-looking marginal ELCC) Requirements for local resources (from Glenarm Replacement/Conversion Study) Clean energy policy targets
Market Interactions	CAISO wholesale market price forecast Restrictions on gross/net imports
Simulation Settings	Modeling horizon Day sampling settings PWP weighted average cost of capital (WACC)

Topology for Capacity Expansion Model

Utility Load	
2024 Peak Demand[4]	332 MW
2030 Peak Demand[5]	361 MW
Owned & Contracted Resources	
Glenarm Power Plant	198 MW
Windsor Reservoir Solar	0.7 MW
Glenarm BESS[2]	25 MW
Existing Customer-Owned Resources	
Customer-Owned Solar	28 MW
Customer Owned Storage	1 MW
Candidate Resource Options	
Distributed Solar PV	
Battery Storage (4hr)	
Mid Duration Storage (10hr)[3]	
Long Duration Storage (100hr[3]	
Demand Response	
Load Flexibility	
Green Hydrogen[3]	

Local PWP System

TM Goodrich
Receiving Station

280 MW limit
(expanding to 336 MW by 2035)

External CAISO System

Owned & Contracted Resources	
Palo Verde Nuclear	10 MW
Intermountain Power Plant[1]	108 MW
Magnolia Power Plant	14 MW
Chiquita Canyon Landfill Gas[1]	7 MW
Puente Hills Landfill Gas[1]	13 MW
Hoover Hydro	15 MW
Azusa Hydro	15 MW
Calwind[2]	20 MW
Coso Geothermal[2]	10 MW
Geysers Geothermal[2]	25 MW
Antelope Big Sky Ranch Solar	7 MW
Big Sky Summer Solar	7 MW
Columbia 2 Solar	3 MW
Kingbird Solar	20 MW
Bonanza Solar[2]	105 MW
Sapphire Solar[2]	39 MW
Bonanza BESS[2]	55 MW
Sapphire BESS[2]	20 MW
Candidate Resource Options	
Utility-Scale Solar PV	
Wind (California)	
Wind (Out of State)	
Geothermal	
Battery Storage (4hr)	
Mid Duration Storage (10hr)[3]	
Long Duration Storage (100hr)[3]	
Wholesale Energy Market	
CAISO Wholesale Market (SP15)	

Notes:
1. Resources with established plans for retirement or contract expirations prior to end of 2030
2. Resources not yet online today
3. Candidate resources included in a select set of portfolios
4. Based on 2023 IRP forecast.
5. Based on 2023 IRP forecast with blended EV charging developed by E3.

LTCE Outputs and next steps after portfolio development

+ **Outputs of the portfolio development phase will be multiple cost-optimized resource portfolios reflecting different pathways to achieving Res. 9977. Key outputs for each portfolio include:**
  - Total Installed Capacity (includes existing, planned, and new generation and battery storage)
  - Total Generation (annual generation from all resources)
  - Annualized Build Cost (total fixed costs (capital and fixed O&M) of candidate resources)
  - Operational Costs (variable O&M, fuel costs)
  - Market Purchases (market net purchases and cost/revenue)

+ **In the Cost Impacts phase of analysis, we will further analyze the compare the cost of each portfolio.**
+ **In the Action Plan, we will synthesize findings across portfolios, identifying common themes, no-regrets actions, and next steps.**

Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel Meeting #6

October 16, 2024

Nick Schlag, Partner

Mike Sontag, Director

Nathan Lee, Sr. Managing Consultant

Michaela Levine, Sr. Managing Consultant

Energy+Environmental Economics

Agenda

- Optimized Strategic Plan progress update
- Demand Response and Flexible Load Study Results
- Update on Transmission Options
- Glenarm Conversion and Replacement – Resource Adequacy Consideration

- *Appendix: Resource Cost Assumptions (requested by TAP)*

Status Updates: Optimized Strategic Plan Supporting Studies

Active Workstreams

Local Solar & Storage

- Geospatial analysis of technical potential complete (ground mount, parking canopy, rooftop)
- Adoption modeling in progress

Demand Response & Flexible Loads

- Downscaling LBNL DR supply curves complete
- EV charging load shaping complete, under review by PWP

New & Emerging Technologies

- Review of emerging technology characteristics and risk factors complete
- Developed cost and performance assumptions for portfolio modeling

Glenarm Conversion & Replacement

- Preliminary modeling underway

Long-Term Capacity Expansion

- Reviewing data provided by PWP, compiling additional inputs and assumptions needed for modeling

Transmission Options

- Discussing options. Identifying key decision points and considerations

Not yet started

Production Simulation

Distribution System Impacts

Cost Impacts

Technical Analysis Plan for Portfolio Development

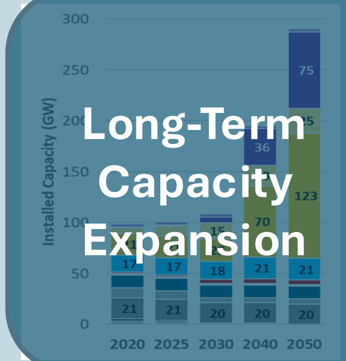
Phase 1: Resource Options

- Distributed Solar and Storage → Local solar & storage potential
- New & Emerging Tech → Supply-side resource characteristics
- Demand Response + Flex Loads → Supply curves for load management
- Transmission Options → Options for transmission expansion

Phase 2: Portfolio Development

Glenarm Conversion and Replacement

Stochastic simulations of system conditions accounting for load and renewable variability, generator and transmission outages across 1000 "draws," each representing a plausible calendar year of conditions



Long-Term Capacity Expansion

Co-optimization of new resource investments and system operations to minimize costs while meeting clean energy targets and reliability requirements

→ Portfolio 1
→ Portfolio 2
→ …
→ Portfolio *n*

Phase 3: Impact Assessments

- Production Cost Modeling
- Distribution System Analysis
- Cost Impacts Evaluation

Updates from Preparatory Studies

Technical Analysis

Phase 1
Preparatory Studies
Identify and characterize all potential resource options

Phase 2
Portfolio Development
Use detailed power system modeling to construct multiple portfolios that meet clean

Phase 3
Impact Assessment
Calculate cost metrics; identify feasibility concerns, dependencies, and risks of

Synthesis

Result
Optimized Strategic Plan
Informed by technical analysis, develop an action plan.

Action Plan/ Final Report

Study	Update
Distributed Solar and Storage (in progress)	✓ Discussed at September 10 MSC & EAC meetings
New & Emerging Tech (in progress)	✓ Discussed at September 10 MSC & EAC meetings
Demand Response + Flex Loads (in progress)	✓ Draft supply curves for "shed" and "shift" demand response in Pasadena
Transmission Options (in progress)	✓ Description of options for transmission expansion explored

Two Phase of Portfolio Development

1 Identify resources needed to ensure local reliability

Glenarm Conversion and Replacement

1A. Evaluate infrastructure investments and options for converting Glenarm to H2.

1B. Identify multiple portfolios of local resources that that could replace Glenarm while providing a similar levels of reliability.

2 Identify additional resources needed to meet PWP long-term system needs, the goals of Res. 9977, and resource adequacy requirements.

Long-Term Capacity Expansion

2. Identify resources needed in addition to those found in step 1.

Each portfolio will be optimized for least cost independently. The cost of each portfolios will be compared in the Cost Impacts study.

Demand Response & Flexible Loads

Energy+Environmental Economics

Scope of DR and Flexible Loads Study

- **Objective: Assess cost and potential for demand response in PWP's service territory.**
- **Motivation: Given constraints on PWP to leverage utility-scale resources due to limited import capability and in-zone resource availability, demand response is one of the zero-carbon demand-side resources that can contribute to meeting PWP's capacity needs for maintaining reliability.**

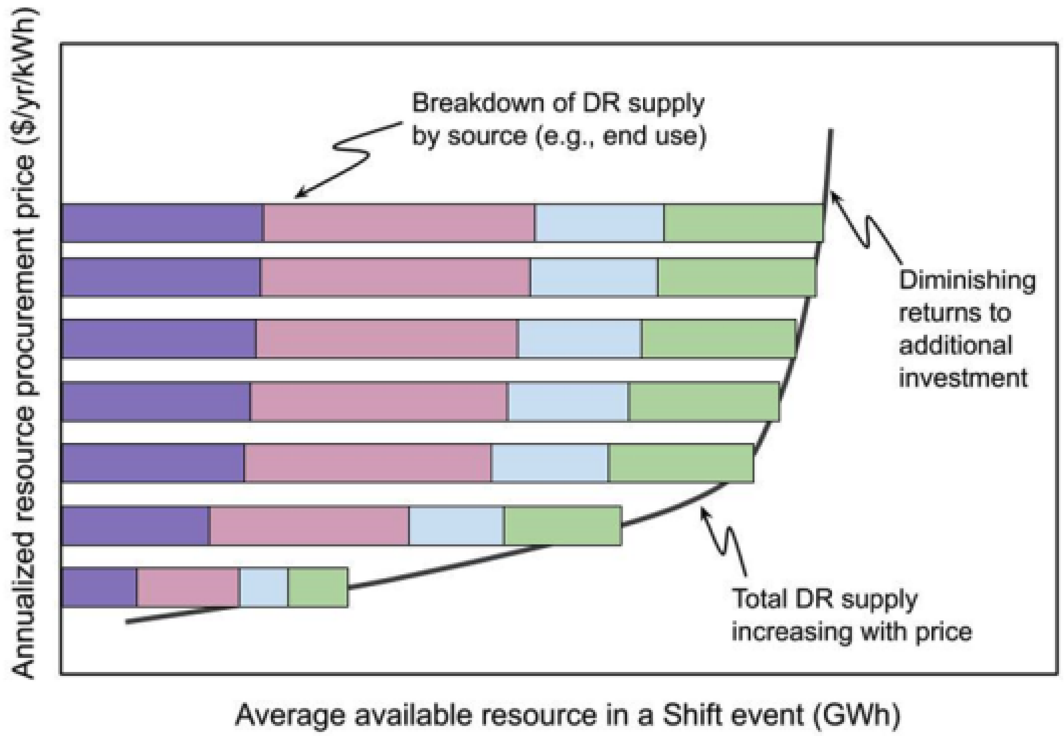
Questions answered in this study:

1. How much demand response potential is available from PWP customers?
2. What are the costs of demand response?
3. How can PWP leverage managed electric vehicle (EV) charging to reduce grid impacts of electrification?

Questions not answered in this study:

1. How should PWP design programs and tariffs to procure demand response?

At what cost?



How much?

Framing the Opportunity: Demand Response & Flexible Loads in California

- **2023 CPUC IRP[1] assumes 1,842 MW of Shed Demand Response in CAISO with an additional 582 MW of interruptible pumping load (from CA Department of Water Resources):**
  - 2,424 MW in total, which is ~5% of CAISO's peak load of 50 GW
- **California's Energy Commission has set a statewide target of 7,000 MW of load-shiftability by 2030[2]**
  - This represents ~15% of California's peak load
- **Advanced Metering Infrastructure plays a critical role in achieving this target, both through advanced rate design, and being able to measure and incentivize load shifting**
- **The resources are some of the building blocks of VPPs, along with distributed solar and storage**

CEC 2030 Load-Shift Goals

Table ES-2: Proposed Statewide Load-Shift Goal by Intervention

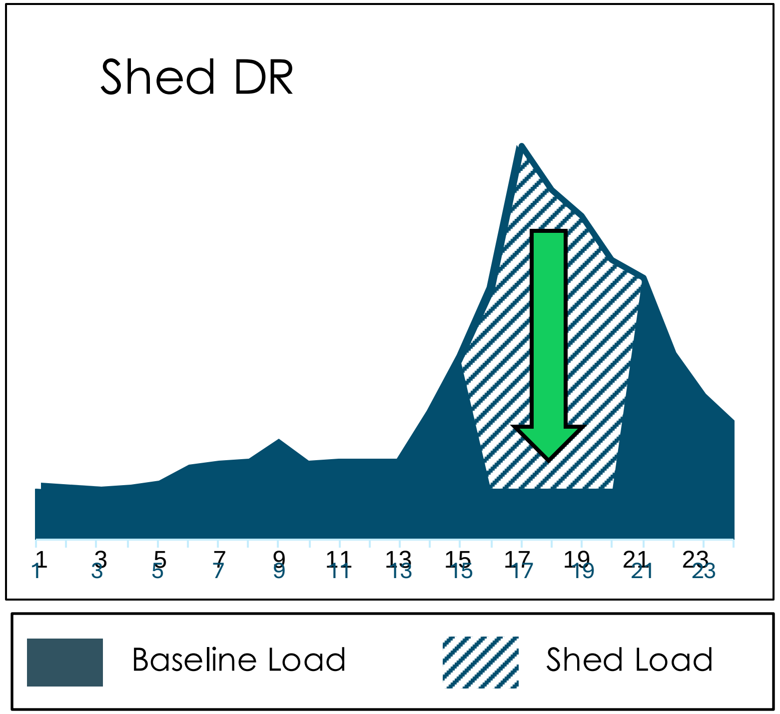
Category	Intervention	2022 Estimate	2030 Goal
Load-Modifying (LM)	TOU Rates	620–1,000 MW	3,000 MW
	Dynamic Pricing	30 MW	
	LM Programs	7 MW	
Resource Planning and Procurement	Economic Supply-side DR	670–825 MW	4,000 MW
	Reliability Supply-Side DR	740 MW	
	POU DR Programs (Non-ISO)	210 MW	
Incremental and Emergency (I&E)	I&E Programs	800 MW	
	Emergency Back-Up Generators*	375 MW*	
Total (nearest 100)		**3,100–3,600 MW**	**7,000 MW**

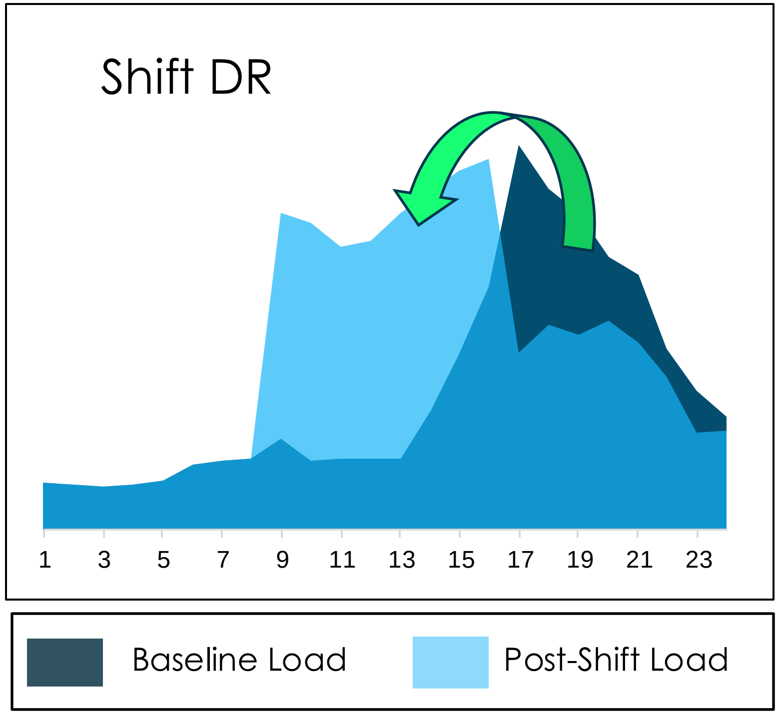
***Includes backup generators with significant local emissions, which are part of the current emergency framework but not included in the 2022 load flexibility total. Only zero- and low-emission behind-the-meter generation consistent with AB 205 (Committee on Budget, Chapter 61, Statutes of 2022) is included in the load-shift goal.**
Source: CEC staff, CPUC staff

1) CPUC 2023 IRP Inputs and Assumptions,
2) CEC 2023 Senate Bill 846 Load-Shift Goal Report;

Lawerence Berkeley National Laboratory (LBNL) Potential Study Overview

- **LBNL produces supply curves for the achievable potential for shed and shift demand response curves characterizing the resource availability at a given cost.**
  - **Shed ("conventional")** – Loads that can be curtailed to provide capacity reductions
  - **Shift** – Loads that can be shifted between hours

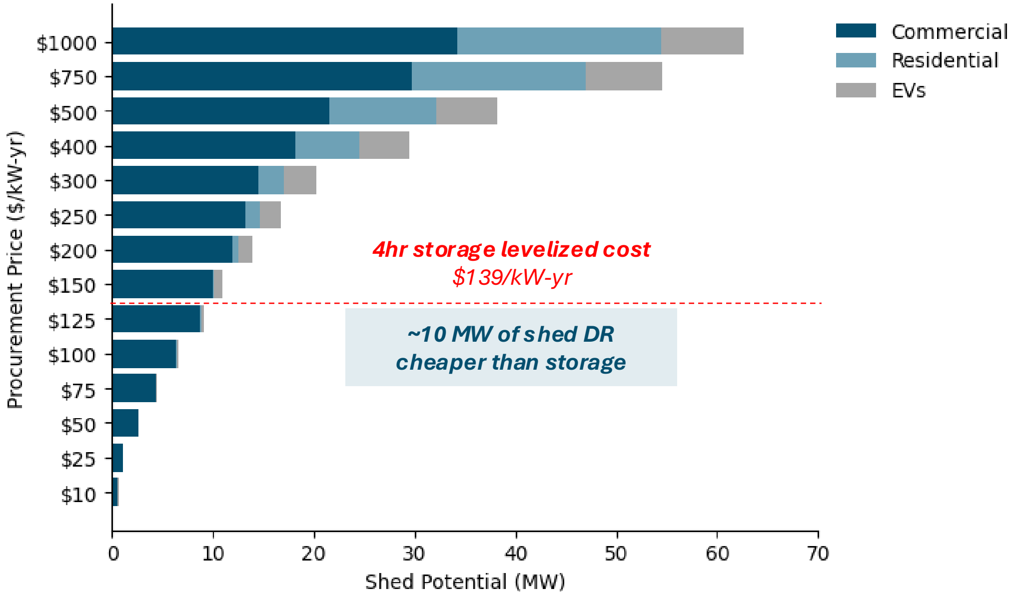




Downscaled Supply Curves of DR Potential for Pasadena

2030: Pasadena Shed DR Potential by Customer Grouping

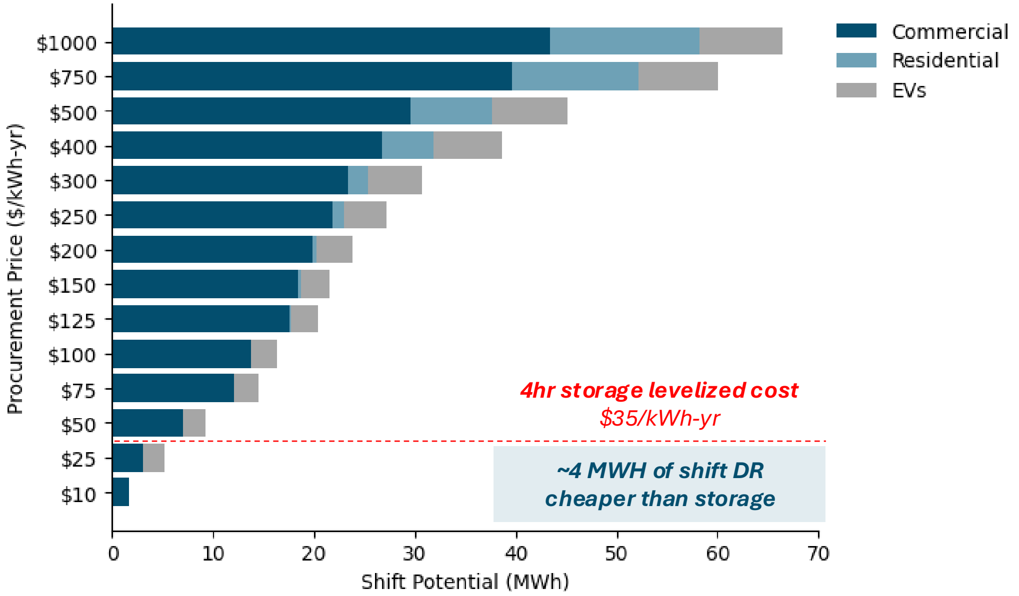
Procurement Price ($)



Shed potential in units of MW to show the amount of load that can be reduced.

2030: Pasadena Shift DR Potential by Customer Grouping

Procurement Price ($)



Shift potential in units of MWh to show the amount of energy can be shifted

Commercial load makes up the majority of PWP's load, creating the largest opportunity to shift and shed load. Electric vehicles are expected to emerge as a large source of shift DR.

Considerations for Enabling this Resource

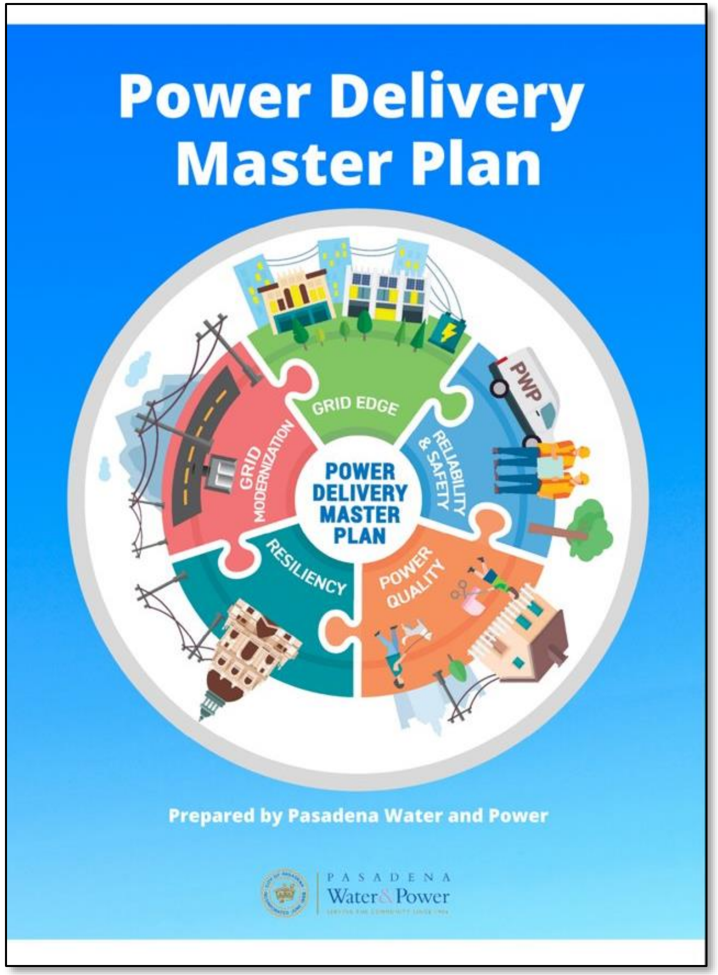
- **Advanced Metering Infrastructure is necessary to enable TOU rates, and measure/incentivize demand response – AMI is currently expected roll out in PWP in 2028**
- **LBNL's supply curve is working from a reasonably mature and developed demand response market in CA's investor-owned utilities which may be optimistic for PWP.**
  - PWP will be starting from scratch and may need some time to build up base of participants, technologies, and dependable DER service providers.
  - Point-of-sale recruitment is seen as much more effective than trying to enroll customers after device installation – may be challenging to leverage devices installed before AMI metering.
- **Establishing good customer relationships will be critical for ramping up DR programs, and PWP can start building those before the AMI project through behavioral demand response and customer engagement.**
  - Customer-focused nature also presents an opportunity to build strong relationships and let more people participate in the clean energy transition
- **Important to target end uses and customers that have load present during hours with high loss of load probability**
  - Majority of PWP's load (~70%) is from commercial customers – programs should look to tap into this sector

Transmission Options

Energy+Environmental Economics

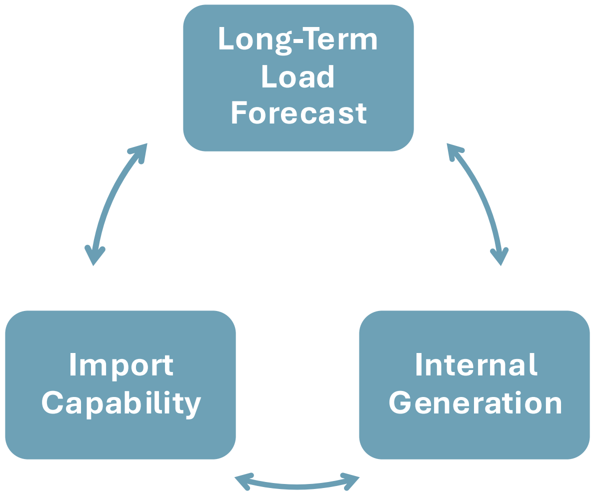
The Power Delivery Master Plan (2022) Identified Three Priorities to Address Constraints on Pasadena's Import Limitations

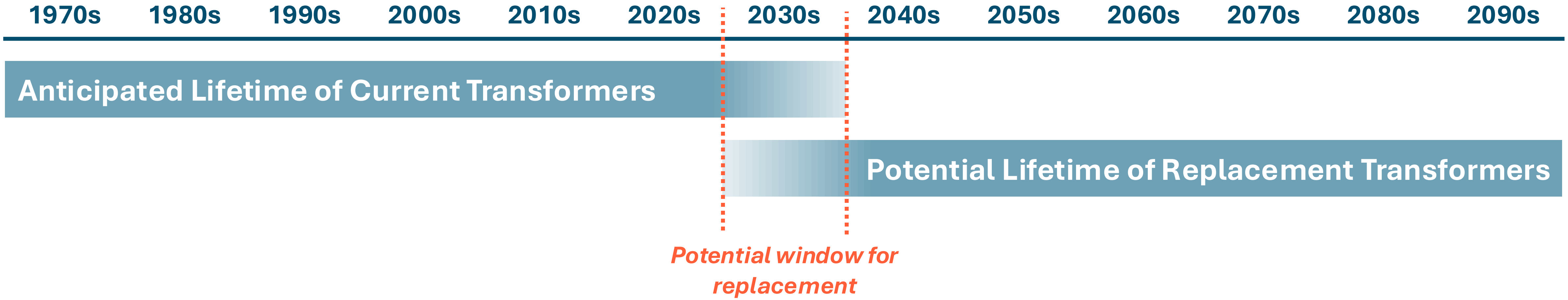
PDMP Priority	Current Status
Replace and upgrade internal 35kV subtransmission lines	Replacement projects currently in progress (planning phase)
Evaluate potential to install phase shifting transformer at interconnection with LADWP	Discussed with CAISO; option not pursued further due to CAISO concerns of PWP operating interconnection to another balancing authority without CAISO control
Upgrade transformers at TM Goodrich to enable increased import limit of 336 MW (contractual limit of interconnection agreement with SCE)	**Recent events have raised question of whether expansion to 336 MW is the right long-term solution for PWP or whether higher levels of expansion should be considered**



Right-Sizing Import Capability for Long-Term Needs Depends on Load Growth and the Role of Internal Generation

- **Replacement of TM Goodrich transformers presents an opportunity for PWP to redesign the power system for long-term needs**
- **Equipment lifetimes for transformers and other key electrical equipment are 50-70 years, meaning that these decisions will set the foundation for what Pasadena's electrical system looks like through the remainder of this century**
- **Multiple key uncertainties and decisions have direct implications for right-sizing of transformers:**
  - What are long-term expectations for **load growth**, accounting for potential for **transportation and building electrification** associated with state's ambitious decarbonization goals?
  - What are Pasadena's long-term plans to build or maintain **internal generation** resources within the system?
  - How would increased import limits impact Pasadena's **subtransmission system**?
  - What are the **costs** associated with various replacement options (and the corresponding infrastructure needs)?





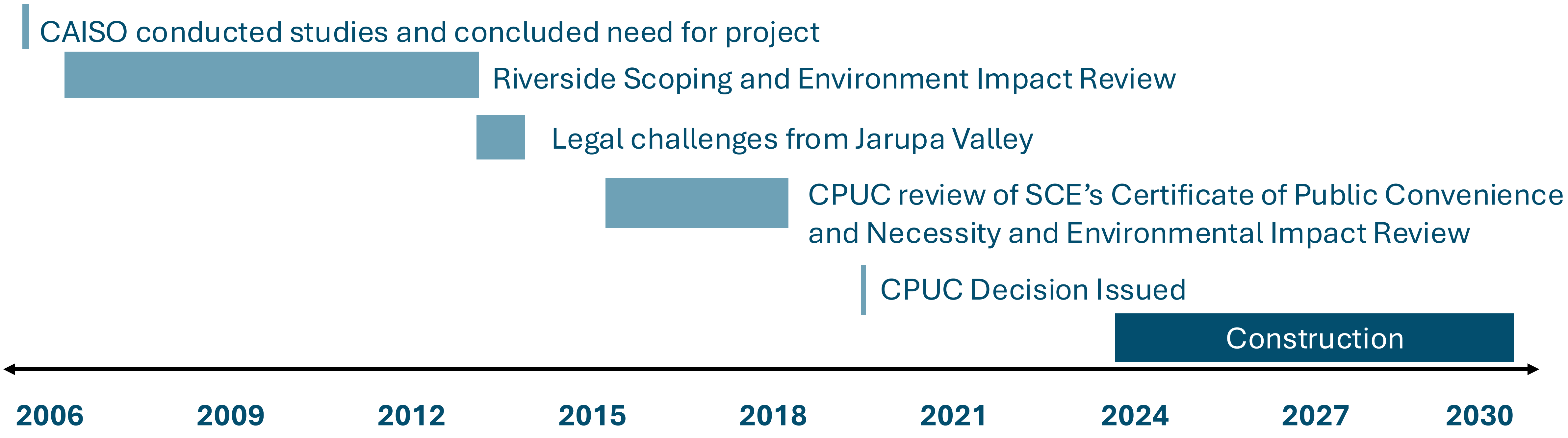
Roadmap for TM Goodrich Expansion

Stage	Estimated Timeframe	Necessary for Upgrade to 336 MW (Option 1)	Necessary for Upgrade above 336 MW (Option 2)
Upgrades to Internal Subtransmission System Identified in PDMP *Replace and upgrade existing 35 kV subtransmission lines to enable greater cross-town power flow and improve reliability*	3-4 years	**Yes** *(in progress)*	**Yes** *(in progress)*
Right-Sizing Study for TM Goodrich *Determine ideal sizing of interconnection considering long-term load growth and plans for internal generation*	1 year	No	**Yes**
Technical & Engineering Studies (TM Goodrich Station) *Develop detailed project plans for selected expansion option*	1-2 years	**Yes**	**Yes**
Technical & Engineering Studies (Internal System) *Evaluate whether additional internal improvements are necessary at higher import levels*	1-2 years	No	**Yes**
Renegotiation of Interconnection Agreement with SCE* *Renegotiate agreement to allow maximum interchange above 336 MW*	Uncertain	No	**Yes**
Competitive Procurement Processes *Conduct request for proposals, evaluate responses, select vendor, negotiate contracts*	1-2 years	**Yes**	**Yes**
Equipment Procurement Lead Time *Place orders transformers and other necessary specialized equipment*	3-5 years	**Yes**	**Yes**
Additional Upgrades to Internal Subtransmission System *Reconfigure PWP subtransmission system to higher voltage level consistent with higher TMG rating*	Uncertain	No	**Maybe** *(depending on rating)*
Upgrades to CAISO/SCE Transmission System* *Study upgrades necessary to SCE system, obtain permits & CPCNs, complete project*	Uncertain	No	**Maybe** *(depending on rating)*
Project Construction *Complete construction outside of summer peak seasons and Rose Bowl event moratorium*	2-4 years	**Yes**	**Yes**

Stages are organized roughly chronologically, but not all stages must occur sequentially; stages marked with asterisks (*) reflect stages involving or led by other parties (SCE & CAISO)

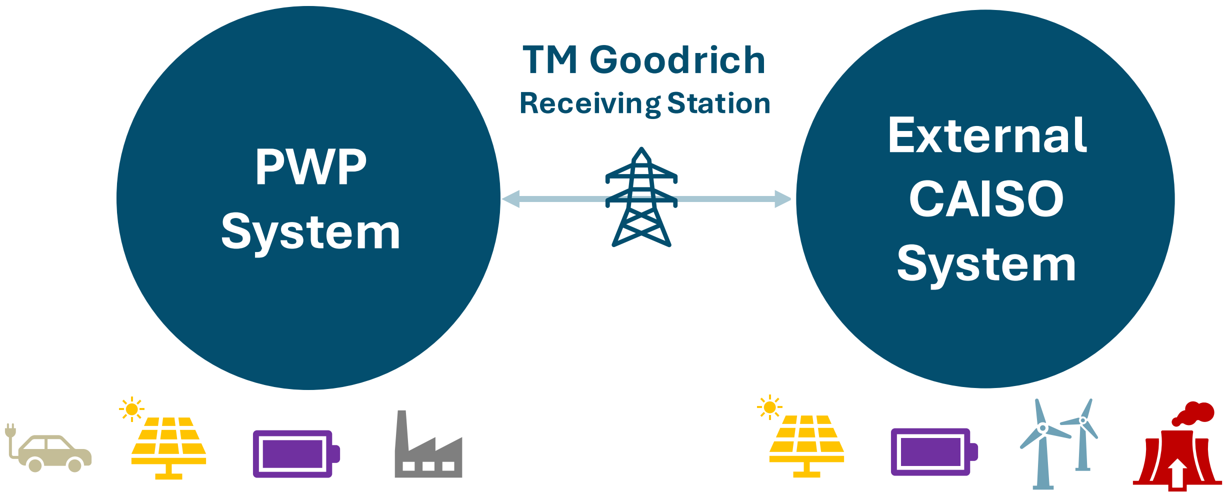
Riverside Transmission Reliability Project (RTRP) as a Case Study for Second CAISO Interconnection

- **Riverside Public Utilities is connected to CAISO via a single point of interconnection at the Vista Substation which has a capacity lower than RPU's peak load.**
- **Project involves a new substation and several miles of transmission lines operated by SCE/CAISO and new switchyard and subtransmission lines operated by RPU.**
  - Transmission lines had to be undergrounded.



How Transmission Options Tie into the Optimized Strategic Plan

- In the near term (by 2030), relieving the import constraint at TM Goodrich poses a significant challenge – so portfolios developed in OSP will reflect the continued need for internal generation to maintain reliability
- At the same time that it pursues the ambitious goal of carbon-free by 2030, Pasadena faces a pivotal decision of how to expand TM Goodrich, a decision that will have long-term implications on its power system
- Key results from OSP portfolio analysis can help inform future efforts to examine right-sizing of intertie
  - Long-term demand forecasts
  - Insights on the potential long-term role of different internal generating resources
- OSP can explore a sensitivity on long-term transmission expansion to provide insight to Pasadena.



Appendix: Resource Costs

Energy+Environmental Economics

Summary of Techno-Economic Modeling Assumptions Recommended for OSP

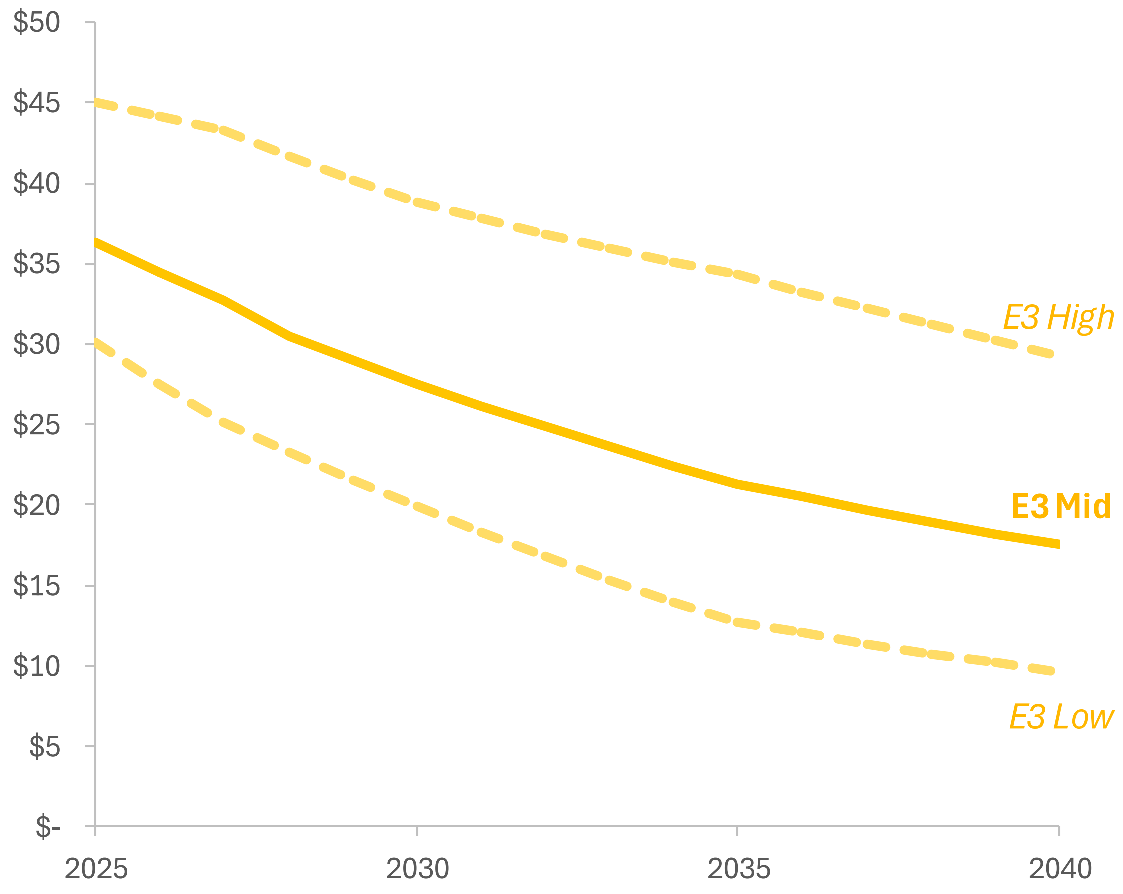
Year	Characteristic	Solar PV	Wind	Geothermal	Lithium Ion Battery (4 hour)	MDES Archetype (10 hour)*	LDES Archetype (100 hour)*
2030	**Capital Cost** ($/kW)	**$1,275** $1,180-$1,370	**$1,570** $1,430-$1,720	**$9,120** $8055-$10,070	**$1,420** $1,055-$1,790	-	-
	Levelized Cost of Energy ($/kW-yr)	**$30** $20-$40	**$35** $25-$45	**$95** $77-$120	-	-	-
	Levelized Fixed Cost ($/kW-yr)	-	-	-	**$140** $100 – $185	-	-
	Delivered Fuel Cost ($/MMBtu)	-	-	-	-	-	-
2035	**Capital Cost** ($/kW)	**$1,206** $965-$1,210	**$1,445** $1260-$1630	**$8,605** $7,050-$9,820	**$1,310** $933-$1,690	**$4,000** $3,140-$4,640	**$2,780** $2,120-$3,440
	Levelized Cost of Energy ($/kW-yr)	**$20** $10-$35	**$30** $20-$40	**$90** $70-$115	-	-	-
	Levelized Fixed Cost ($/kW-yr)	-	-	-	**$130** $90 – $180	**$310** $225-$400	**$245** $177-$335
	Delivered Fuel Cost ($/MMBtu)	-	-	-	-	-	-

* Numbers are rounded to nearest tenth.

Utility-Scale Solar PV: OSP Modeling Assumptions

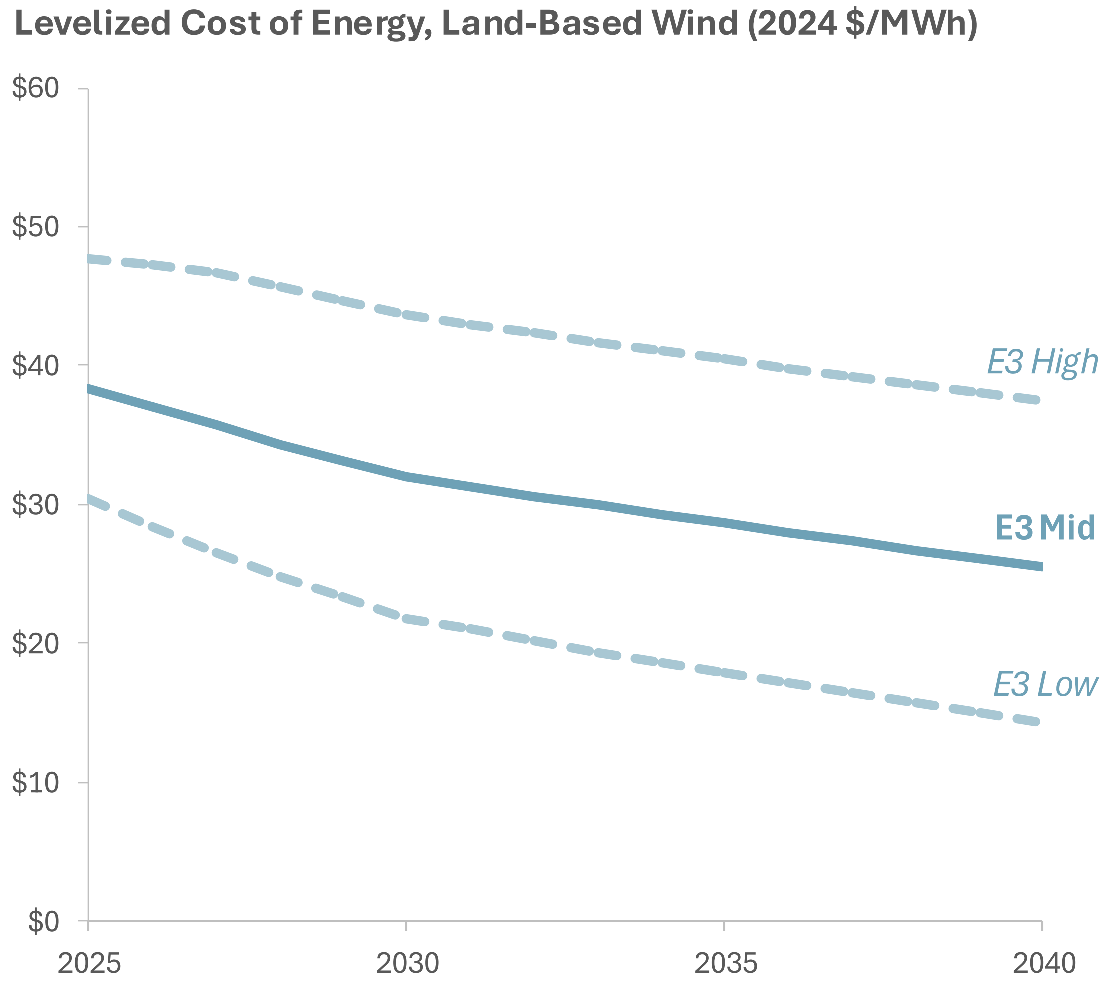
+ **Present-day cost assumptions reflect range observed across a range of data sources (with adjustments for California labor & materials costs):**
    - 2024 Annual Technologies Baseline (NREL)
    - 2023 Annual Energy Outlook (EIA)
    - 2024 Levelized Cost of Energy + (Lazard)
    - Solar Market Insight Report Q2 2024 (SEIA)
    - Generation Technology Options – 2024 (EPRI)
+ **Future cost reduction trajectories derived from NREL ATB assuming exponential cost reductions between present day and 2050**
+ **Levelized cost of energy calculated for informational purposes based on standard performance and financing assumptions:**
    - *Capacity factor of 31%-36% for high and low cost trajectories*
    - IRA production tax credit available throughout horizon
    - Costs of debt and equity tied to current market indices

Levelized Cost of Energy, Utility-Scale Solar PV (2024 $/MWh)



Land-Based Wind: OSP Modeling Assumptions

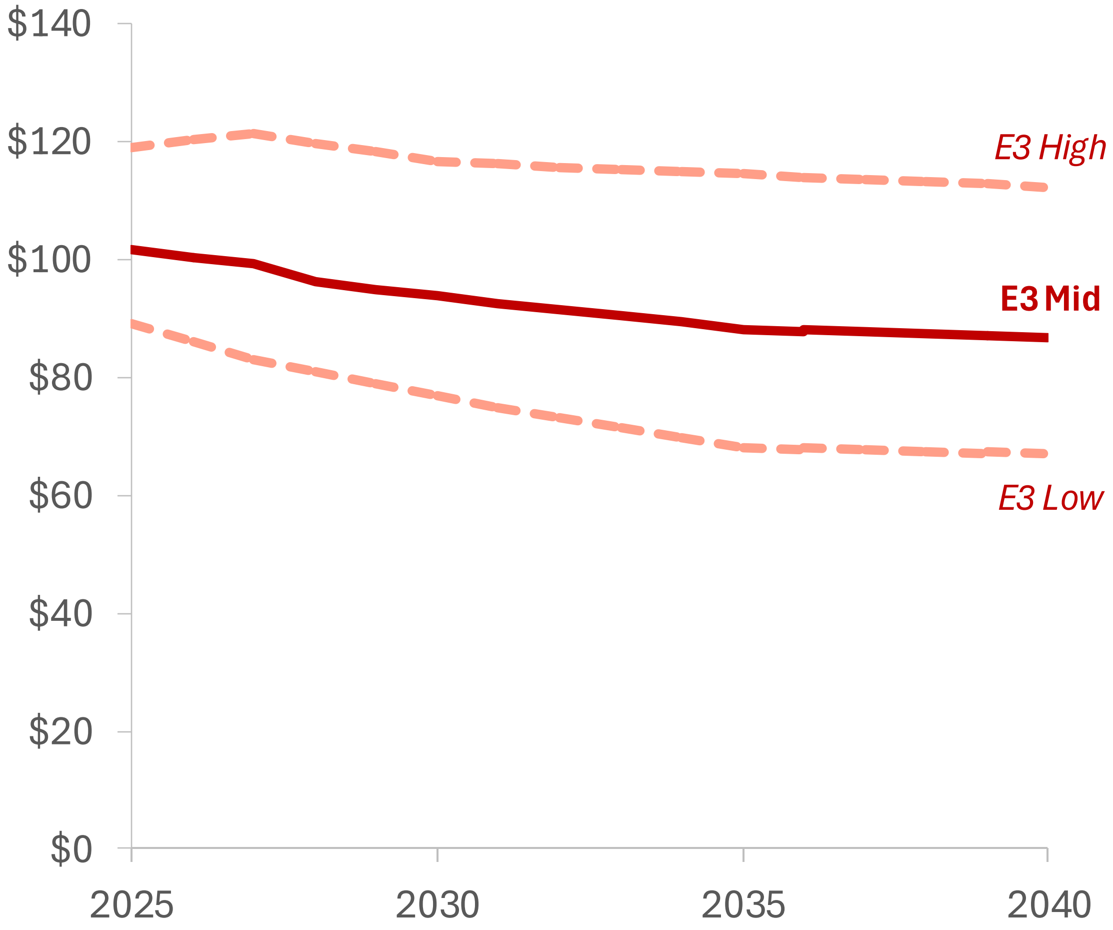
- **Present-day cost assumptions reflect range observed across a range of data sources (with adjustments for California labor & materials costs):**
  - 2024 Annual Technologies Baseline (NREL)
  - 2023 Annual Energy Outlook (EIA)
  - 2024 Levelized Cost of Energy + (Lazard)
  - Land-Based Wind Market Report (DOE)
  - Generation Technology Options – 2024 (EPRI)
- **The High trajectory is derived from NREL ATB assuming exponential cost reductions between present day and 2050; the Low trajectory assumes the CAPEX holds flat in nominal terms throughout 2050**
- **Levelized cost of energy calculated for informational purposes based on standard performance and financing assumptions:**
  - Capacity factor of 33% - 38% for high and low cost trajectories
  - 30 years useful life
  - IRA production tax credit available throughout horizon
  - Costs of debt and equity tied to current market indices



Conventional Geothermal: OSP Modeling Assumptions

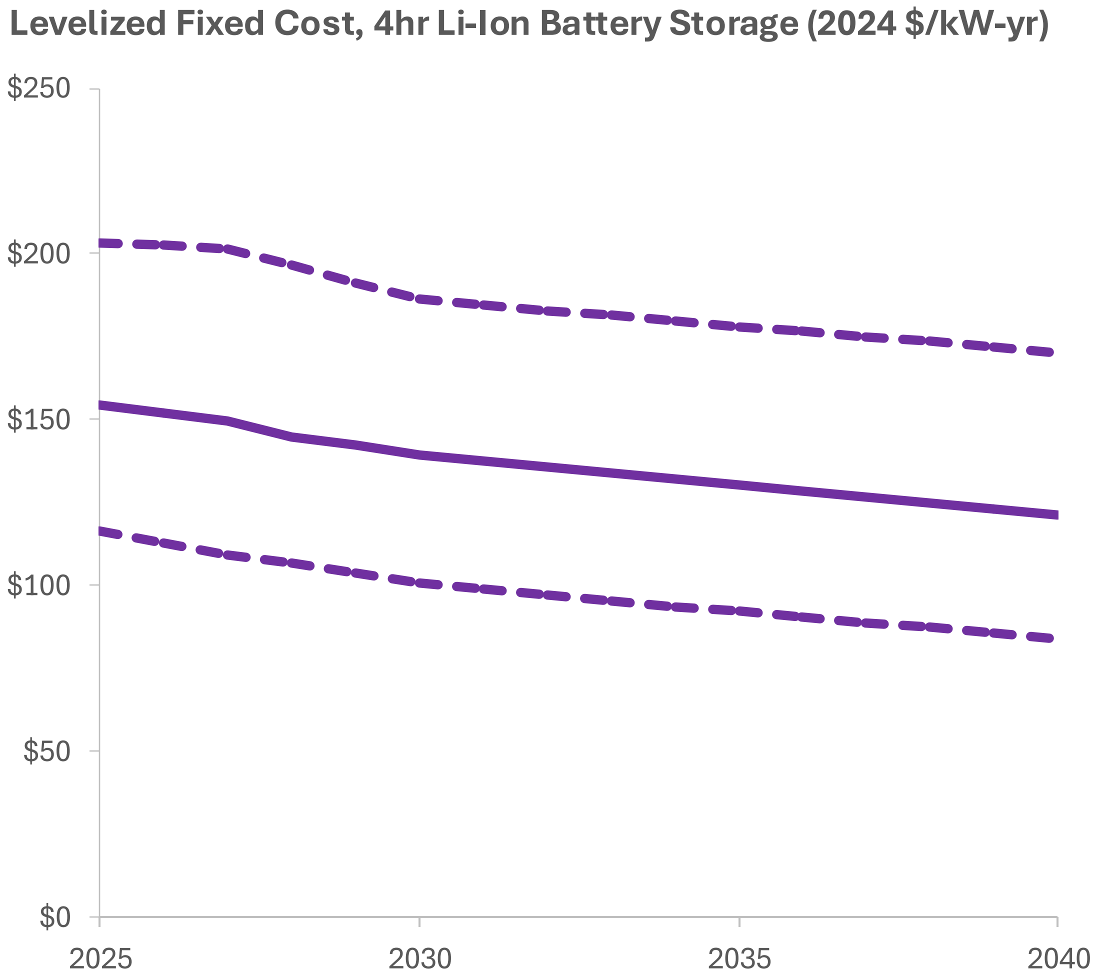
- **Present-day cost assumptions reflect range observed across a range of data sources (with adjustments for California labor & materials costs):**
  - 2024 Annual Technologies Baseline (NREL)
- **Future cost reduction trajectories, derived from 2024 NREL ATB, assume 13% in Mid, 30% in Low and 0.5% in High case between present day and 2035**
- **Levelized cost of energy calculated for informational purposes based on standard performance and financing assumptions:**
  - 80% capacity factor (for E3 Mid) of hydro binary type with a 30-year useful life
  - IRA production tax credit available throughout horizon
  - Costs of debt and equity tied to current market indices

Levelized Cost of Energy, Conventional Geothermal (2024 $/MWh)



Cost assumptions for Lithium-Ion Batteries (Four Hour Duration)

- **E3 benchmarked recent year li-ion CAPEX**
  - 2024 Annual Technologies Baseline (NREL)
  - 2023 Annual Energy Outlook (EIA)
  - 2024 Levelized Cost of Energy + (Lazard)
  - Generation Technology Options – 2024 (EPRI)
  - Energy Storage Cost and Performance Database (PNNL)
- **Cost reduction trajectory for E3 High case is derived from NREL ATB assuming exponential cost reductions between present day and 2050**
- **The E3 Low trajectory assumes the capital cost remains flat in nominal terms through 2050**
- **The Mid trajectory is the average of Low and High**
- **National average costs are adjusted for higher California labor & materials costs**



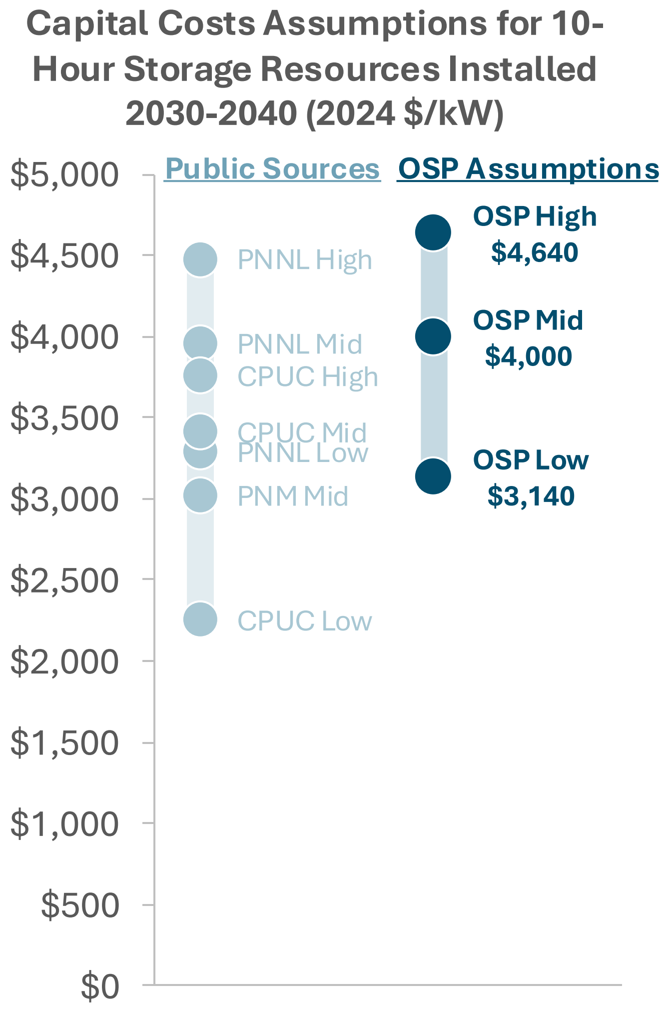
Energy Storage Archetypes Considered in Development of OSP

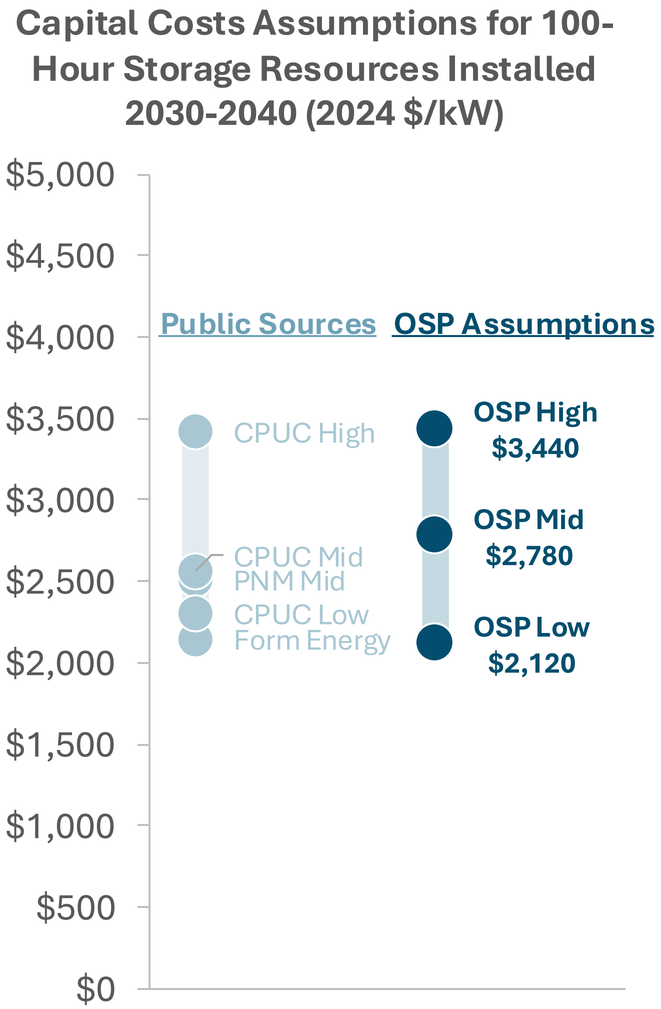
- **The rapidly evolving technology landscape presents a challenge to representing storage technologies in resource planning:**
  - Significant uncertainty in which technologies will mature and at what pace
  - High levels of cost uncertainty
- **For the development of the OSP, three options for energy storage are considered:**
  - **Short-duration lithium-ion batteries (4 hr)**
  - **A generic medium-duration storage resource with 10 hours of duration**
  - **A generic multi-day duration energy storage resource with 100 hours of duration**
- **Use of MDES and LDES archetypes allows exploration of the role of different storage technologies without predetermining a preferred technology prior to a market test**

Characteristic	Lithium Ion Battery	MDES Archetype	LDES Archetype
Duration (hrs)	4	10	100
Round-Trip Efficiency (%)	85%	70%	45%
Min Charging State (%)	10%	10%	10%
Lifetime (years)	20	20	20
2035 Total Capital Cost (2024 $/kW)	**$1,310** ($933 – $1,690)	**$4,000** ($3,140 – $4,640)	**$2,780** ($2,120-$3,440)
2035 Levelized Fixed Cost (2024 $/kW-yr)	**$130** ($92 – $178)	**$310** ($225 – $400)	**$245** ($180 – $330)
Portfolio Suitability	Include as option across all portfolios	Include as option in select portfolios	Include as option in select portfolios

Development of Cost Assumptions, Mid- and Long-Duration Storage Archetypes

+ **Because of a lack of technological maturity, cost data for longer-duration storage resources is inherently sparse and uncertain**
+ **Public data sources span wide ranges and inherently capture varying degrees of technological optimism**
+ **Cost assumptions developed for OSP represent a plausible range of market outcomes by 2035:**
  - **High:** limited technological improvements from today; low likelihood that technology will be competitive with alternatives
  - **Mid:** evolutionary technological improvements that enable market readiness
  - **Low:** technology breakthrough that allows competition with existing mature technologies





Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel Meeting #7

December 16, 2024

Energy+Environmental Economics

Nick Schlag, Partner
Mike Sontag, Director
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Sr. Managing Consultant

Agenda

- **Summary of key findings from preparatory studies**
- **Brief update on DR and Flexible Load Study**
- **Glenarm Conversion and Replacement**
  - Replacement portfolio analysis
  - Conversion pathways

Optimized Strategic Plan: Study Workflow

Technical Analysis

Phase 1
Preparatory Studies

Identify and characterize all potential resource options

- Distributed Solar and Storage
- New & Emerging Tech
- Demand Response + Flex Loads
- Transmission Options

Phase 2
Portfolio Development

Use detailed power system modeling to construct multiple portfolios that meet clean energy goals and maintain reliability

- Glenarm Conversion/ Replacement
- Long-Term Capacity Expansion

Phase 3
Impact Assessment

Calculate cost metrics; identify feasibility concerns, dependencies, and risks of each portfolio

- Cost Impacts
- Production Cost Modeling
- Distribution System Analysis

Synthesis

Result
Optimized Strategic Plan

Informed by technical analysis, develop an action plan.

- Action Plan/ Final Report

Highlights from Preparatory Studies

Technical Analysis | **Synthesis**

Phase 1

Preparatory Studies

Identify and characterize all potential resource options

Distributed Solar and Storage

- ✓ Potential for ground-mount solar within the city is severely limited by land use constraints (10 MW_{AC}).
- ✓ Potential for rooftop and parking canopy solar is much more significant (470 MW_{AC})

New & Emerging Tech

- ✓ Wind, solar, and battery storage are carbon-free resources commercially available today. These technologies have experienced recent upward cost pressures.
- ✓ Emerging long-duration energy storage technologies are unlikely to reach commercial viability before the early 2030s.
- ✓ Deploying hydrogen for peaking capacity is technically feasible but will require technological advancement and significant new infrastructure development.

Demand Response + Flex Loads

- ✓ Demand response and managed EV charging can reduce the need for incremental generation and distribution capacity.
- ✓ AMI deployment will be critical for scaling this resource.

Transmission Options

- ✓ In the near term (by 2030), increasing import capacity poses a significant challenge due to the long-lead times and multistakeholder approval processes for transmission projects.
- ✓ Upgrading TM Goodrich is a critical long-term decision for PWP which will have significant implications for the system for the remainder of the century.

Demand Response & Flexible Loads

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Demand Response and Flexible Loads Study Recap

Previously…

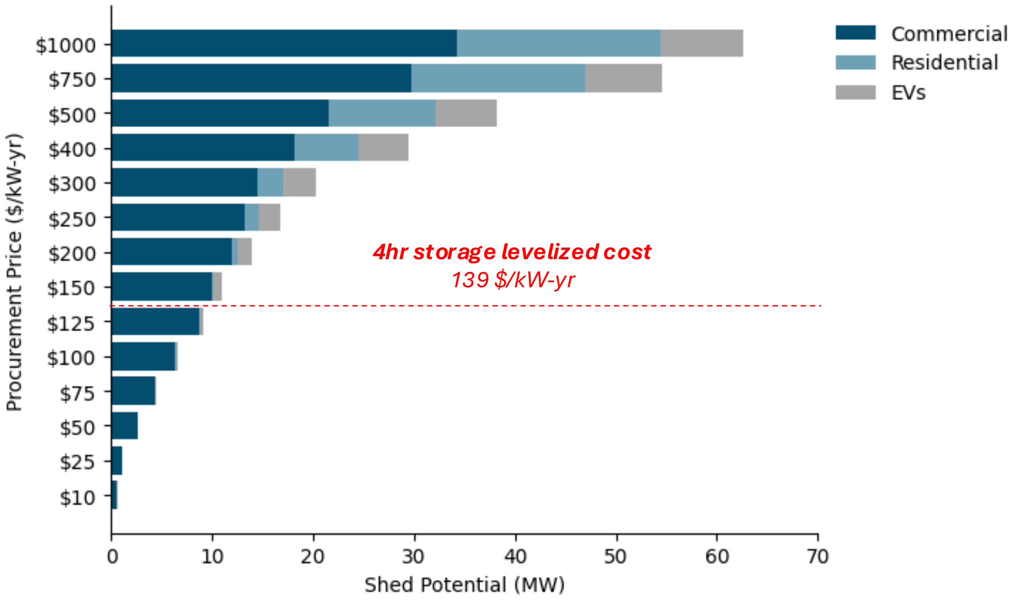
+ Presented shift and shed demand response supply curves.
+ TAP provided feedback that PWP should model high DR and load flexibility scenarios.

Today…

+ Deep dive on managed EV charging and impact on PWP's load forecast.
+ Range of load flexibility sensitivities modeled in the Portfolio Development phase of the OSP.

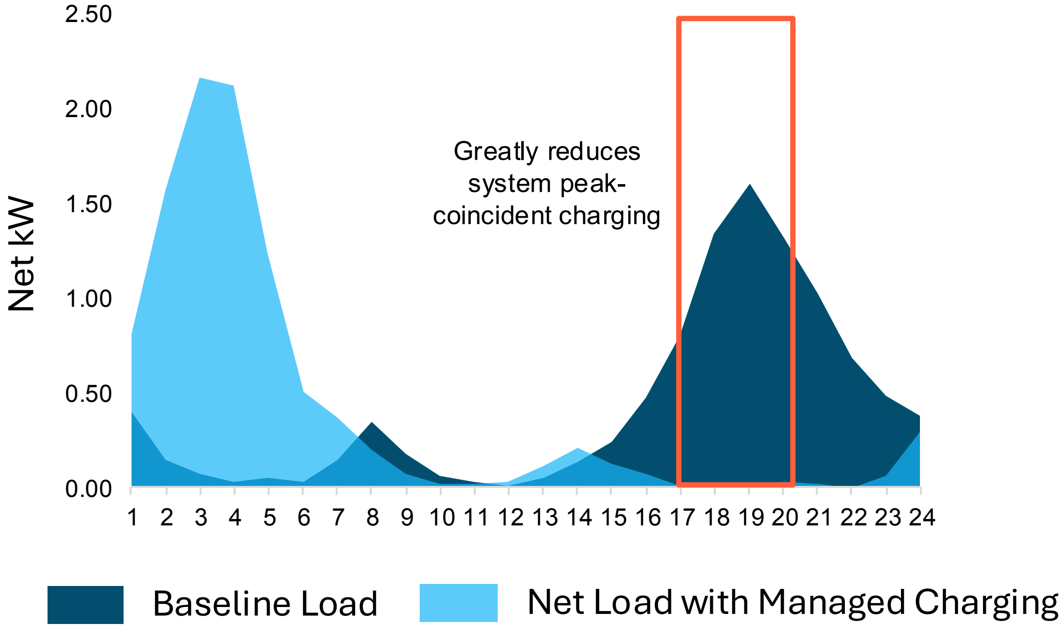
2030: Pasadena Shed DR Potential by Customer Grouping

Procurement Price ($)



Managed electric vehicle charging overview

+ **In addition to Demand Response and BTM Solar/Storage, managed EV Charging is another key demand side resource.**
+ **Two key goals for managed EV charging include:**
  - Supporting the grid and reducing electric system costs for accommodating electrification.
  - Lowering the costs of EV ownership and operation.
+ **A range of technologies are needed to enable and scale managed charging.**
  - Advanced Metering Infrastructure is foundational.
+ **The managed charging resource can be procured though several pathways including:**
  - Retail rates
  - Demand response programs
  - Customer education programs
  - Virtual Power Plants / 3rd party aggregated demand management providers



+ **Retail rates are the most readily available pathway for enabling managed charging and a large portion of the resource can be accessed via this pathway.**

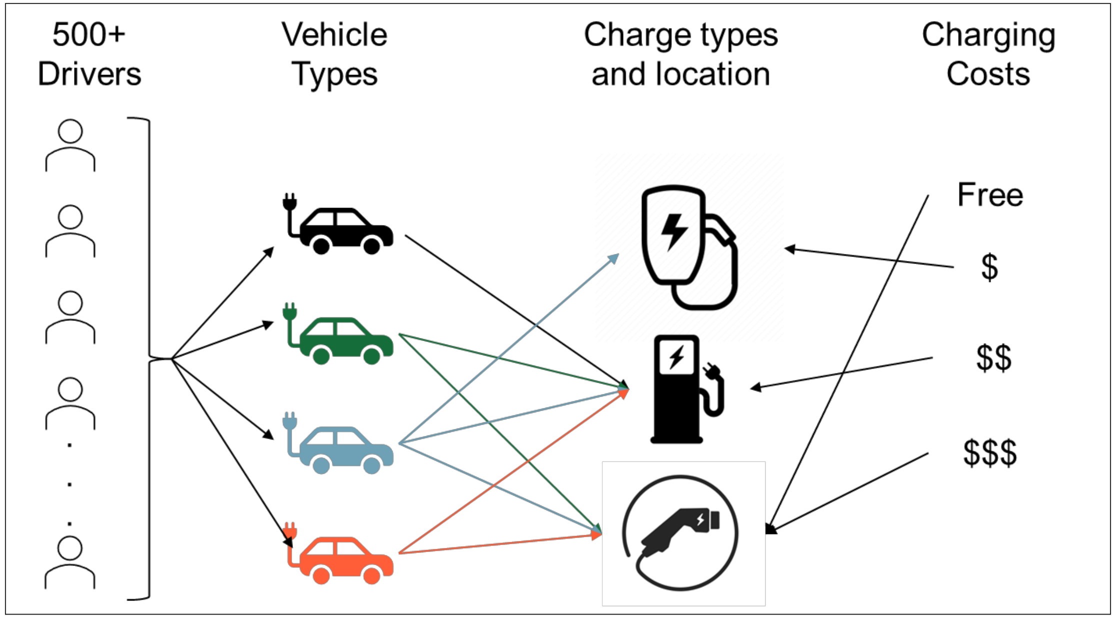
EV charging load shape modeling

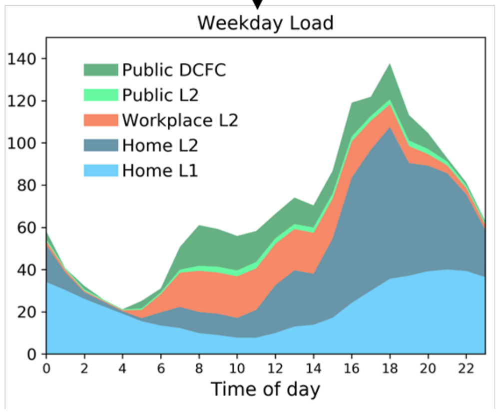
E3's RESHAPE-EV model

E3's RESHAPE-EV model generates diversified EV charging load shapes considering the driving pattern of thousands of drivers and characteristics of the driver population including charger access, vehicle types, and cost to charge vehicles in various locations.

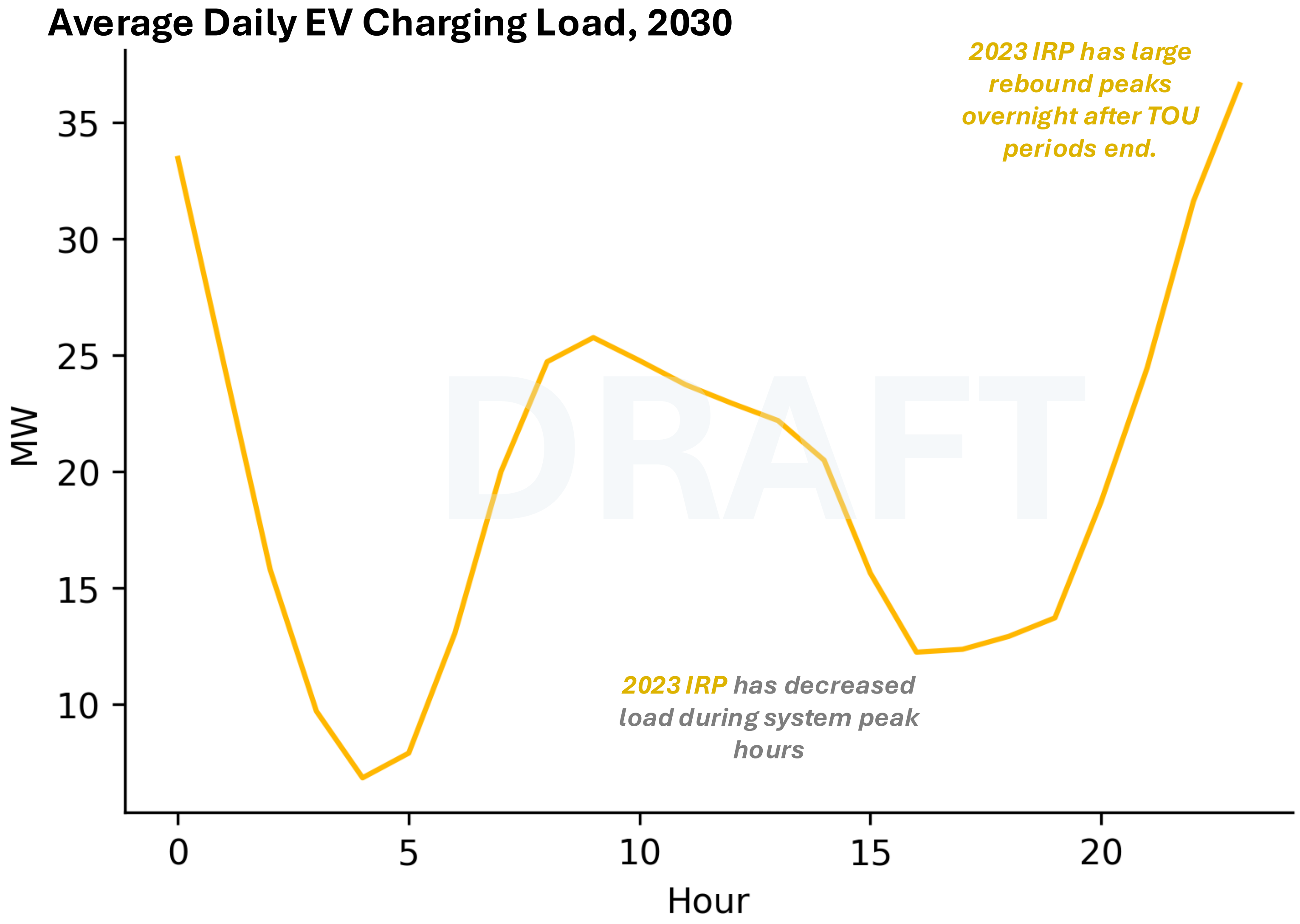
E3's RESHAPE-EV model can be leveraged to model custom scenarios of EV charging load shapes:

+ **Base or unmanaged charging load shapes are created based on drivers' travel needs and access to different charger types.**
+ **Managed charging load shapes are then developed by optimizing load in response to price signals, such as time-of-use rates, wholesale market prices, or utilities' avoided costs.**
+ **Managed charging can be passive, in response to time varying rates, or active with participation in demand response programs.**





Transportation electrification load shapes



+ **2023 IRP** is derived from the California Energy Commission's 2022 Integrated Energy Policy Report Update (IEPR) IEPR load shapes generally assume **75-85%** of customers are price responsive.

Managed charging uptake with opt-in time-of-use

Opt-in TOU participation rates are low. Managed charging behavior amongst customer enrolled in TOU rates is high.

% of residential customers enrolled in a TOU rate

1.7% (Utility Dive, 2019)
3% (Brattle, 2019)
5% (American Public Power Association, 2019)

*Average = **3%***

% of customers managing charging on a TOU rate

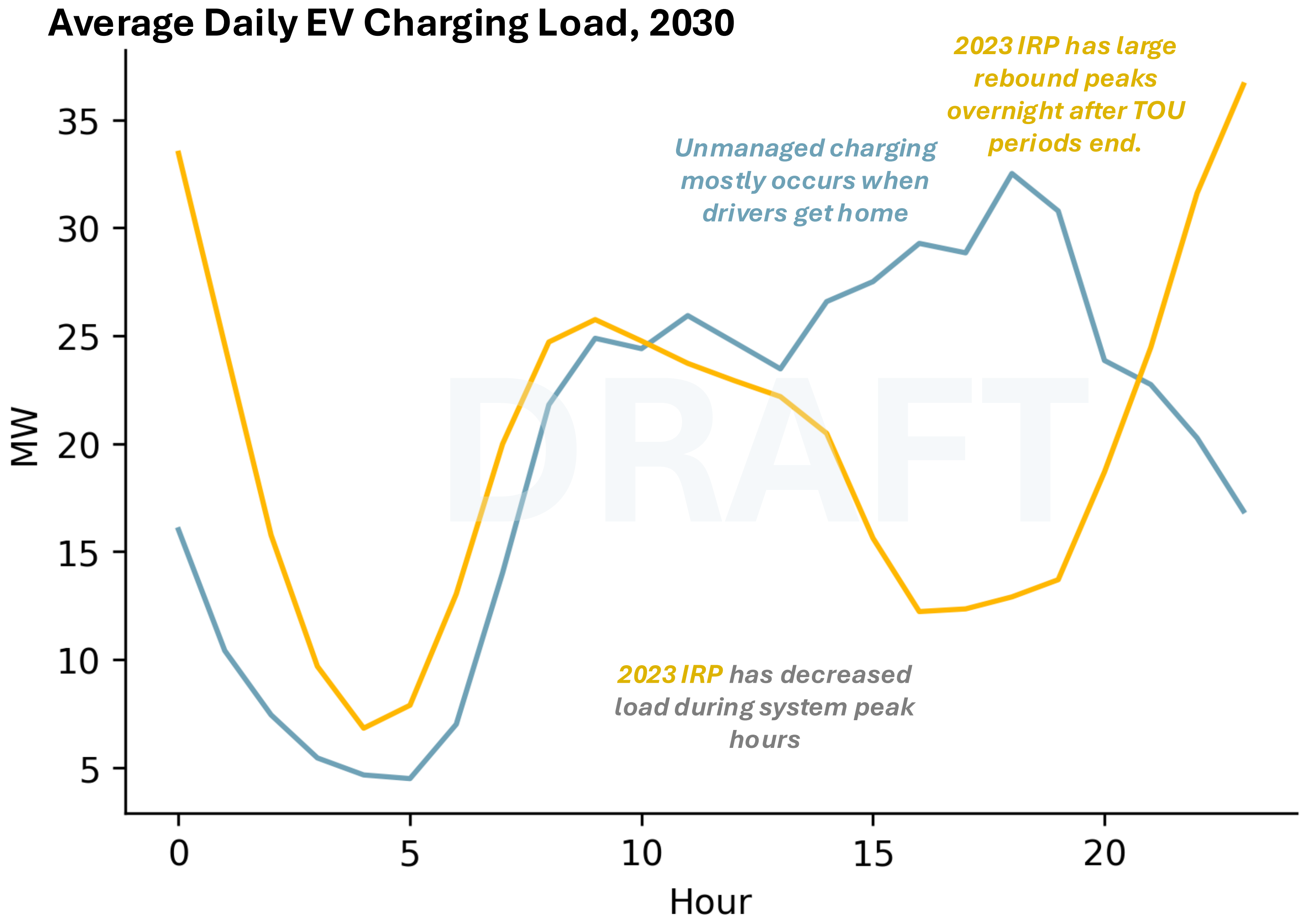
50% (Uplight, 2024)
68% (National Bureau of Economic Research, 2024)
72% (Enel X Way, 2020)
80% (E3 assumption used in various projects)

*Average = **68%***

*Percentage of all residential customers managing their charging = 3% * 68% = **2%***

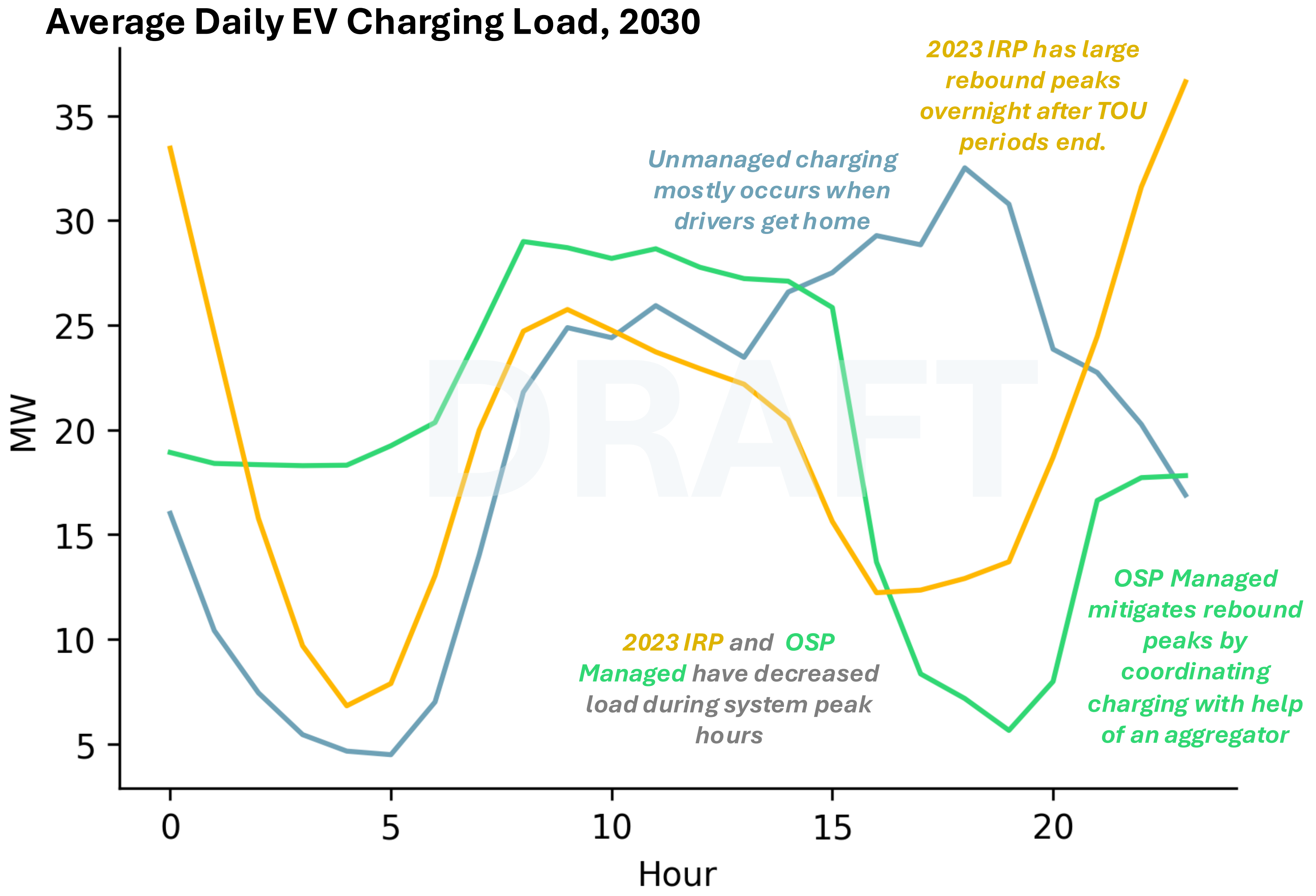
In an opt-in regime, customer must choose to be billed according to TOU rates while in an opt-out regime, customers are automatically enrolled in a TOU and must choose to be billed under a flat rate or other tariff structure.

Transportation electrification load shapes



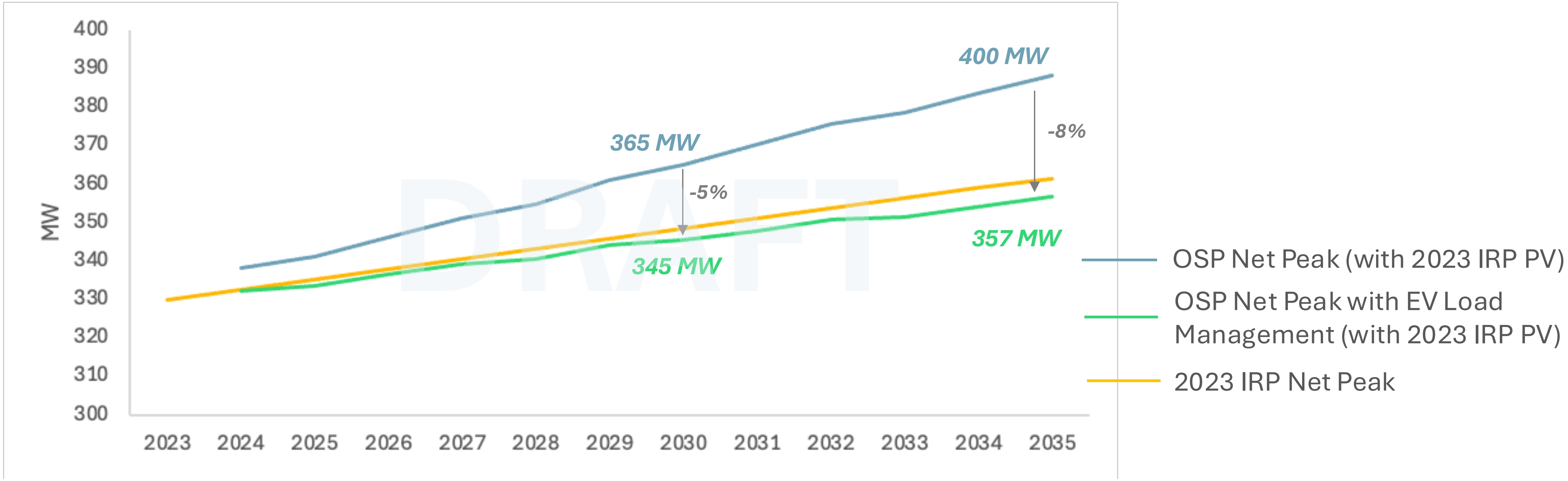
- **2023 IRP** is derived from the California Energy Commission's 2022 Integrated Energy Policy Report Update (IEPR) IEPR load shapes generally assume **75-85%** of customers are price responsive.
- **OSP Forecast** is E3's modeling reflecting the expected uptake of managed charging with opt-in TOU rates of **2%.**

Transportation electrification load shapes



- **2023 IRP** is derived from the California Energy Commission's 2022 Integrated Energy Policy Report Update (IEPR) IEPR load shapes generally assume **75-85%** of customers are price responsive.
- **OSP Forecast** is E3's modeling reflecting the expected uptake of managed charging with opt-in TOU rates of **2%.**
- **OSP Managed Forecast** is E3's modeling reflecting **100%** customer responsiveness to TOU rates and a **VGI aggregator** coordinating charging.

Transportation electrification load impacts with charging management



+ **With highly managed EV charging, where 100% of drivers respond to time-of-use rates and a VGI aggregator coordinates charging, peak load growth from electrification could be significantly mitigated.**
  - The 2023 IRP forecast relied upon IEPR which assumed 75-85% of drives of responsive to time-of-use rates.
+ **Without managed charging, system peak load could be much higher than the scenario with managed charging.**
+ **Additional uncertainties in load growth not modeled include new large customers (e.g. data centers).**

Demand Response and Load Flexibility Sensitivities in the OSP, 2031

Unmanaged

Load forecast: OSP Forecast

Demand response:
Shed: 0 MW
Shift: 0 MW

Managed EV + DR

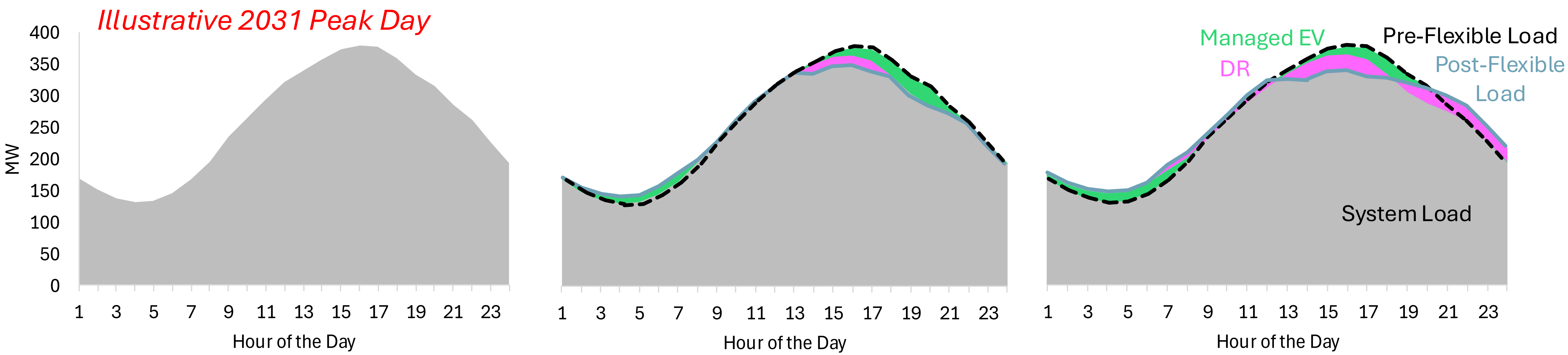
Load forecast: OSP Managed (~20 MW)

Demand response:
Shed: 11 MW
Shift: 4 MW

Managed EV + High DR

Load forecast: OSP Managed (~20 MW)

Demand response:
Shed: 38 MW
Shift: 11 MW



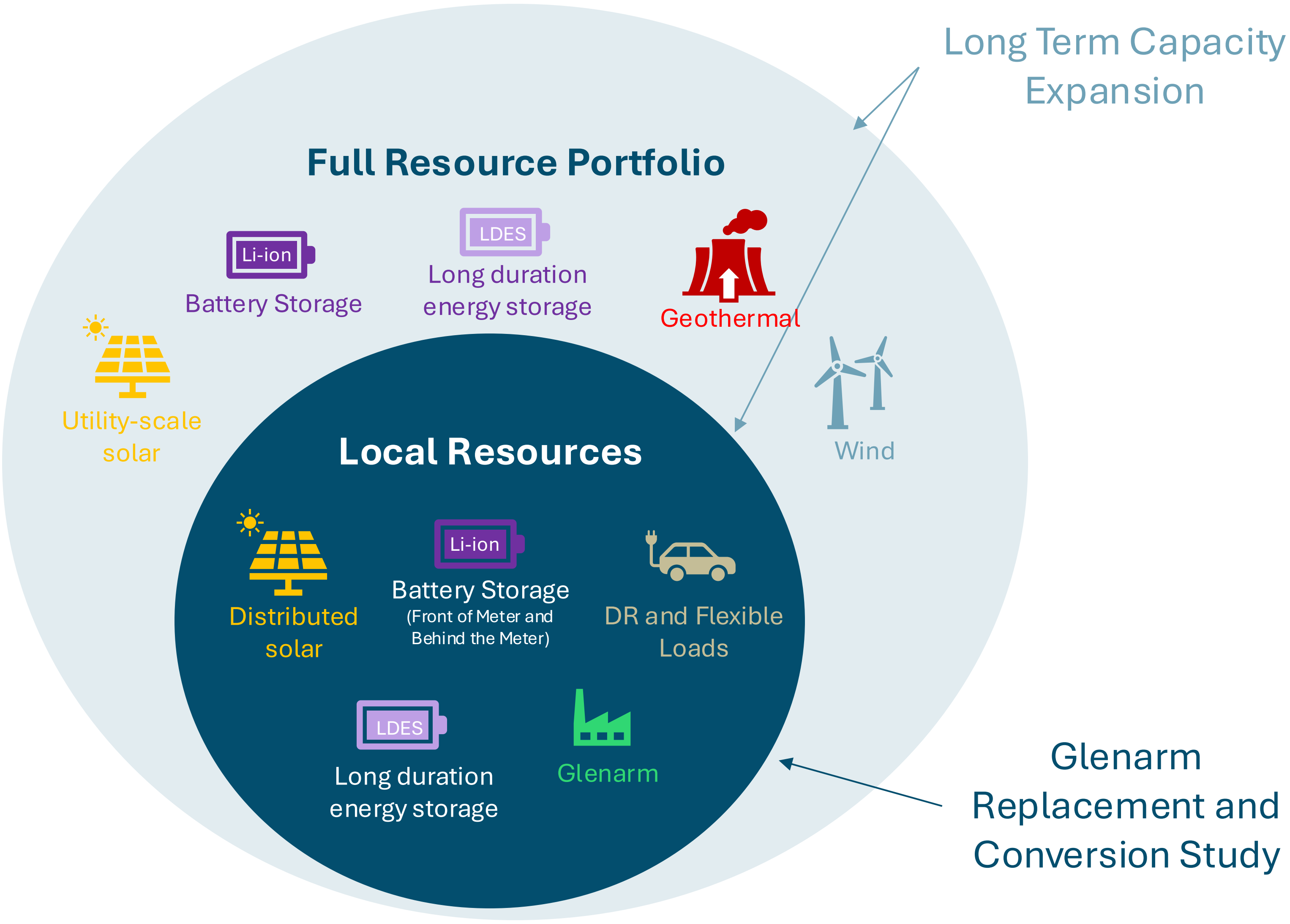
Update on Glenarm Conversion & Replacement Analyses

Energy+Environmental Economics

Portfolio Development Process

Portfolio development process comprises two phases of analysis:

1. **<u>Glenarm Replacement and Conversion Study:</u> Identify a range of internal resource solutions to meet local reliability needs of PWP system given limitations of transmission system**
   - Focus on a single specific challenge on the path to Resolution 9977 goals
   - **Not yet considering relative cost of different options**
2. **<u>Long-Term Capacity Expansion:</u> Create complete resource portfolios that consider objectives of clean energy, reliability, affordability, and equity**
   - Focus on holistic view of resource portfolio to support Resolution 9977 goals



Scope of Glenarm Conversion & Replacement Study

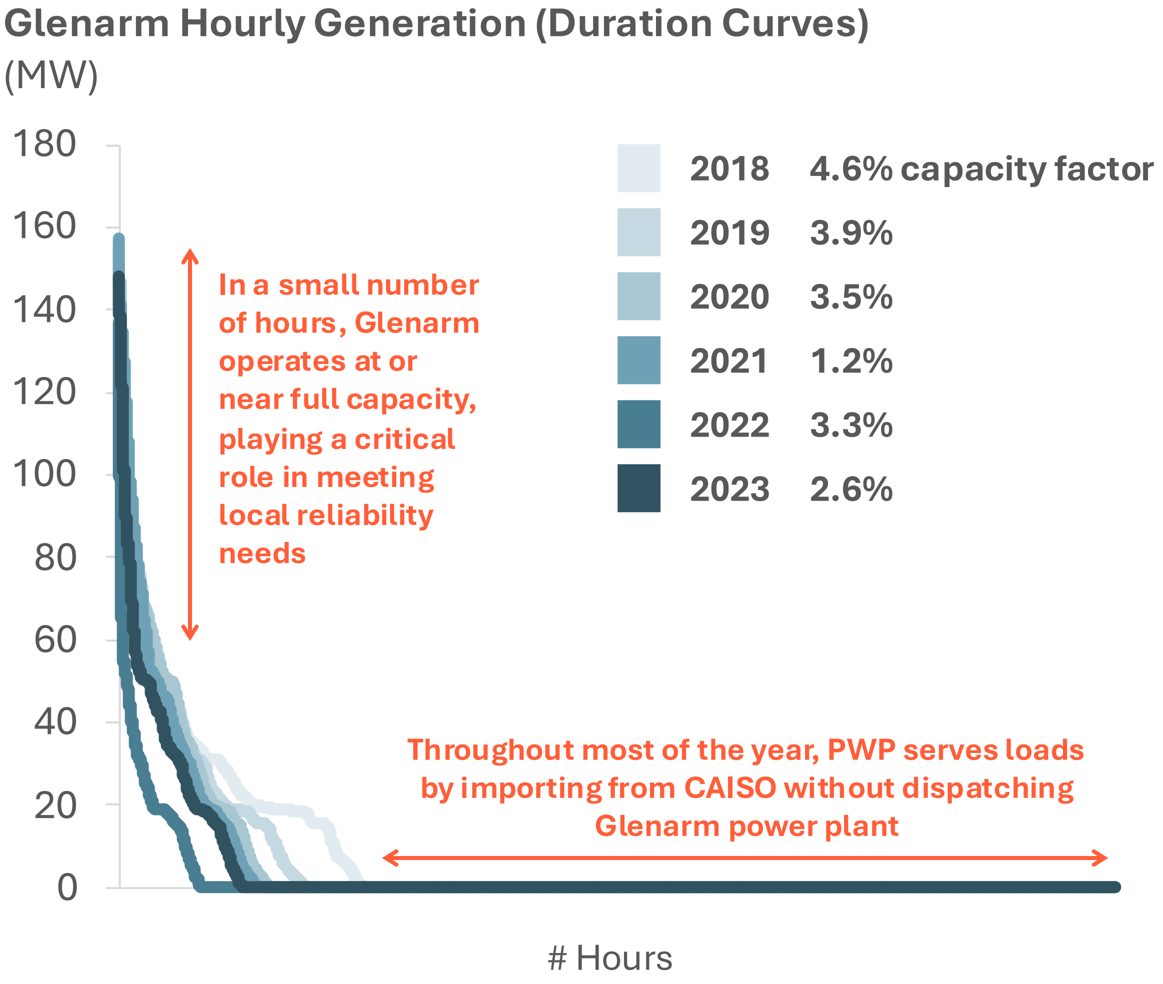
- **Pasadena's Glenarm Power Plant is a 200 MW peaking facility comprising five units fueled by natural gas**
- **While operations of Glenarm are limited (<5% annual capacity factor), the power plant plays a crucial role in maintaining local reliability**
- **Achieving PWP's goals of carbon-free supply requires a long-term transition plan for Glenarm that either:**
  1. Results in continued operations in a limited fashion using a carbon-free fuel
  2. Provides for the replacement of Glenarm with a portfolio of local resources that results in comparable levels of local reliability

Step	Approach
Development of Replacement Portfolios	Use loss-of-load-probability modeling to identify alternative generation portfolios that yield similar levels of reliability within PWP system
Review of Regulatory Considerations	Review requirements associated with PWP's participation in CAISO market
Options for Hydrogen Conversion	Assess infrastructure investments needed to convert Glenarm to H2, including pilot project and milestones

Local System Reliability Analysis

Energy+Environmental Economics

A Historical Perspective on the Role of Glenarm



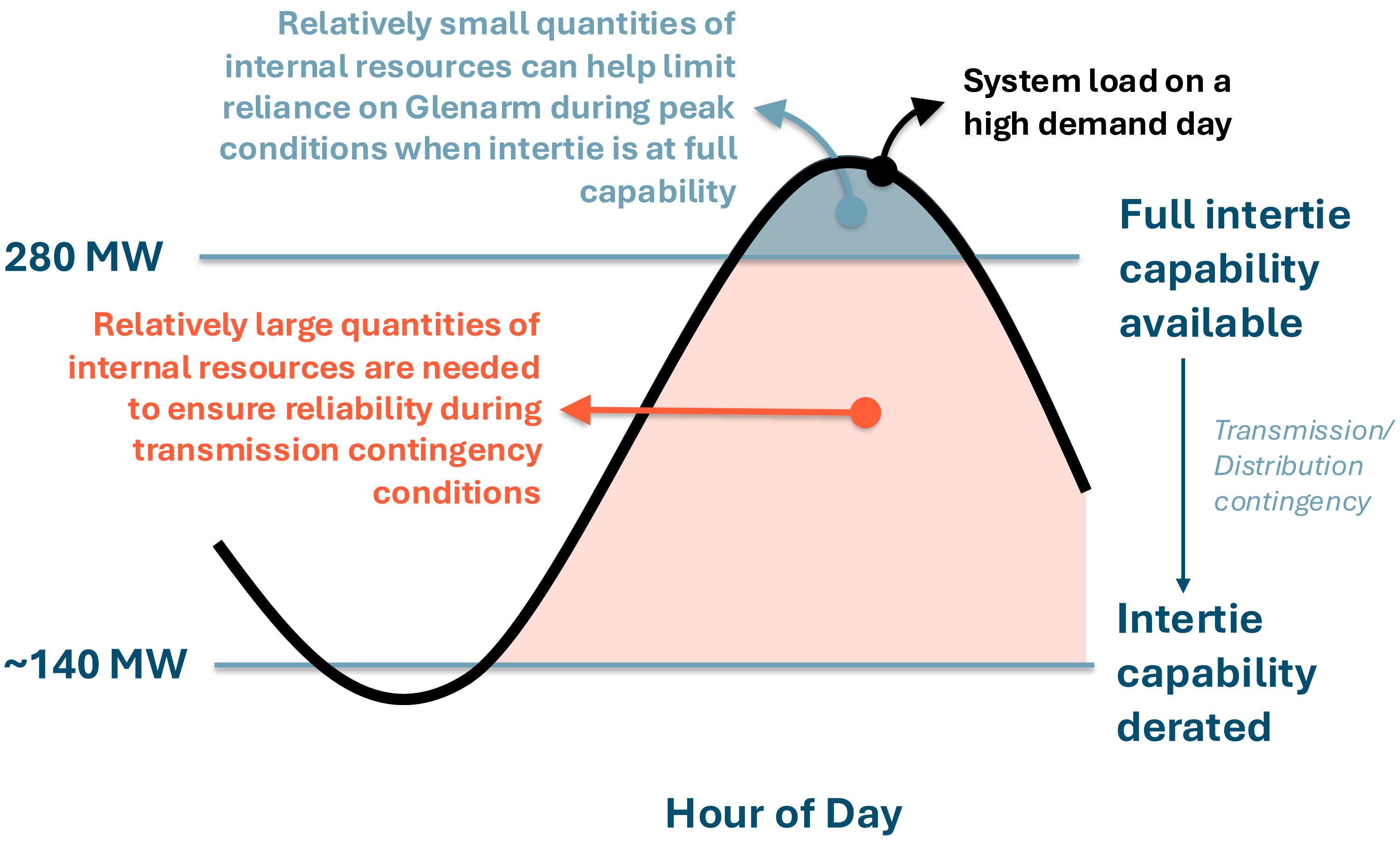
- **Historical operational patterns of Glenarm Power Plant consistent with a resource whose primary purpose is supporting reliability:**
  - Low capacity factor, frequently not operated
  - Dispatched up to full capacity in a select number of hours per year
- **Conditions that currently require operations of Glenarm:**
  - Peak demand conditions (above import capability)
  - Transmission/distribution contingencies
  - High wholesale electricity prices in California Independent System Operator (CAISO)
  - CAISO resource deficiencies

A long-term reliability solution will require local resources that can operate reliably under very specific circumstances

Visualizing Reliability Needs for Internal Generation

Maintaining reliability in Pasadena's service territory requires internal resources that can meet needs under a range of extreme conditions:

1. During peak demand conditions (above import capability)
2. During transmission or distribution contingencies that reduce intertie capability



Three Frames for Internal Reliability Analysis

Augment Glenarm	What internal resources are needed to meet growing loads while **maintaining reliability if Glenarm remains in service**?
Mitigate Glenarm	*What additional internal resources can **mitigate the need to operate Glenarm** under "normal" operating conditions (i.e. when import capability is available up to full 280 MW)?*
Replace Glenarm	What are the total resource needs to **maintain reliability even in the event of transmission contingency**?

Internal resources considered

Solar

Storage

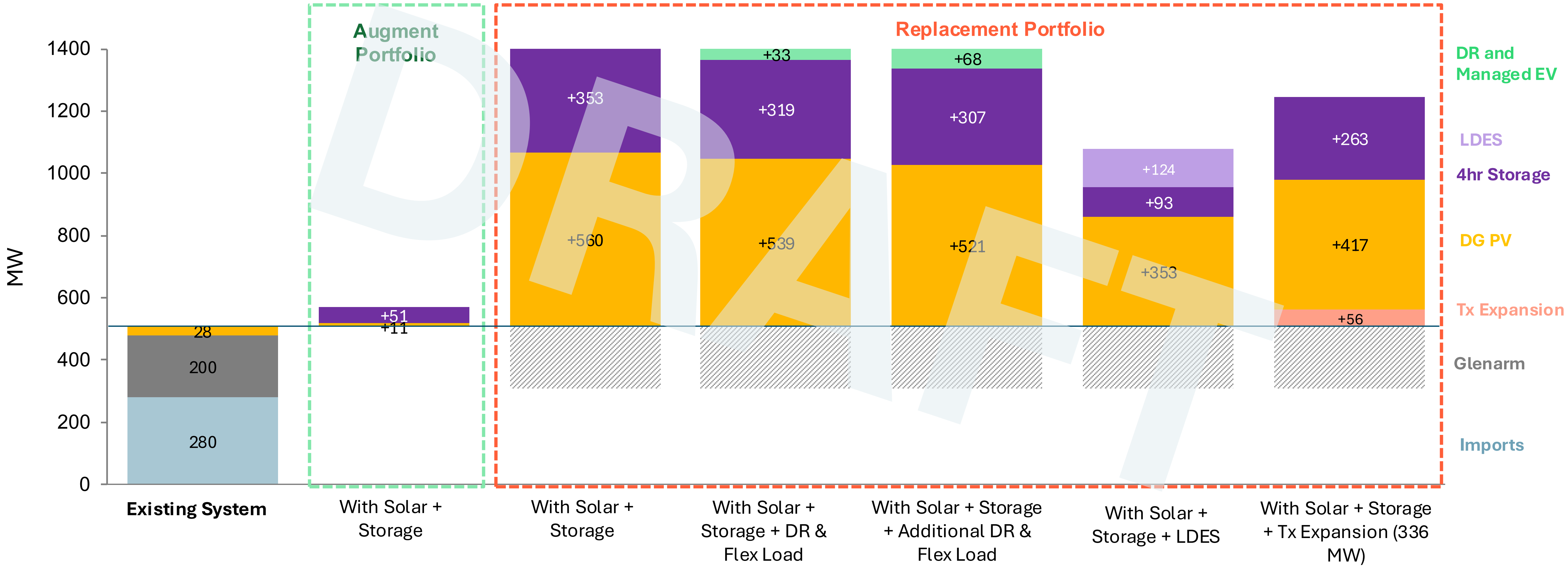
Increased Load Flexibility & Managed Charging

Long Duration Storage

Sensitivities also explore increased import capability

Glenarm Replacement Portfolio Summary

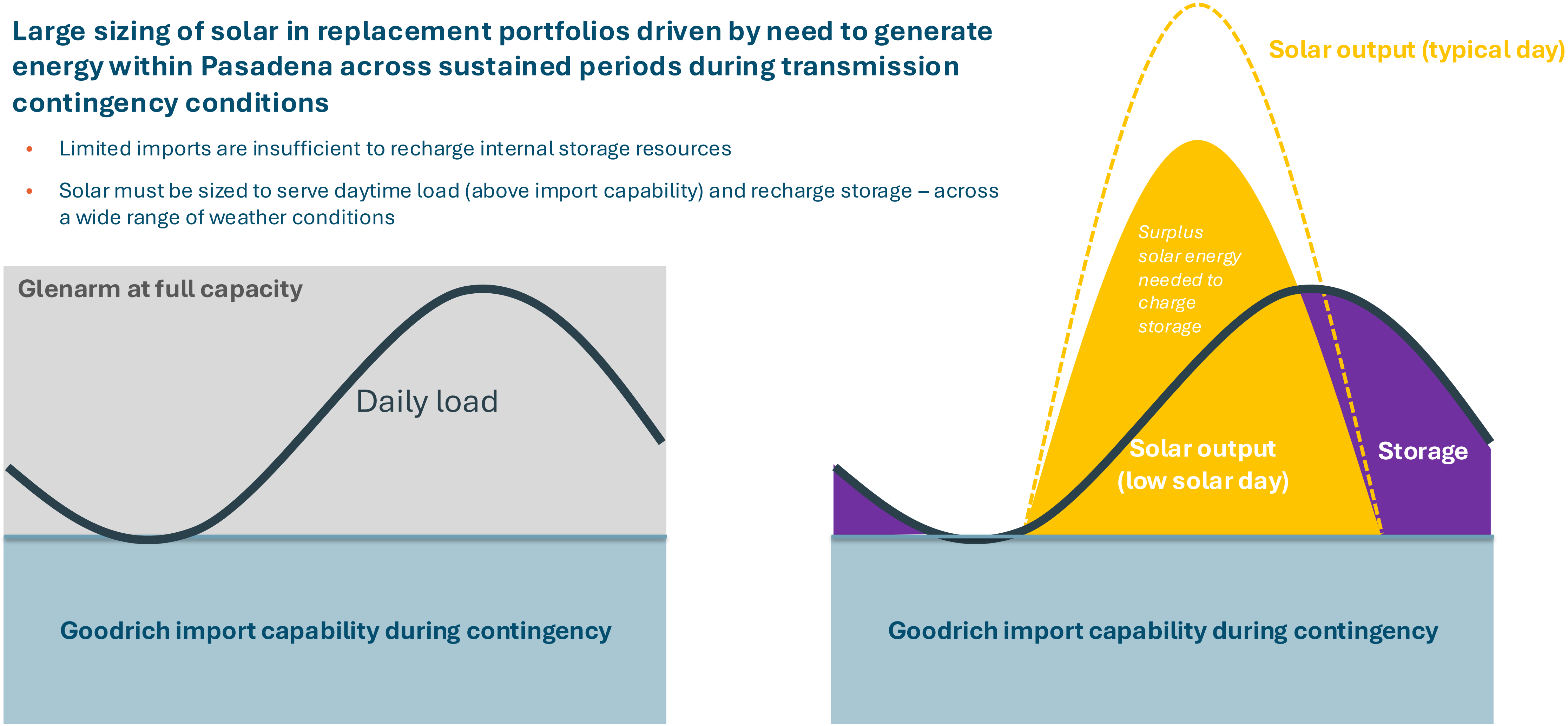
Glenarm Supplement and Replacement Portfolios, *Incremental Nameplate MW*



These values represent the minimum quantities of resources needed to ensure local reliability. Additional local resources will be included in portfolios to the extent that (a) the rate of naturally occurring customer adoption exceeds this level or (b) additional resources are found to be economic in LTCE. E3's modeling indicates that naturally occurring adoption could result in an additional ~35 MW of customer-owned resources by 2031.

Visualizing Resource Needs for Internal Reliability

- **Large sizing of solar in replacement portfolios driven by need to generate energy within Pasadena across sustained periods during transmission contingency conditions**
  - Limited imports are insufficient to recharge internal storage resources
  - Solar must be sized to serve daytime load (above import capability) and recharge storage – across a wide range of weather conditions



System with Glenarm in Service | **System with Replacement Portfolio**

RECAP: E3's Renewable Energy Capacity Planning model

+ **RECAP is a loss-of-load-probability model that uses a <u>time-sequential simulation</u> approach to assess the availability of supply to meet system needs on an <u>hour-to-hour</u> basis**
  - Simulation approach designed to focus on challenges resulting from increasing penetrations of variable & energy-limited resources
+ **Each simulation analyzes conditions across hundreds or thousands of possible years using a Monte Carlo approach to capture year-to-year variations in:**
  - Underlying weather, load, wind & solar profiles
  - Power plant outage patterns
  - Energy-limited resource dispatch
+ **Primary results include an array of indicators of system resource adequacy, including statistics of <u>loss of load frequency, duration, and magnitude</u>**

*Key correlations between **load and variable** resources preserved*

System Demand
simulated hourly demand across a range of weather conditions

Variable Resource
simulated with weather-matched hourly profiles (including BTM PV)

Firm Resources
simulated based on rated capacity and outage rates

Transmission Capability
represented under contingency conditions

***Energy-limited resources** dispatched time-sequentially*

Storage Resources
dispatched according to limits on duration and round-trip losses

DR Programs
dispatched subject to limits on number of calls & duration

Unserved Energy
identified based on any unmet demand

Process for Developing Alternative "Replacement" Portfolios

Evaluate local reliability of current PWP system (2024)

Calculate reliability metrics to establish reliability baseline

Include simulations of hourly load & outages at Glenarm consistent with historical levels

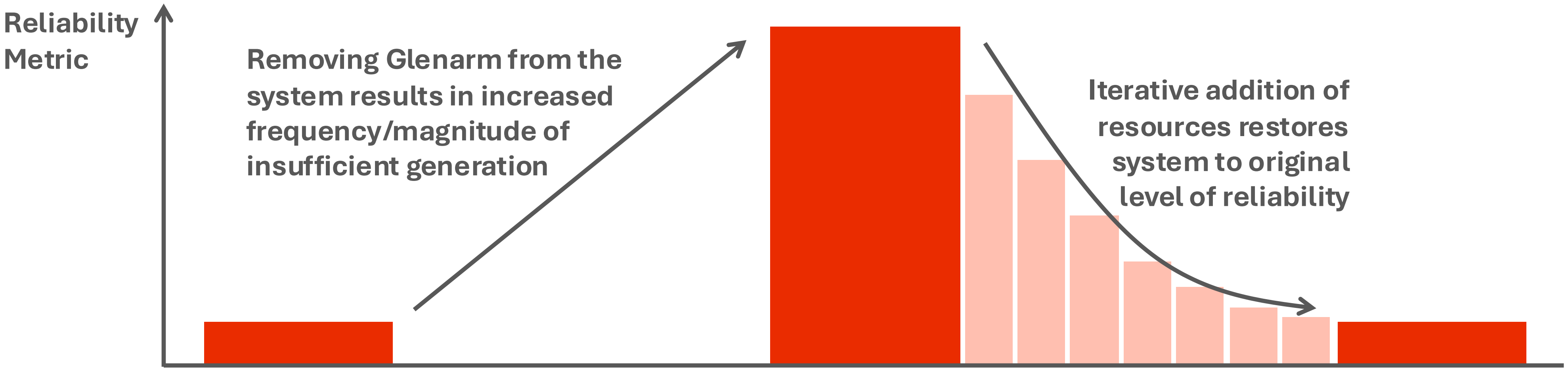
Remove Glenarm and rerun LOLP simulations in 2031

Frequency and magnitude of unserved energy events increases, particularly during peak periods and outages at Goodrich

Add portfolios of new resources to restore original level of reliability

Add solar, storage, flexible load resources, as well as EV load management until reliability is restored

Maintain same sampling of load and outage conditions as Step 1

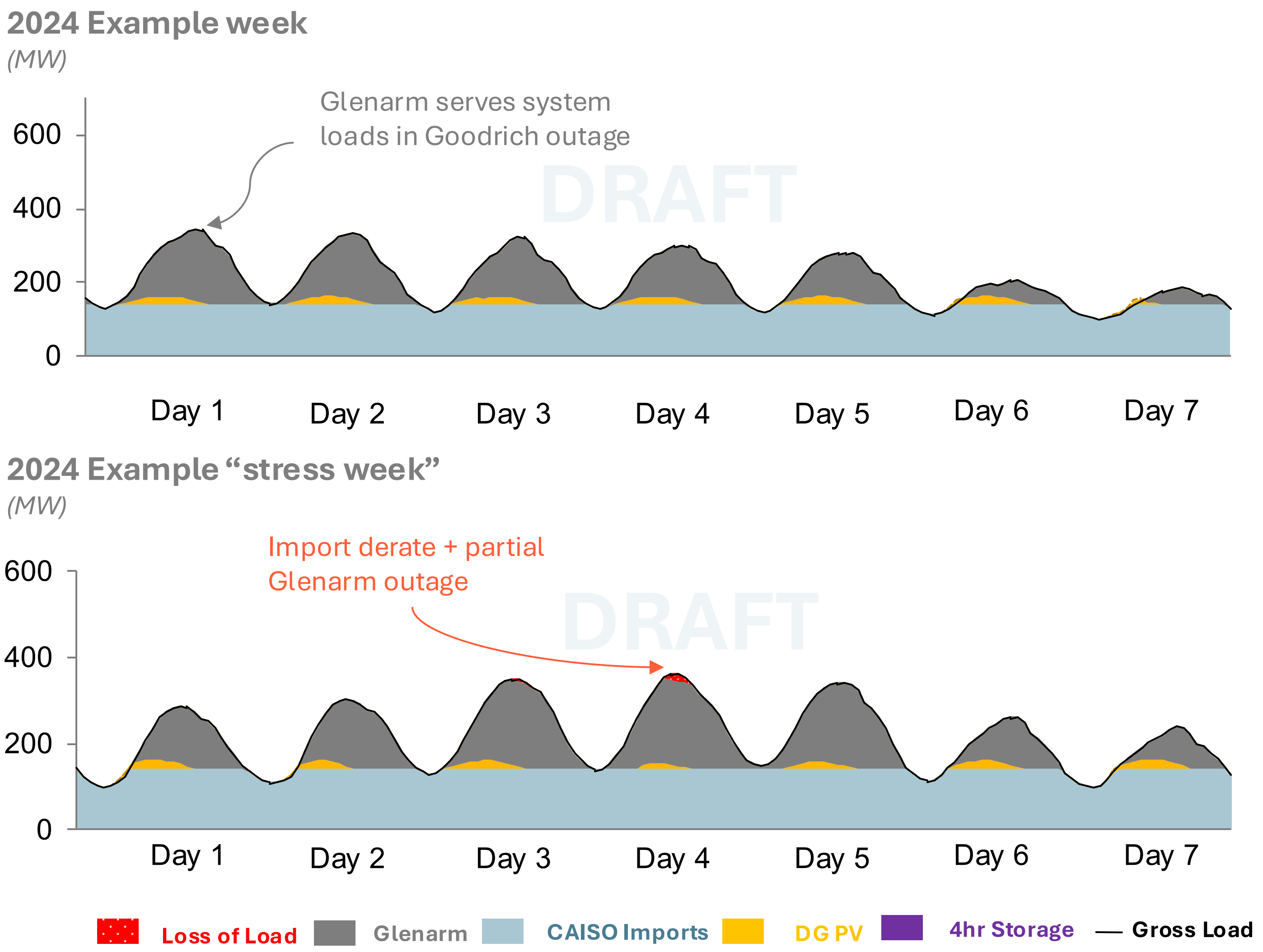


Snapshot Simulated Weeks during TMG Outage

The 2024 PWP system is simulated with reduced intertie capacity across 500 years of conditions. Across this sample:

5	Number of days per year on which a reduction in import availability at Goodrich would put the system at risk of loss of load
441	Total amount of load shed (MWh) across reliability events that occur during Goodrich outages

Reliability events are most likely to occur on the days of highest peak demand when at least one unit at Glenarm experiences an outage



Additional Internal Resource Needs to Maintain Reliability with Glenarm

The 2031 PWP system is simulated across the same 500 years of conditions *with Glenarm present*. Across this sample:

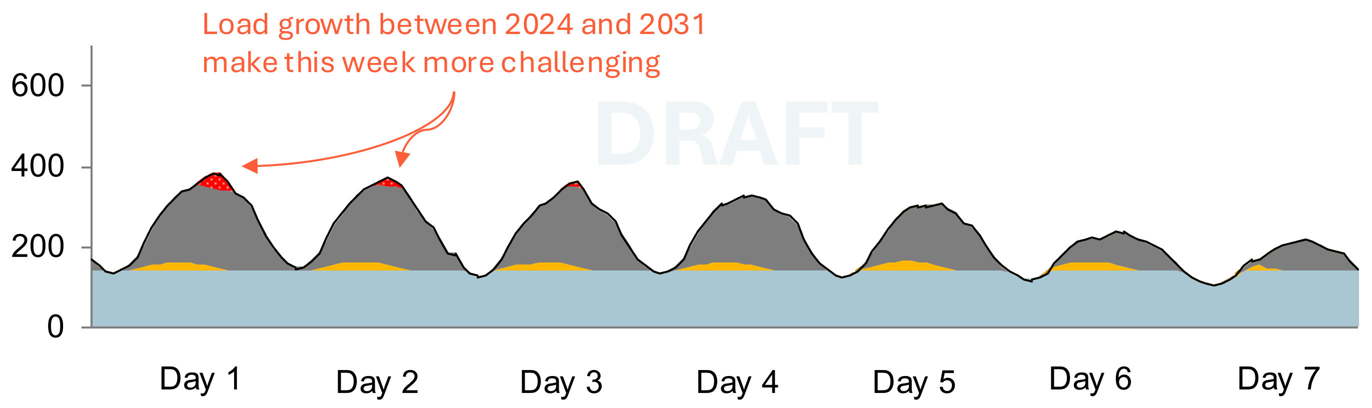
17 Number of days per year on which a reduction in import availability at Goodrich would put the system at risk of loss of load without internal generation resources (a *3x* relative to the 2024 baseline)

1,777 Total amount of load shed (MWh) across reliability events that occur during Goodrich outages (4x to 2024 baseline)

With forecasted load growth, additional internal resource are need to meet loads on summer days even when Glenarm is in service

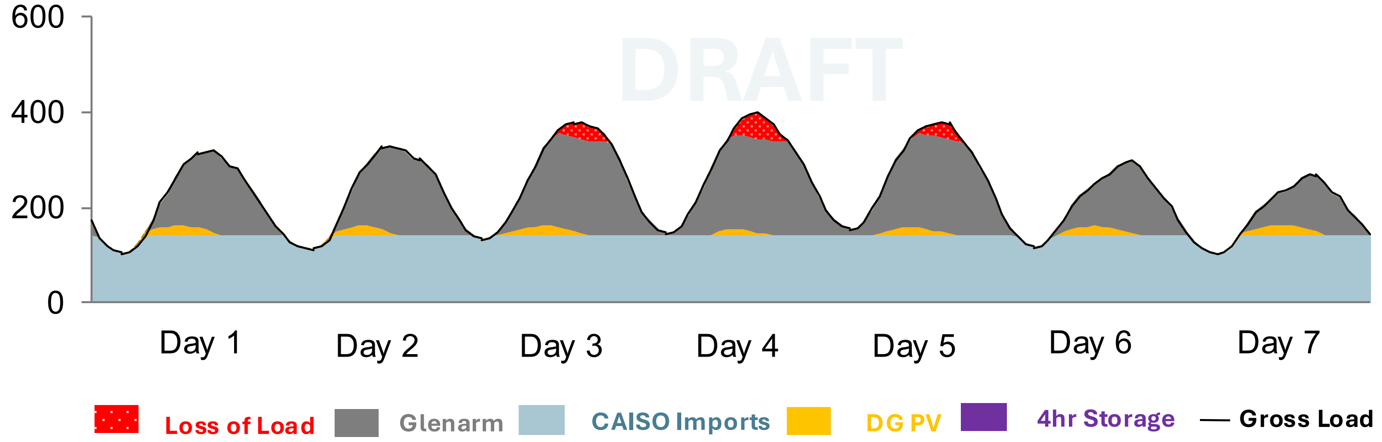
2031 Example week with Glenarm

(MW)



2031 Example "stress week" with Glenarm

(MW)



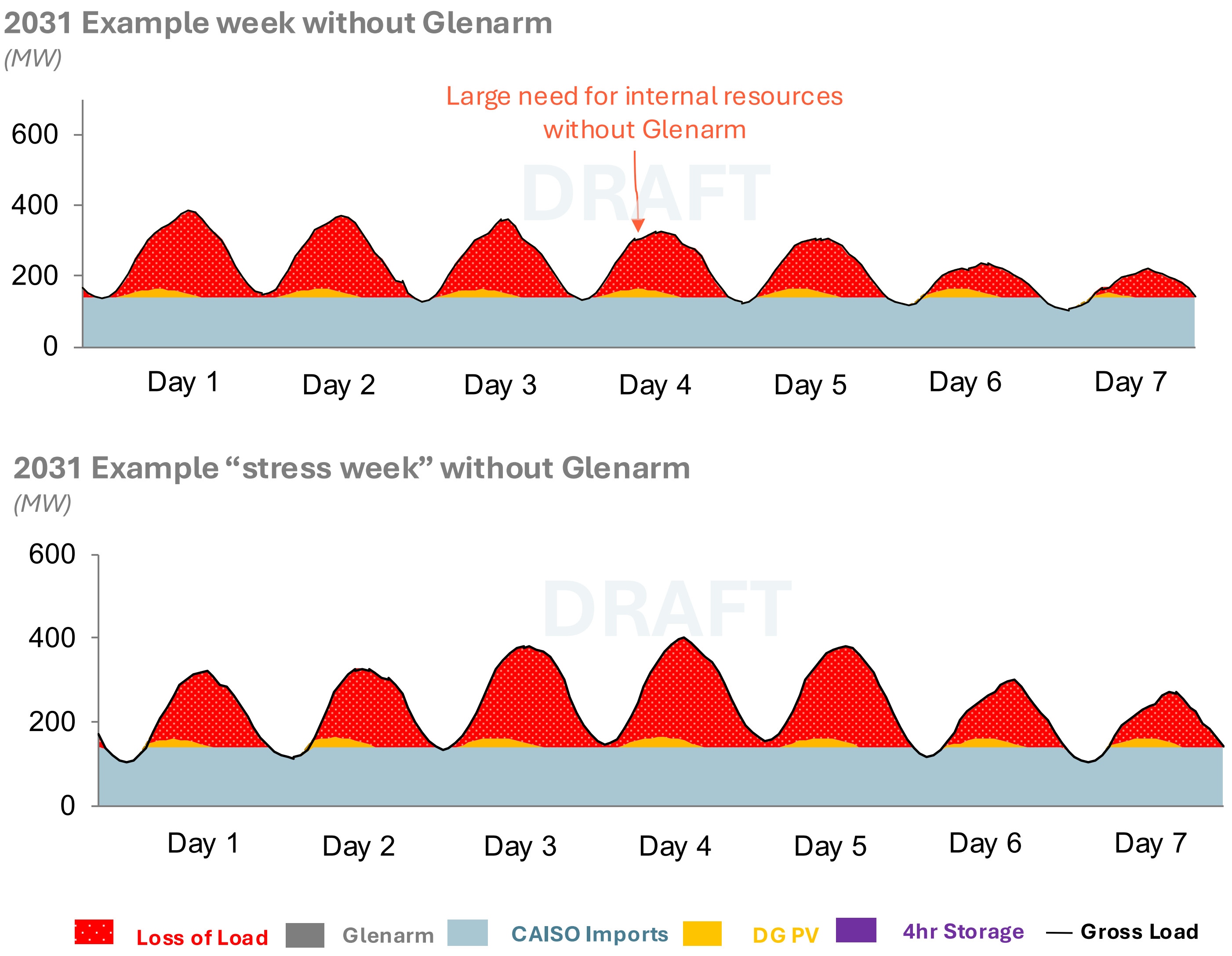
Same Snapshot Weeks show Large Needs during TMG Outage

The 2031 PWP system is simulated across the same 500 years of conditions *without Glenarm present*. Across this sample:

365 Number of days per year on which a reduction in import availability at Goodrich would put the system at risk of loss of load without internal generation resources (a *68x increase* relative to the 2024 baseline)

228,712 Total amount of load shed (MWh) across reliability events that occur during Goodrich outages (a *519x increase* relative to the 2024 baseline)

Without internal resources, PWP would be unable to meet loads on most days in the event of an outage at Goodrich



Adding Distributed Solar & 4-hr Storage to Restore Reliability

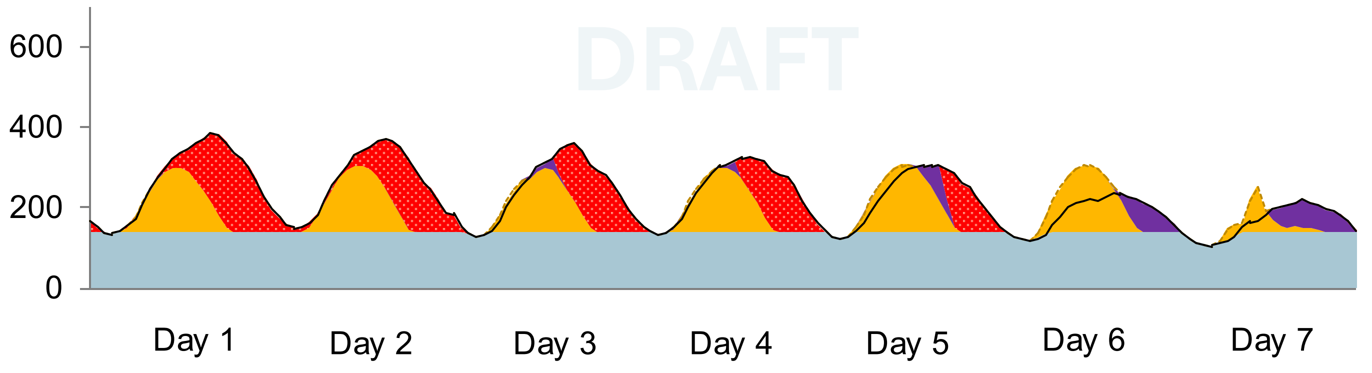
Adding 170 MW local solar & 160 MW local storage to the system without Glenarm improves reliability – but significant risks remain:

66 Number of days per year on which a reduction in import availability at Goodrich would put the system at risk of loss of load (still 11 times higher than the 2024 baseline)

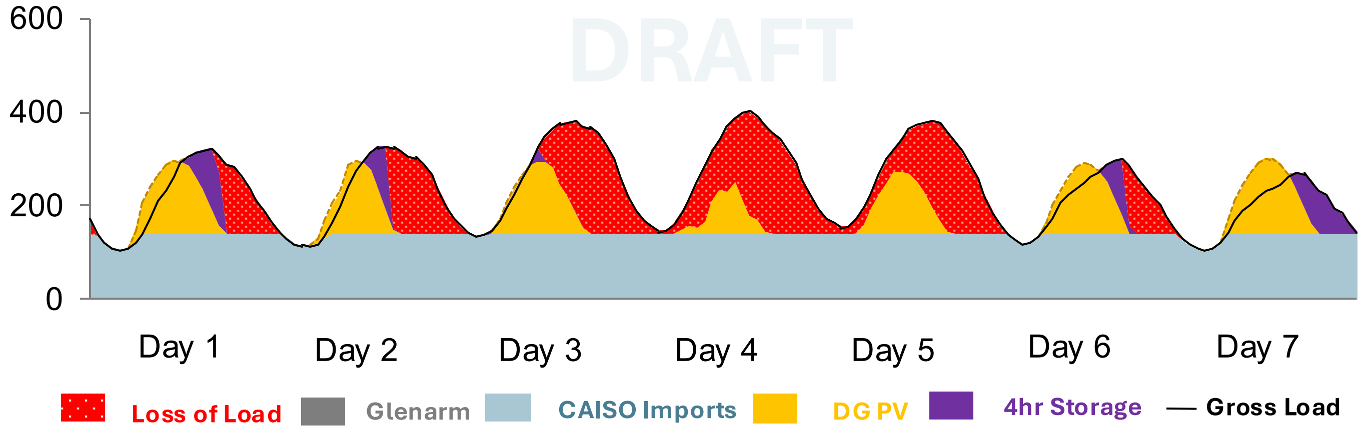
31,970 Total amount of load shed (MWh) across reliability events that occur during Goodrich outages (a *72x increase* relative to the 2024 baseline)

System remains at risk of experiencing loss of load if imports are limited during (a) nighttime hours on high load days and (b) across multi-day periods of low solar output

2031 Example week
(MW)



2031 Example "stress week"
(MW)



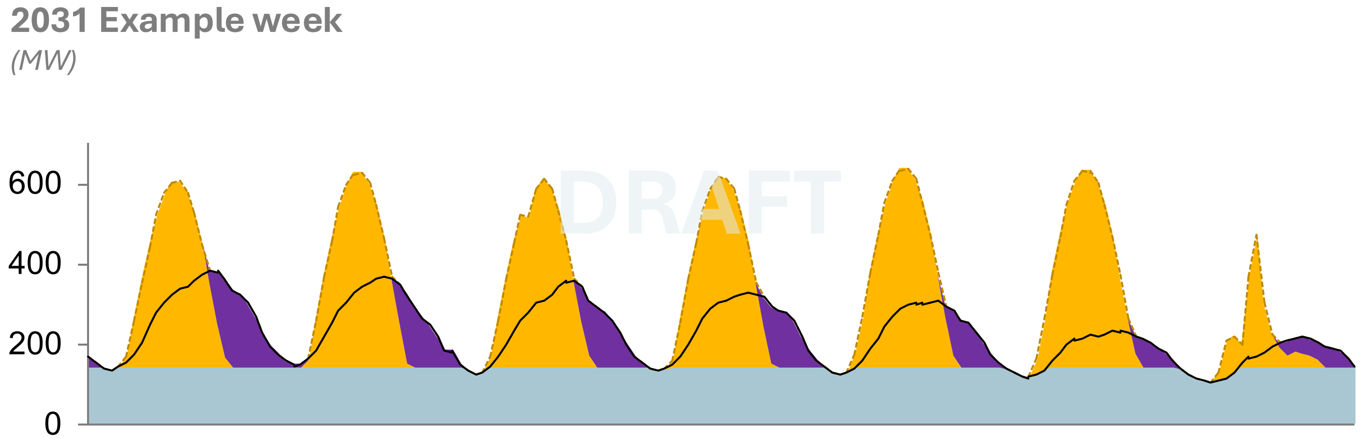
Adding Distributed Solar & 4-hr Storage to Restore Reliability

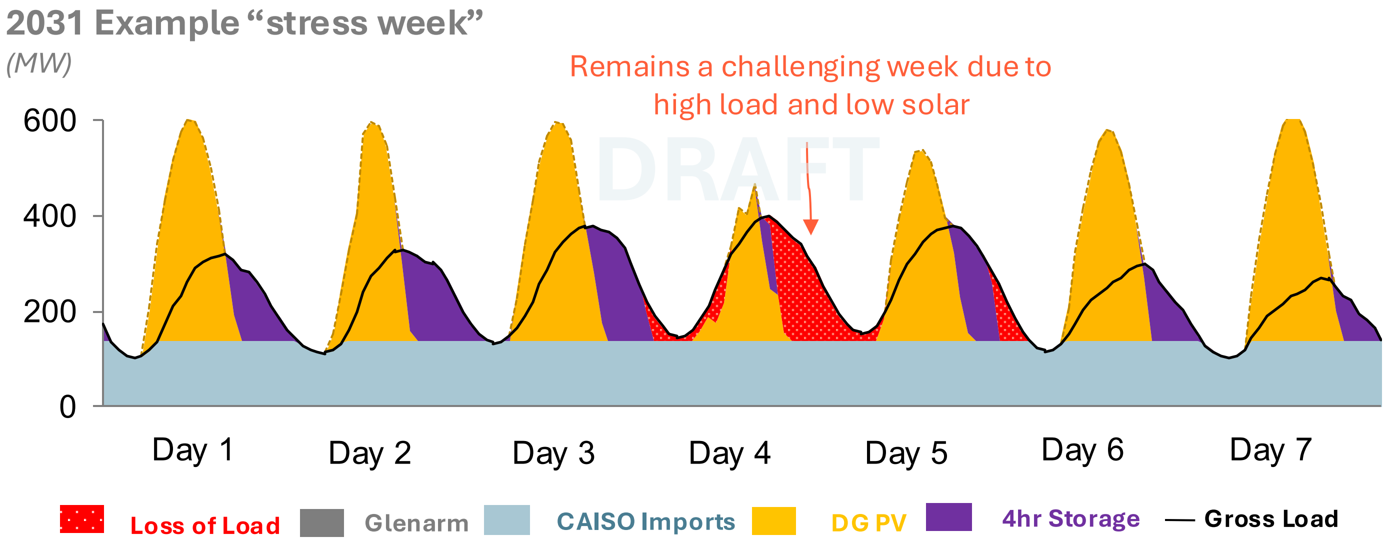
Adding 560 MW local solar & 350 MW local storage to the system without Glenarm reduces the magnitude of loss of load risk to 2024 levels:

2 Number of days per year on which a reduction in import availability at Goodrich would put the system at risk of loss of load (less frequent than 2024 baseline)

441 Total amount of load shed (MWh) across reliability events that occur during Goodrich outages (equal to 2024 baseline)

Risks on hot, sunny days are limited; multi-day periods of low solar output pose greatest risk as storage resources are unable to recharge from surplus resources



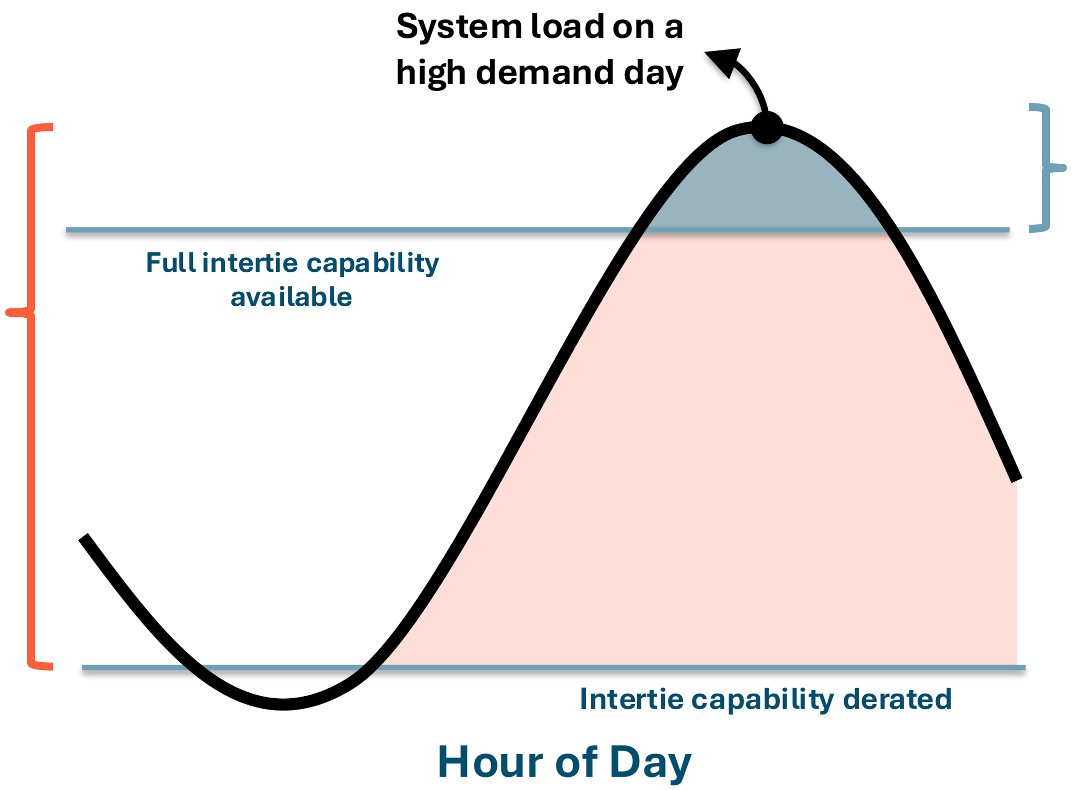


Visualizing Reliability Needs for Internal Generation

+ While large quantities of internal renewables and storage are needed to replace *all* reliability services currently provided by Glenarm, smaller quantities can reduce utilization of Glenarm during peak periods

Local resources needed to replace Glenarm during contingencies while maintaining reliability:

500 MW+ solar
300 MW+ storage
>5% DR peak load reductions



Local resources needed to mitigate reliance on Glenarm during peak periods during "normal" transmission conditions (in addition to flexible loads & demand response):

95% of energy needs above full intertie limit:
43 MW solar
50 MW storage

99% of energy needs above full intertie limit:
53 MW solar
101 MW storage

100% of energy needs above full intertie limit:
75 MW solar
160 MW storage

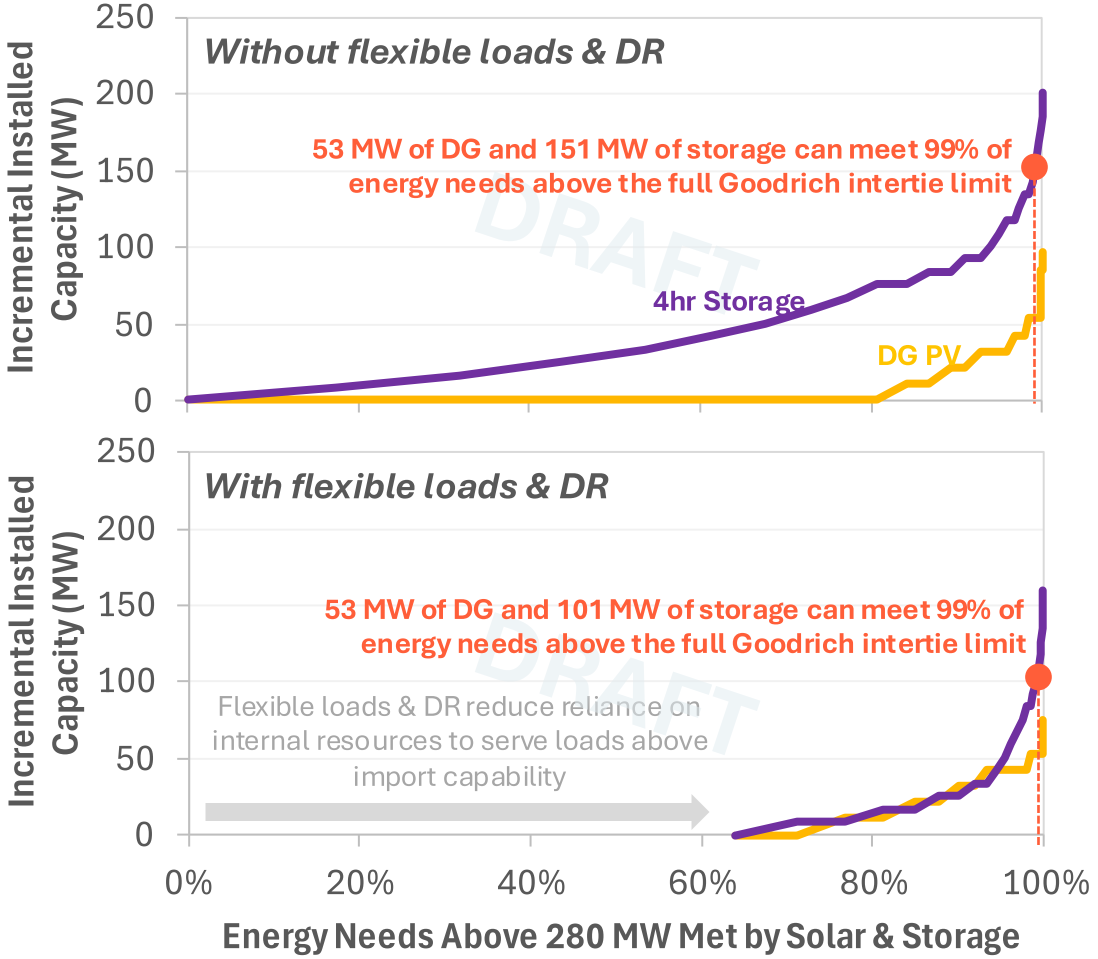
Additional resources would also improve resilience under contingency conditions

Adding Internal Resources to Mitigate Reliance on Glenarm During Peak Periods

- **Additional internal resources can limit need to rely on Glenarm, reducing its capacity factor and frequency of operations.**
- **"Mitigate" portfolios assume retention of Glenarm as a backstop resource predominantly for transmission contingencies – but would not allow for its retirement**
  - Glenarm's role is reduced to ensuring reliability during the most extreme conditions (extreme loads or transmission contingencies)

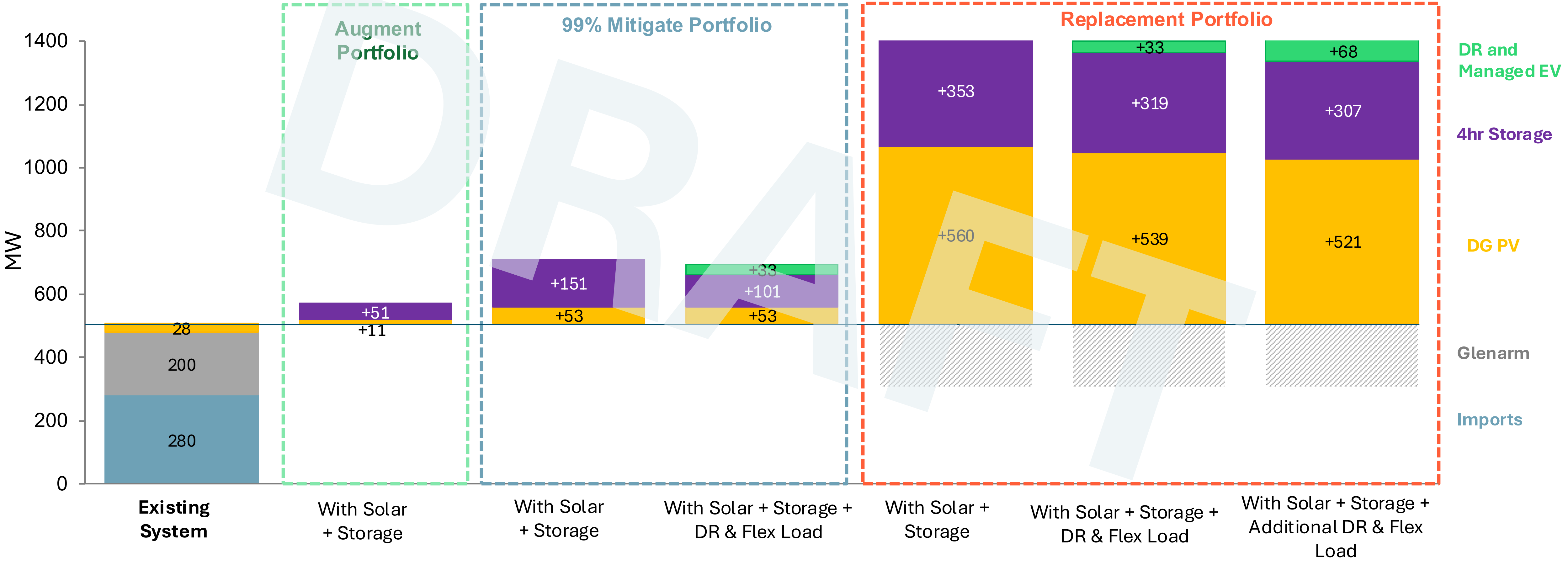
Modeling Framework to Develop "Mitigate" Portfolios:

- Use same Monte Carlo modeling tools used in replacement analysis, capturing a range of weather and peak load conditions
- Assume normal operating conditions (i.e. intertie at 280 MW)
- Add solar, storage, and load flexibility to meet remaining energy needs above 280 MW



Glenarm Replacement and Mitigate Portfolio Summary

Glenarm Augment, Mitigate, and Replacement Portfolios, *Incremental Nameplate MW*



These values represent the minimum quantities of resources needed to ensure local reliability. Additional local resources will be included in portfolios to the extent that (a) the rate of naturally occurring customer adoption exceeds this level or (b) additional resources are found to be economic in LTCE. E3's modeling indicates that naturally occurring adoption could result in an additional ~35 MW of customer-owned resources by 2031.

Glenarm Conversion Pathways

Energy+Environmental Economics

Fuel Options for Glenarm

PWP faces three fuel supply options for Glenarm with different emissions impacts, infrastructure needs, costs, and uncertainties.

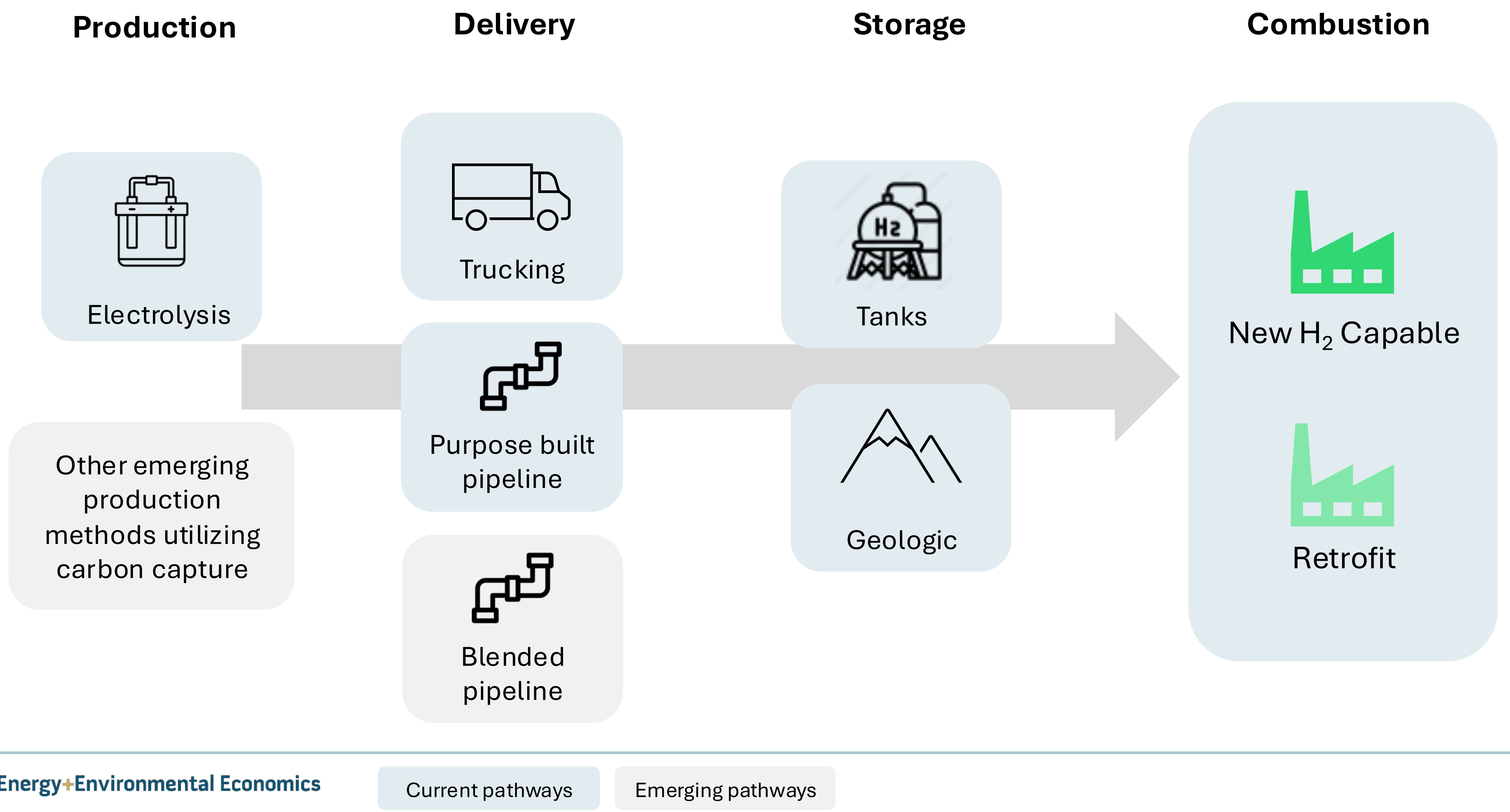
	Emissions reductions	Fuel Price Premium	Infrastructure Needs	Uncertainty / Risk
Fossil Gas	Emissions reductions driven only by decreased operation.			
Renewable Natural Gas	**Up to 100% carbon neutral** depending upon production pathway	Larger Premium	**No infrastructure upgrades**	Moderate
Hydrogen	Up to **100% carbon-free** (with full conversion)	Premium (with tax credits)	Infrastructure upgrades at Glenarm + Infrastructure development outside of PWP control	High

RNG may be an effective short-term substitute for natural gas while longer-term options for replacement or conversion remain uncertain.

Key Questions for Glenarm Hydrogen Conversion

Conversion Pathways	What are the options for **combusting hydrogen** at Glenarm? What are the options for **producing and delivering hydrogen fuel** to Glenarm? What conversion pathway(s) are most **viable** for Glenarm? What are the **interim steps** to conversion?
Infrastructure Requirements	What are the required **infrastructure investments** would **PWP** need to enable hydrogen conversion? What are the required **infrastructure investments** and **technology developments outside of Pasadena's control** that would be needed to enable conversion?
Costs	For the Cost Impacts study in the OSP, what are the **costs** associated with the most viable conversion pathway(s)?

Green Hydrogen and Production Pathways



Evaluating Options to Supply Hydrogen at Glenarm

On-site storage of trucked in hydrogen or on-site production of hydrogen at Glenarm are not viable options for 100% conversion due to scale of plant fuel needs

Land use requirements for on-site hydrogen storage or production are prohibitive.

Delivering hydrogen to Glenarm would require…

To store fuel supply for…	1 day	3 days
Tons of H2 Fuel	375	1,125
Acres for storage	25	75
Truck trips to fill storage tank	375	1,125

H_2 To produce hydrogen on-site…

To generate enough fuel within a summer week for..	1 day	3 days	
MW of electolyzers	125	375	*50-100% of existing system peak load.*
Acres for electrolyzers	<1	<1	
MW of solar for electrolysis	300	900	*Ground-mount PV potential in Pasadena is ~10 MW.*
Acres for solar for electrolysis	1,650	5,000	
Acres for storage	25	75	

General Roadmap for Hydrogen Conversion

Today	Pilot Phase	Full Conversion
Operations fueled entirely by natural gas	Natural gas remains primary fuel	Connection to natural gas pipeline maintained for redundancy and resiliency
	Two turbines retrofit (87 MW) to allow up to 100% hydrogen combustion	All turbines retrofit or replaced to allow 100% hydrogen combustion
	Green hydrogen produced via electrolysis	Green hydrogen produced via electrolysis
	Smaller volumes of hydrogen transported by truck and stored on site	Larger volumes of hydrogen transported by dedicated pipeline
	Hydrogen blending up to 100% demonstrated at retrofit turbines	Hydrogen is primary fuel used in all turbines

Factors outside of PWP control for full conversion

- Development of dedicated H_2 pipeline
- Scaling of Green H_2 production for delivery
- Development of viable turbine retrofit / replacement option.
- Permitting

Neighboring Utilities Planning for a Transition to Hydrogen Fuel in 2030s

Los Angeles Department of Water & Power

- Implementing H2 conversion at Intermountain Power Plant in Delta, Utah (in partnership with BWP and GWP)
- Currently pursuing Scattergood modernization project with plans to operate with 30% blending by 2029 and 100% hydrogen by 2035
  - One of two California power plants identified explicitly in ARCHES plan for conversion to hydrogen
- Strategic Long-Term Resource Plan provides schedule for long-term conversion of remaining peak power plants to hydrogen by 2035

Glendale Water & Power

- 2024 IRP identifies green hydrogen as “most probable” option for clean firm resource while acknowledging infrastructure challenges
- Current Preferred Plan includes ~165 MW of hydrogen CTs beginning in 2035-’36
  - From which 35 MW is the share of GWP from hydrogen-repowered Intermountain power plant

Southern California Gas Company

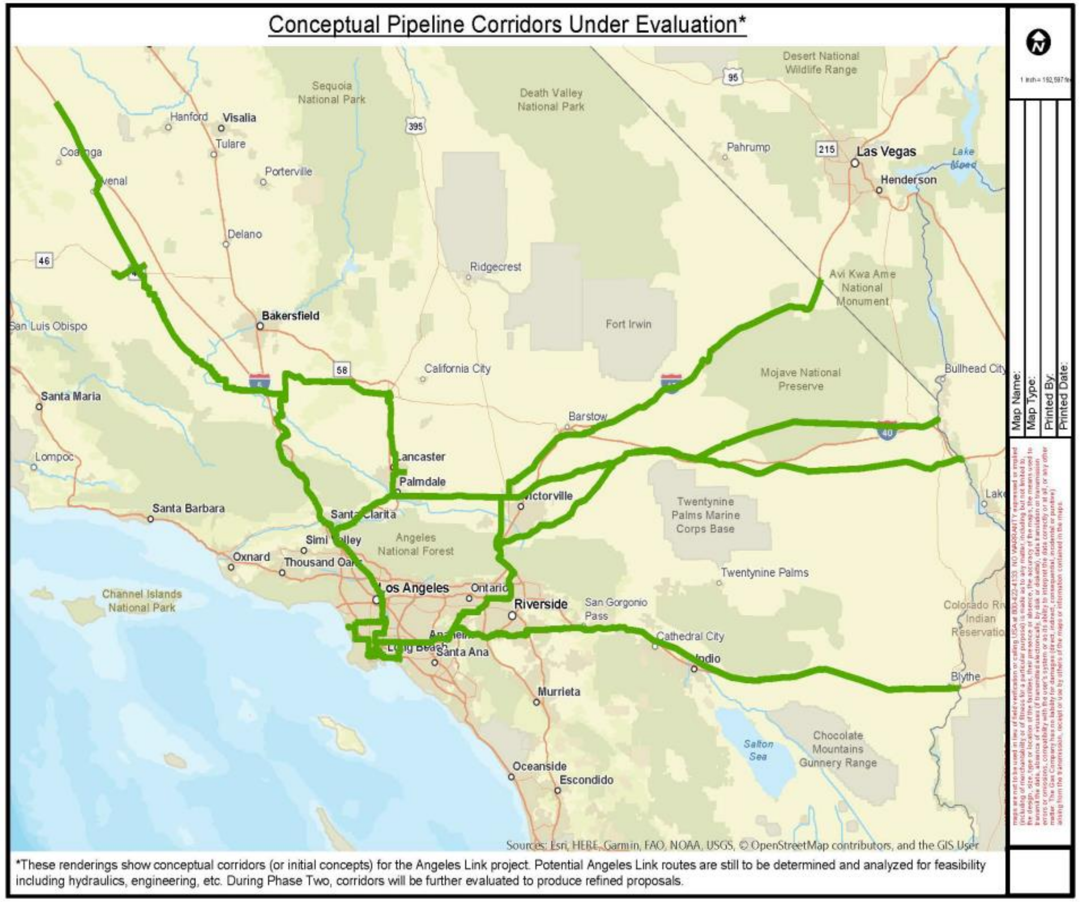
- The Angeles Link project is proposed to explore development of a dedicated hydrogen pipeline system of 200 to 750 miles to transport clean renewable hydrogen from production sites to various users in central and southern California
- In December 2022, the CPUC approved SoCalGas to commence Phase 1 feasibility studies and the creation of a memorandum account to record cost

Neighboring electric utilities’ plans rely on hydrogen to support local reliability needs, but with a slower transition (mid 2030s) than goals set by Resolution 9977 (2030); the timing of a viable transition to hydrogen at scale will depend upon how quickly supporting infrastructure (including pipelines and storage) in the region can be developed

Angeles Link: Proposed Hydrogen Pipeline

- **In 2022, the California Public Utilities Commission (CPUC) authorized SoCalGas to start Phase 1 (2022-2024) of the Angeles Link project which included stakeholder engagement activities and feasibility studies.**
  - PWP and Southern California Public Power Authority have been engaging with SoCalGas on project development.
- **The Phase 1 routing/configuration identified several potential routes considering:**
  - Utilization of existing right-of-ways
  - Areas of hydrogen production and offtake.
  - Land use limitations, environmental considerations, disadvantaged communities
- **Phase 2 (est. 2025-2026) will identify a preferred route and conduct refined design, engineering, and environmental studies.**
- **Phase 3 (est. 2025-2029) will involve final refinements to the design, permitting, and regulatory applications.**

Figure 1 Conceptual Pipeline Corridors Under Evaluation



Insights & Initial Learnings from Glenarm Replacement and Conversion Study.

1. **If Glenarm remains in service, the need for additional resources to meet growing loads is relatively modest and is largely consistent with resources already procured by PWP and naturally occurring customer adoption of solar.**
2. **Replacing Glenarm with a combination of internal renewables, storage, and demand-side resources requires new internal generation resources at a significant scale that approaches technical potential.**
   - Sizing of replacement portfolio largely driven by need to maintain reliability during (a) transmission contingency conditions even when (b) solar output is limited (short-term cloudy days)
   - Demand-side resources, emerging longer-duration storage technologies and incremental transmission upgrades can reduce scale of resource needs. None offer a "silver bullet" solution to the challenge of replacing firm generation.
   - A larger transmission upgrade, potentially constructed in the 2030s, could reduce the challenge of replacing Glenarm.
   - Consistent with broader literature and experience in the industry showing that meeting reliability needs without "firm" resources (short-term resources that can be dispatched on demand for as long as needed) is prohibitively challenging.
3. **While the scale of resources needed to replace Glenarm entirely is significant, smaller quantities of new internal resources can reduce the reliance on Glenarm except for the most extreme conditions.**
4. **Full hydrogen conversion of Glenarm requires significant infrastructure developments that are beyond PWP's control and are unlikely to built before 2030.**
   - RNG may be an effective short-term substitute for natural gas while longer-term options for replacement or conversion remain uncertain.

Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel #8

February 10, 2025

Energy+Environmental Economics

Nick Schlag, Partner
Mike Sontag, Director
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Sr. Managing Consultant

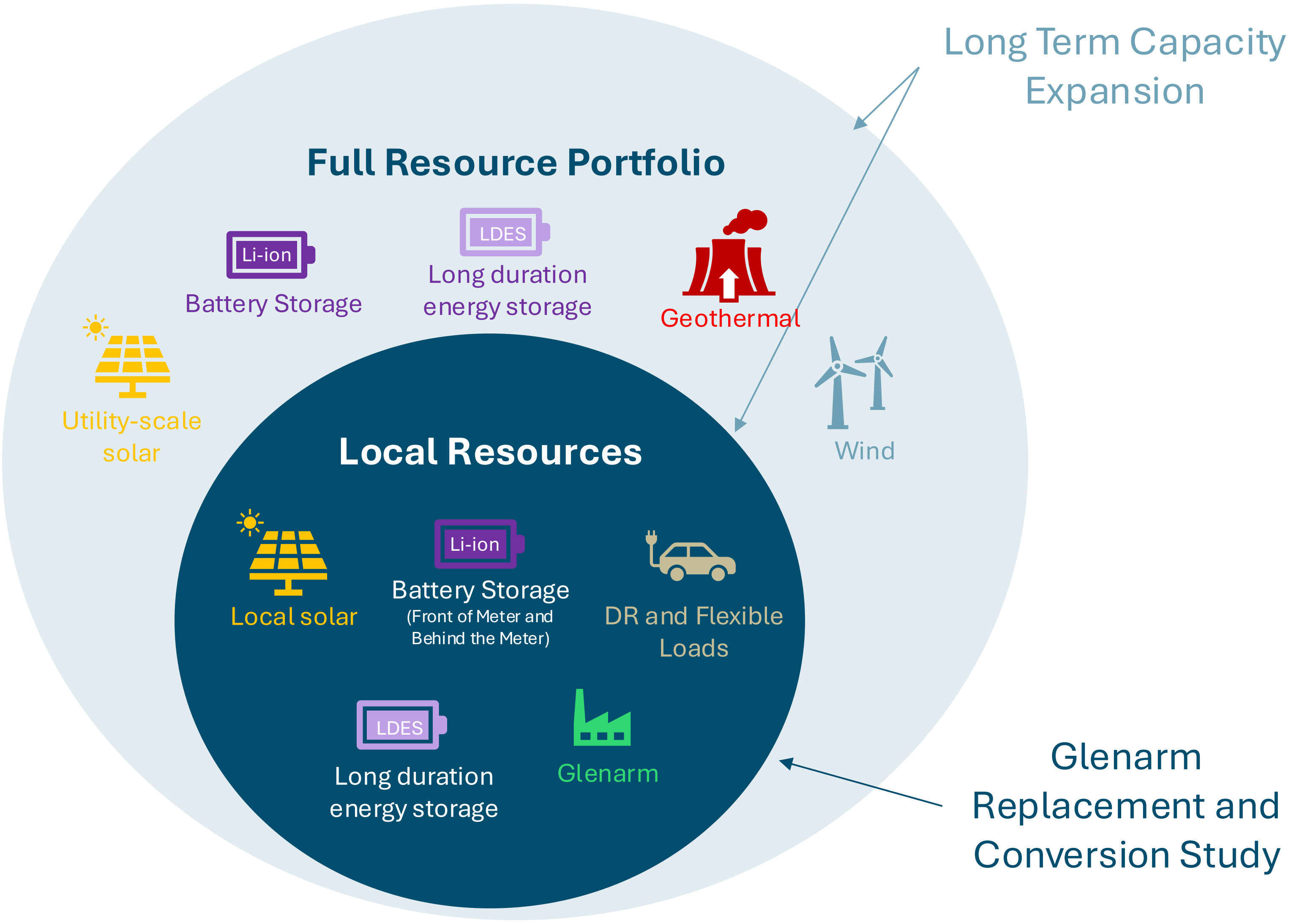
Agenda

- Update on Glenarm Conversion and Replacement Study
- Long-Term Capacity Expansion (LTCE) Methodology and Inputs
- LTCE Results – Mature Technologies Only
- Additional LTCE Case Studies
  - Long-Duration Energy Storage
  - Glenarm Hydrogen Conversion
- Next steps

Portfolio Development Process

Portfolio development process comprises two phases of analysis:

1. **<u>Glenarm Replacement and Conversion Study:</u> Identify a range of internal resource solutions to meet local reliability needs of PWP system given limitations of transmission system**
   - Focus on a single specific challenge on the path to Resolution 9977 goals
   - **Not yet considering relative cost of different options**
2. **<u>Long-Term Capacity Expansion:</u> Create complete resource portfolios that consider objectives of clean energy, reliability, affordability, and equity**
   - Focus on holistic view of resource portfolio to support Resolution 9977 goals



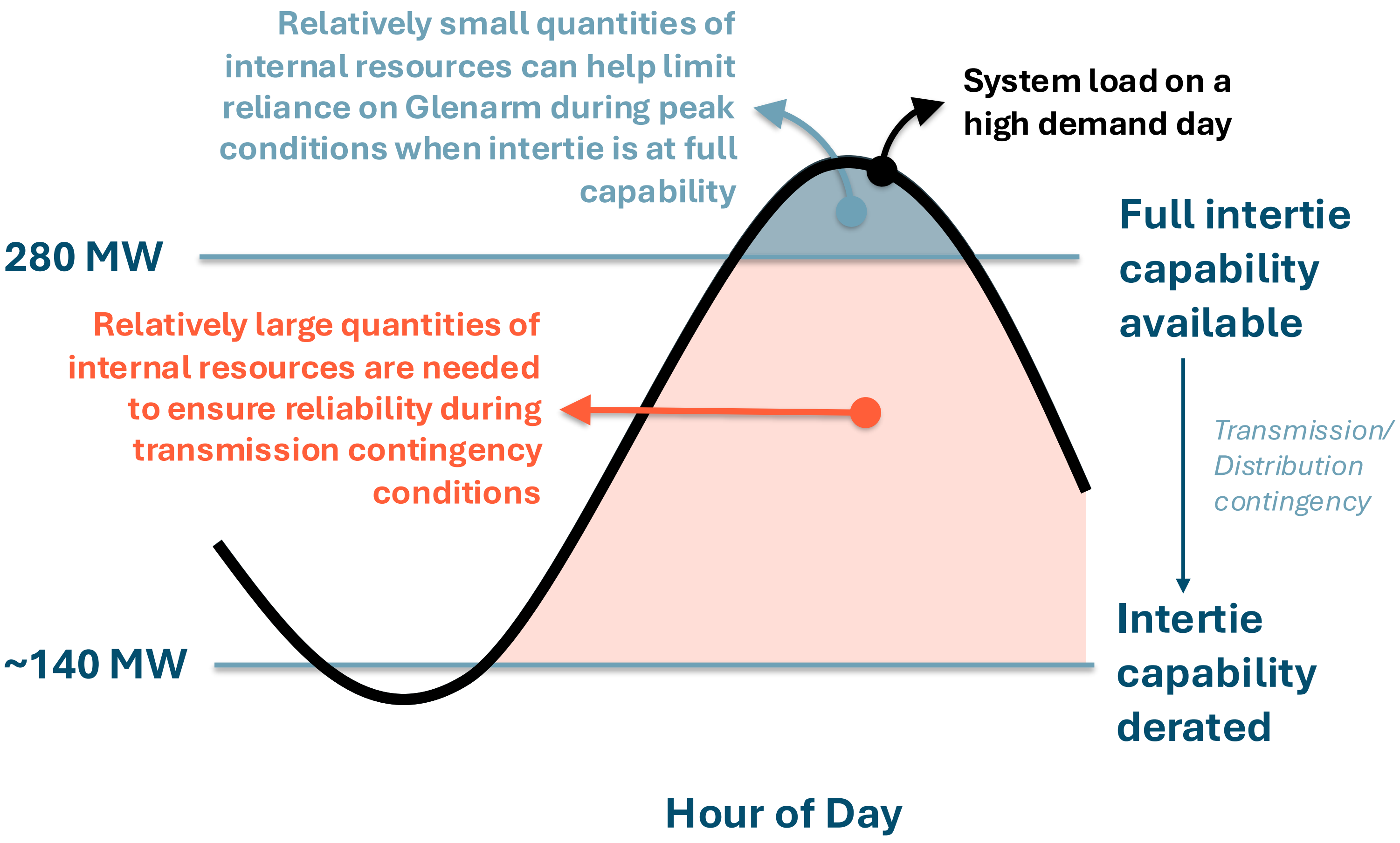
Update on Glenarm Replacement Portfolio Analysis

Energy+Environmental Economics

Visualizing Reliability Needs for Internal Generation

Maintaining reliability in Pasadena's service territory requires internal resources that can meet needs under a range of extreme conditions:

1. During peak demand conditions (above import capability)
2. During transmission or distribution contingencies that reduce intertie capability



Three Frames for Internal Reliability Analysis

Augment Glenarm	What internal resources are needed to meet growing loads while **maintaining reliability if Glenarm remains in service**?
Mitigate Glenarm	*What additional internal resources can **mitigate the need to operate Glenarm** under "normal" operating conditions (i.e. when import capability is available up to full 280 MW)?*
Replace Glenarm	What are the total resource needs to **maintain reliability even in the event of transmission contingency**?

Internal resources considered

Solar

Storage

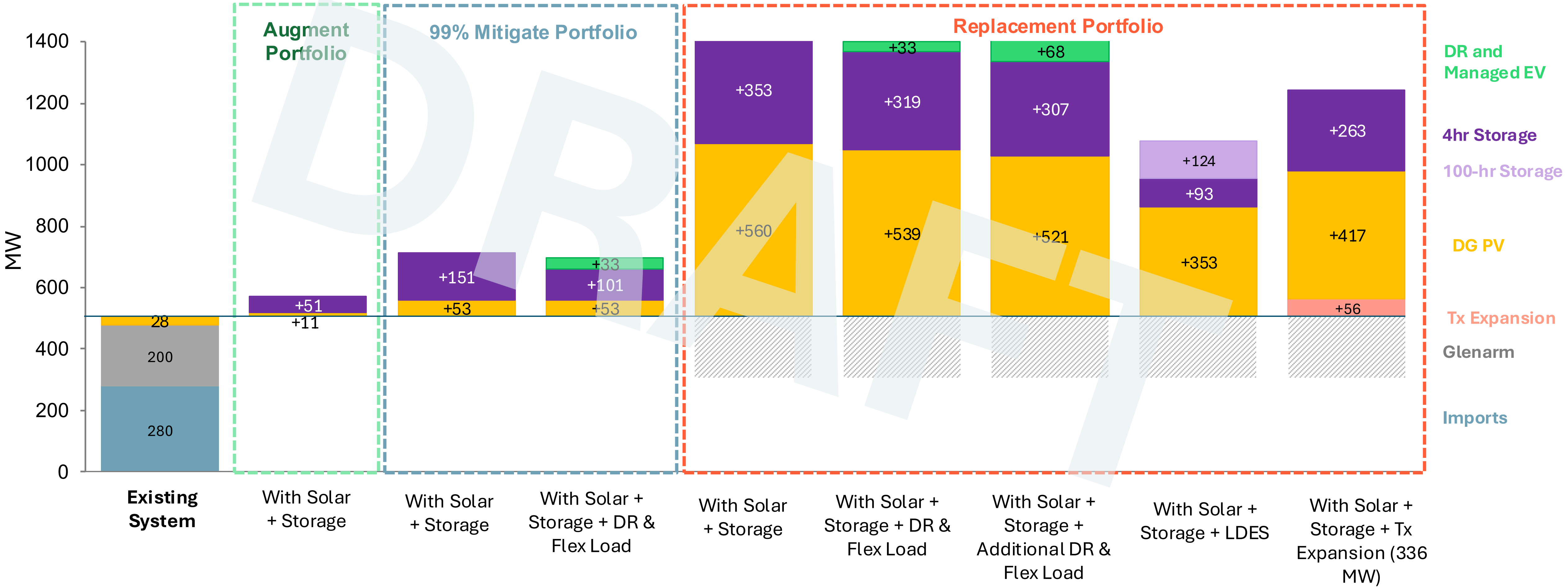
Increased Load Flexibility & Managed Charging

Long Duration Storage

Sensitivities also explore increased import capability

Reminder of Glenarm Replacement Analysis Presented at Last TAP Meeting

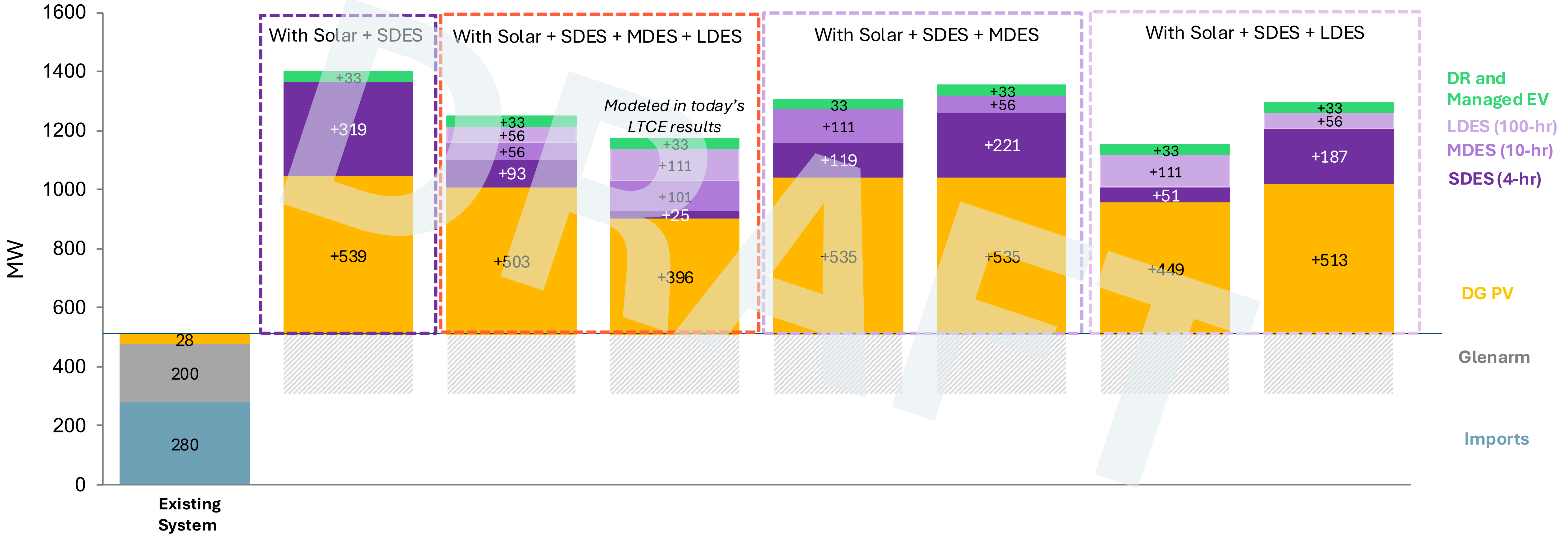
Glenarm Augment, Mitigate, and Replacement Portfolios, *Incremental Nameplate MW*



These values represent the minimum quantities of resources needed to ensure local reliability. Additional local resources will be included in portfolios to the extent that (a) the rate of naturally occurring customer adoption exceeds this level or (b) additional resources are found to be economic in LTCE. E3's modeling indicates that naturally occurring adoption could result in an additional ~35 MW of customer-owned resources by 2031.

Glenarm Replacement Portfolio Summary with MDES and LDES

Glenarm Replacement Portfolios, *Incremental Nameplate MW*



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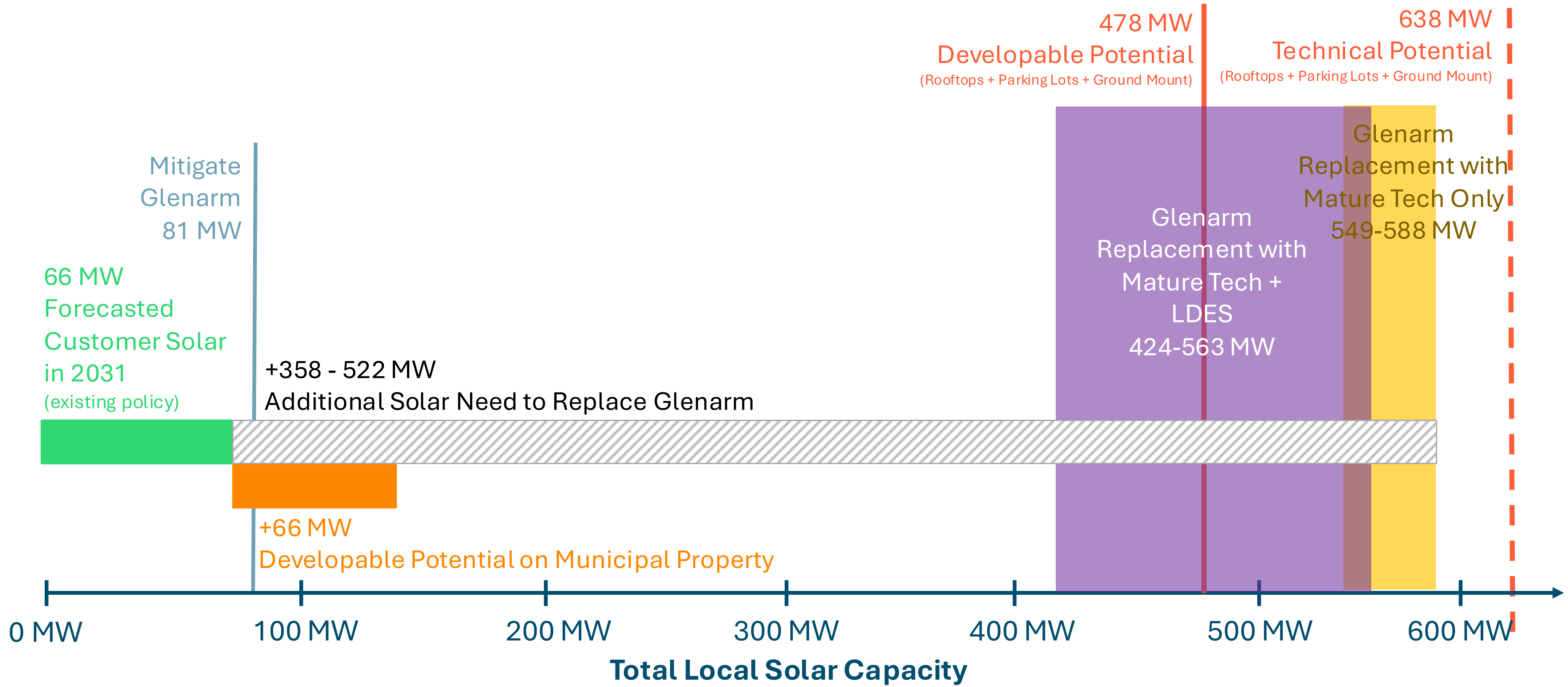
LDES = Long-Duration Energy Storage
MDES = Medium-Duration Energy Storage
SDES = Short-Duration Energy Storage

Scale of Local Solar Need and Resource Potential



LTCE Modeling Background

Energy+Environmental Economics

Long-Term Capacity Expansion Modeling Overview

Objective Function

+ **Investment Costs**
  - New resources
  - New transmission (optional)

+ **Fixed Costs**
  - Renewables
  - Energy storage
  - Thermal

+ **Variable Costs**
  - Variable O&M*
  - Fuel Costs
  - Market purchases

*Operation and Maintenance

Decisions

Investments

↓ ↑

System Operations

Constraints

- Clean energy targets
- Resource adequacy requirements
- Resource Limits
- Operations
- Transmission

Common Assumptions Across Cases Modeled in LTCE

Load Forecast	Customer Resources	Existing Portfolio	Transmission	Resource Potential
2031 peak demand: **360 MW** *(reflects managed EV charging)*	Adoption of customer resources by 2031 based on current NEM structure: Solar: **65 MW** Storage: **1 MW**	All resources currently owned or under contract to PWP included across portfolios *(retirement dates vary across cases)*	**280 MW** import limit at TM Goodrich, expanding to 336 MW by 2035	External resource options informed by CPUC IRP planning assumptions; internal resource options informed by preparatory studies

Resource Costs	Commodity Pricing	Clean Energy	Local Reliability	Resource Adequacy
Informed by the OSP New and Emerging Tech Study	Natural gas, carbon allowance, and CAISO wholesale electricity prices based on E3 fundamentals-based forecast	All portfolios include *at least* enough carbon-free energy to meet PWP's annual energy needs by 2031	All portfolios include a minimum requirement for local resources informed by LOLP modeling	All portfolios must meet future RA requirements based on "marginal ELCC" accreditation framework

Topology for Capacity Expansion Model

Utility Load	
2031 Peak Demand[5]	361 MW
Owned & Contracted Resources	
Glenarm Power Plant	198 MW
Windsor Reservoir Solar	0.7 MW
Glenarm BESS[2]	25 MW
2031 Customer-Owned Resources	
Customer-Owned Solar	66 MW
Customer Owned Storage	1 MW
Candidate Resource Options	
Local Solar PV	
Local Battery Storage (4hr)	
Local Mid Duration Storage (10hr)[3]	
Local Long Duration Storage (100hr)[3]	
Demand Response	
Load Flexibility	
Green Hydrogen[3]	

Local PWP System

TM Goodrich
Receiving Station

280 MW limit
(expanding to 336 MW by 2035)

External CAISO System

Owned & Contracted Resources	
Palo Verde Nuclear	10 MW
Intermountain Power Plant[1]	108 MW
Magnolia Power Plant	14 MW
Chiquita Canyon Landfill Gas[1]	7 MW
Puente Hills Landfill Gas[1]	13 MW
Hoover Hydro	15 MW
Azusa Hydro	15 MW
Calwind[2]	20 MW
Coso Geothermal[2]	10 MW
Geysers Geothermal[2]	25 MW
Antelope Big Sky Ranch Solar	7 MW
Big Sky Summer Solar	7 MW
Columbia 2 Solar	3 MW
Kingbird Solar	20 MW
Bonanza Solar[2]	105 MW
Grace Solar[2]	50 MW
Bonanza BESS[2]	55 MW
Candidate Resource Options	
Utility-Scale Solar PV	
Wind (California)	
Wind (Out of State)	
Geothermal	
Battery Storage (4hr)	
Mid Duration Storage (10hr)[3]	
Long Duration Storage (100hr)[3]	
Wholesale Energy Market	
CAISO Wholesale Market (SP15)	

Notes:
1. Resources with established plans for retirement or contract expirations prior to end of 2030
2. Resources not yet online today
3. Candidate resources included in a select set of portfolios
4. Based on 2023 IRP forecast.
5. Based on 2023 IRP forecast with blended EV charging developed by E3.

Three Core Case Studies to Achieve Resolution 9977 Goals

Case Studies	New Resources Considered to Meet Resolution 9977 Goals					
Mature Technologies Only	Solar PV	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	
Mature Technologies + Green Hydrogen	Solar PV	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	Green Hydrogen (H_2) Conversion at Glenarm
Mature Technologies + Long-Duration Storage	Solar PV	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	Long-Duration Energy Storage

Common methods & assumptions across all three case studies:

- Natural gas combustion at Glenarm ceases by end of 2030 (either converted to H_2 or replaced)
- No reliance on wholesale market purchases ("24x7 carbon free electricity")
- Quantities of each resource optimized in each case study to meet reliability needs and carbon-free objectives

Additional variations explored to provide PWP and City Council with robust analyses to inform the Optimized Strategic Plan:

+ **"Accelerated Local Resources": What are the comparative impacts of portfolios that accelerate the deployment of local resources while maintaining Glenarm Power Plant as a backup for reliability?**
+ **Timing: How does each strategy change if transition to carbon-free occurs less rapidly?**
  - Opportunity to synchronize transition with transmission expansion
  - More plausible timelines for technology readiness for emerging technologies
+ **Markets: How does short-term market transaction flexibility impact these case studies?**
+ **Renewable Natural Gas: What are the cost impacts of utilizing RNG to reduce carbon emissions from Glenarm?**

Case-Specific Modeling Assumptions

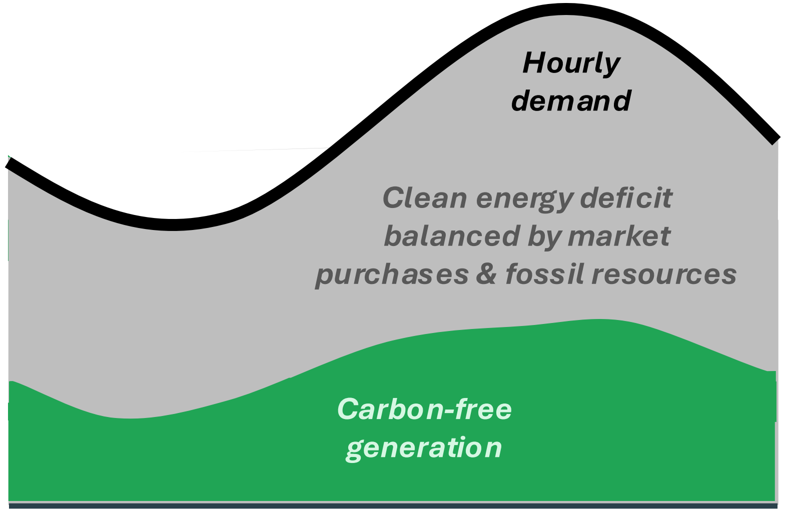
No.	Portfolio Name	Glenarm	Local resource portfolio (2031)	Market Purchases (2031)	
1	100% Annual Matching	Retained*	66 MW local solar 26 MW 4-hr storage	No net market purchases	Mature Technologies only
2	100% Annual Matching (Accelerated Local Resources)	Retained*	81 MW local solar 101 MW 4-hr storage	No net market purchases	
3	100% Annual Matching (Glenarm Replacement)	Replaced	567 MW local solar 319 MW 4-hr storage	No net market purchases	
4	100% Hourly Matching	Replaced	567 MW local solar 319 MW 4-hr storage	No market purchases	
5	100% Annual Matching (with Hydrogen)	H_2 Conversion	66 MW local solar 26 MW 4-hr storage	No net market purchases	Mature Technologies + Hydrogen
6	100% Hourly Matching (with Hydrogen)	H_2 Conversion	66 MW local solar 26 MW 4-hr storage	No market purchases	
7	100% Annual Matching (with LDES)	Replaced	396 MW local solar, 25 MW 4-hr storage, 101 MW MDES, 111 MW LDES	No net market purchases	Mature Technologies + LDES
8	100% Hourly Matching (with LDES)	Replaced	396 MW local solar, 25 MW 4-hr storage, 101 MW MDES, 111 MW LDES	No market purchases	

*Sensitivity analysis will explore use of renewable natural gas at Glenarm.

Different Procurement Strategies Will Lead to Large Differences in PWP's Position in the CAISO Market

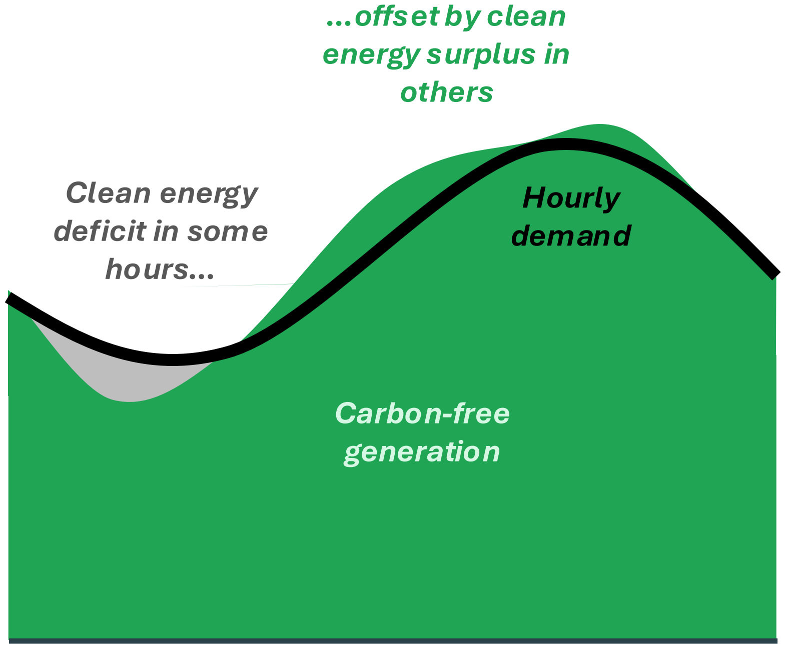
Current Portfolio (2025)

Utility has a ***short market position***, relying on market purchases (and fossil resources) to serve a portion of load in all hours



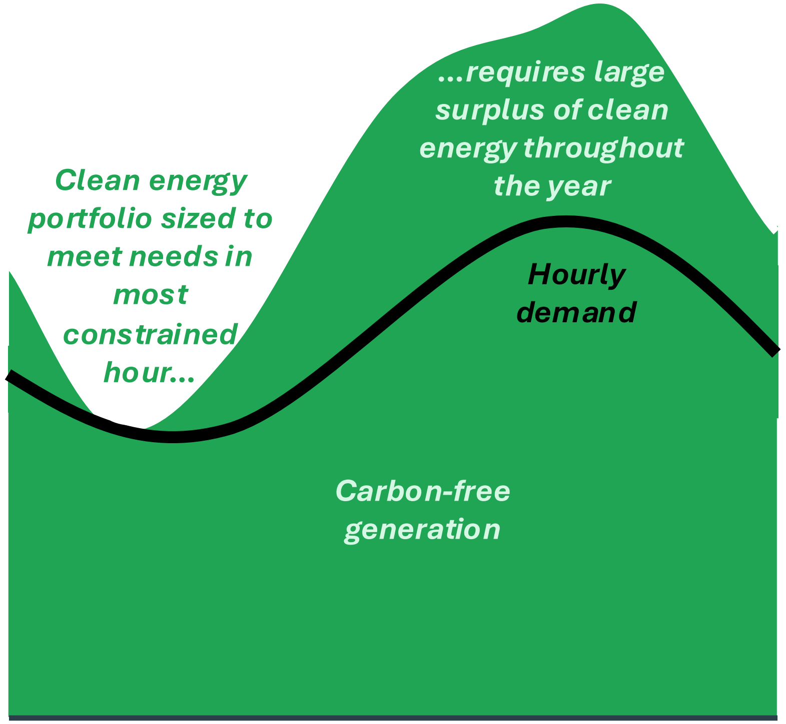
"100% Annual Matching"

Utility maintains a ***balanced market position***, offsetting market purchases with sales of surplus clean energy



"100% Hourly Matching"

Utility takes a ***long market position***, resulting in significant off-system sales and/or curtailment so carbon-free resources can meet load in most constrained periods



Figures are illustrative – not a modeling result

Relative Incremental Cost Metric

<u>Cost metrics presented today:</u>

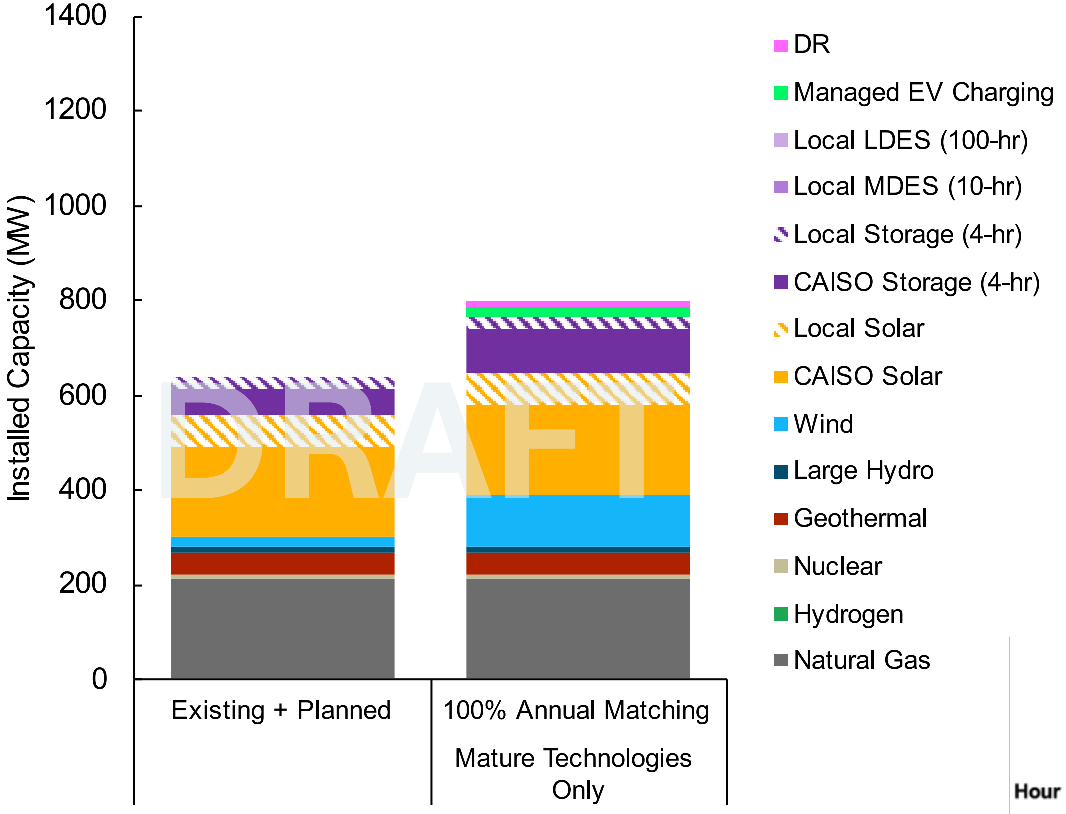
+ **Incremental costs include the following components:**
  - Fixed Operations and Maintenance for existing utility-owned generation
  - Operating costs (fuel, operations and maintenance) for new and existing resources
  - Procurement costs for new resources
  - Market purchases and sales
  - Transmission Access Charge
+ **Costs are presented relative to the lowest cost case (100% Annual Matching)**
+ **Costs reflect annual costs in 2031 to serve loads; additional on-going costs are associated with the portfolio in each case study**

+ ***Next steps: Calculate total system cost including existing or embedded costs and develop average system cost metrics***

LTCE Modeling Results: Mature Technologies Only

Energy+Environmental Economics

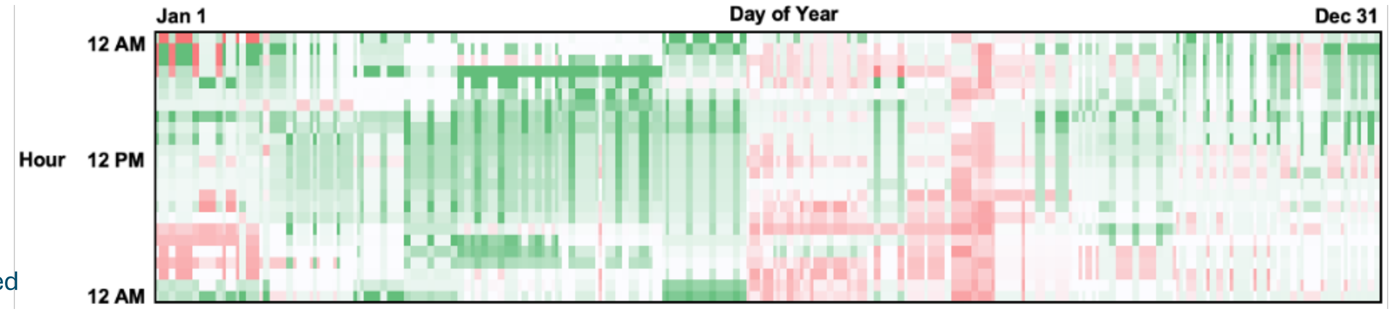
100% Annual Matching, Mature Technologies Only



Initial Learnings & Portfolio Highlights:

+ Modest incremental additions of renewables and storage allow PWP to meet 100% of annual energy needs with carbon-free sources
+ Glenarm retained and operated infrequently for local reliability
+ "Annual matching": sales of surplus carbon-free resources offset market purchases and limited Glenarm operations (mostly summer)

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 96%	Metric 3: 90%*
2031 Incremental Cost:	+$0 million per year		

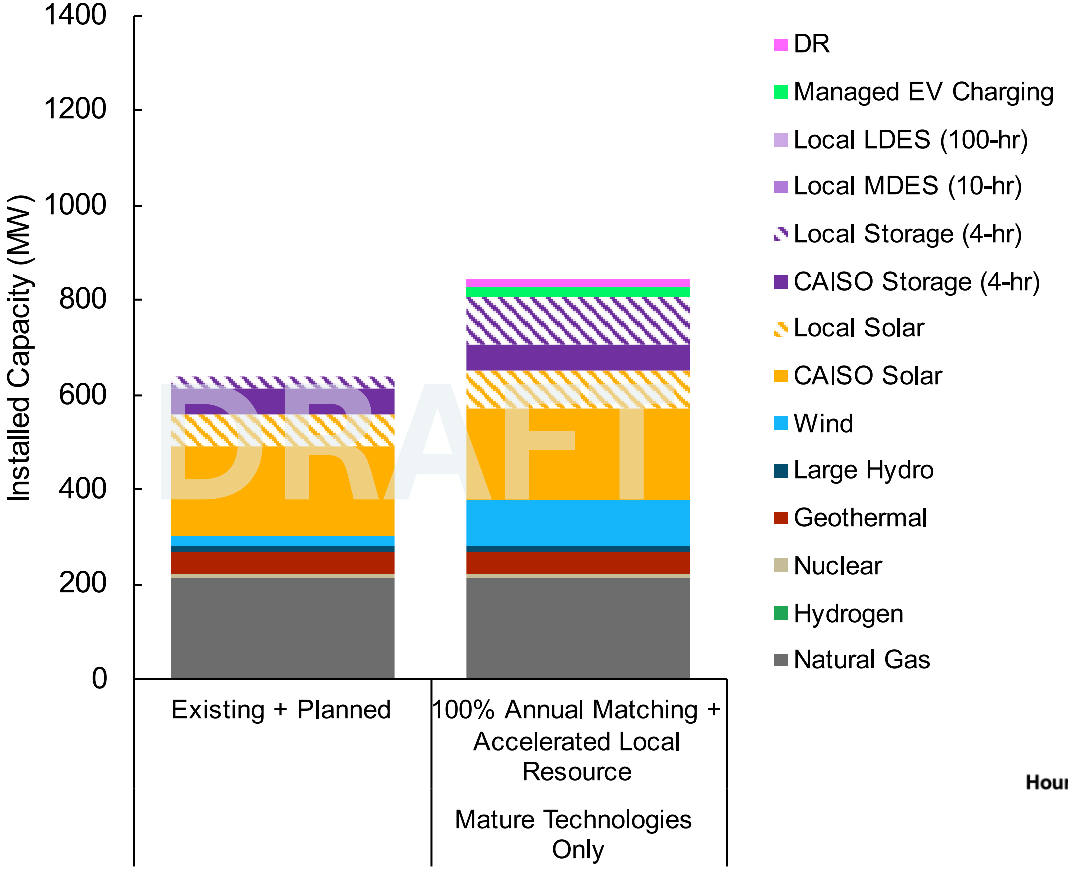


Hourly Carbon-Free Electricity vs. Hourly Load

0% 100% >200%

* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

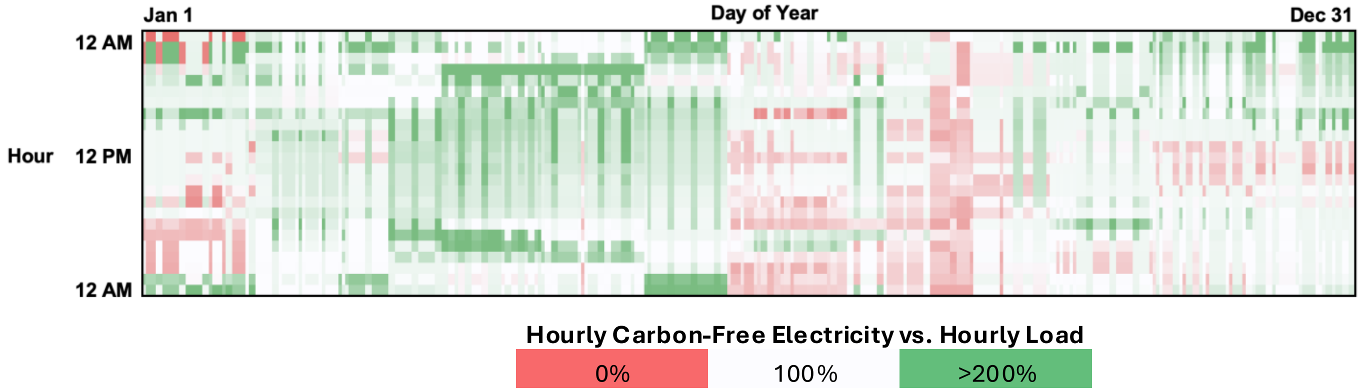
100% Annual Matching, Mature Technologies Only (Accelerated Local Resources)



Initial Learnings & Portfolio Highlights:

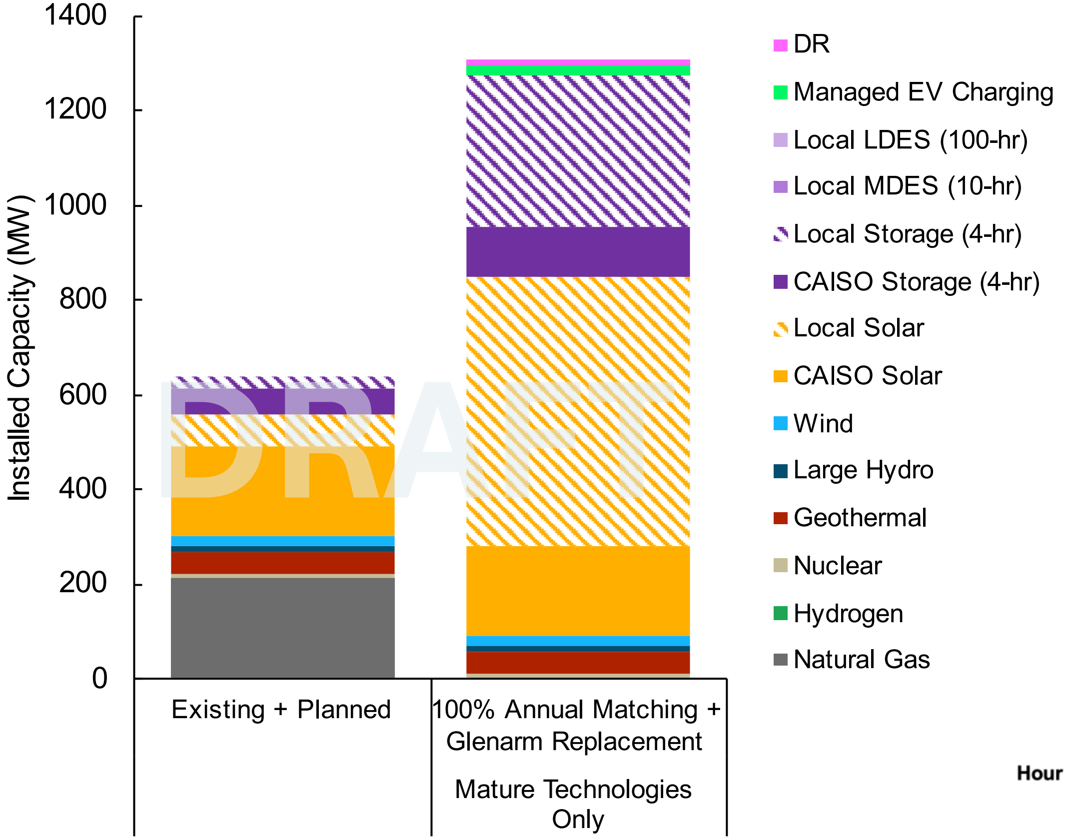
+ Increased focus on local solar & storage development further reduces frequency of Glenarm's use to meet local reliability needs and reduces imports from CAISO at limited incremental cost
+ Increased internal resource development reduces level of external resources developed

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 97%	Metric 3: 90%*
2031 Incremental Cost:	+$3 million per year		



* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

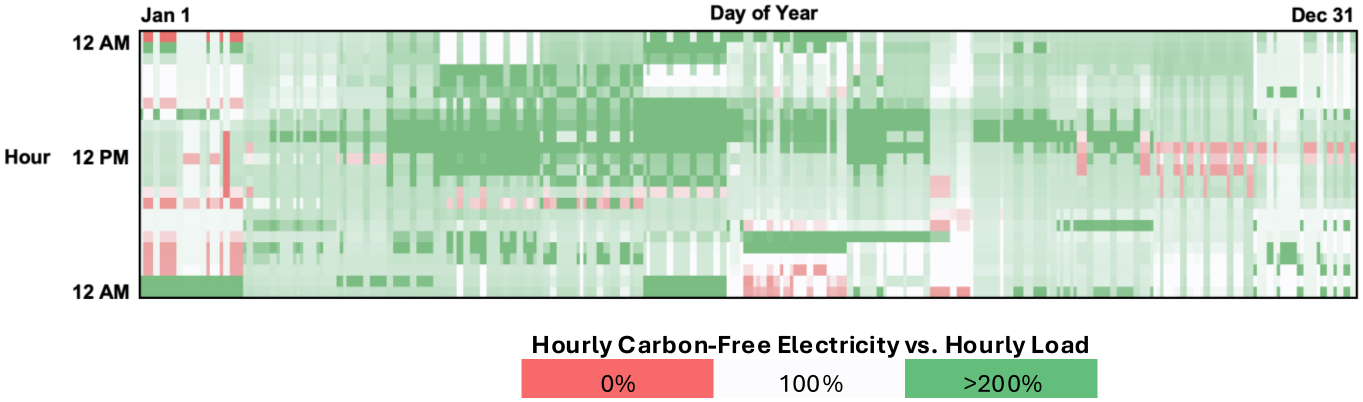
100% Annual Matching, Mature Technologies Only (Glenarm Replacement)



Initial Learnings & Portfolio Highlights:

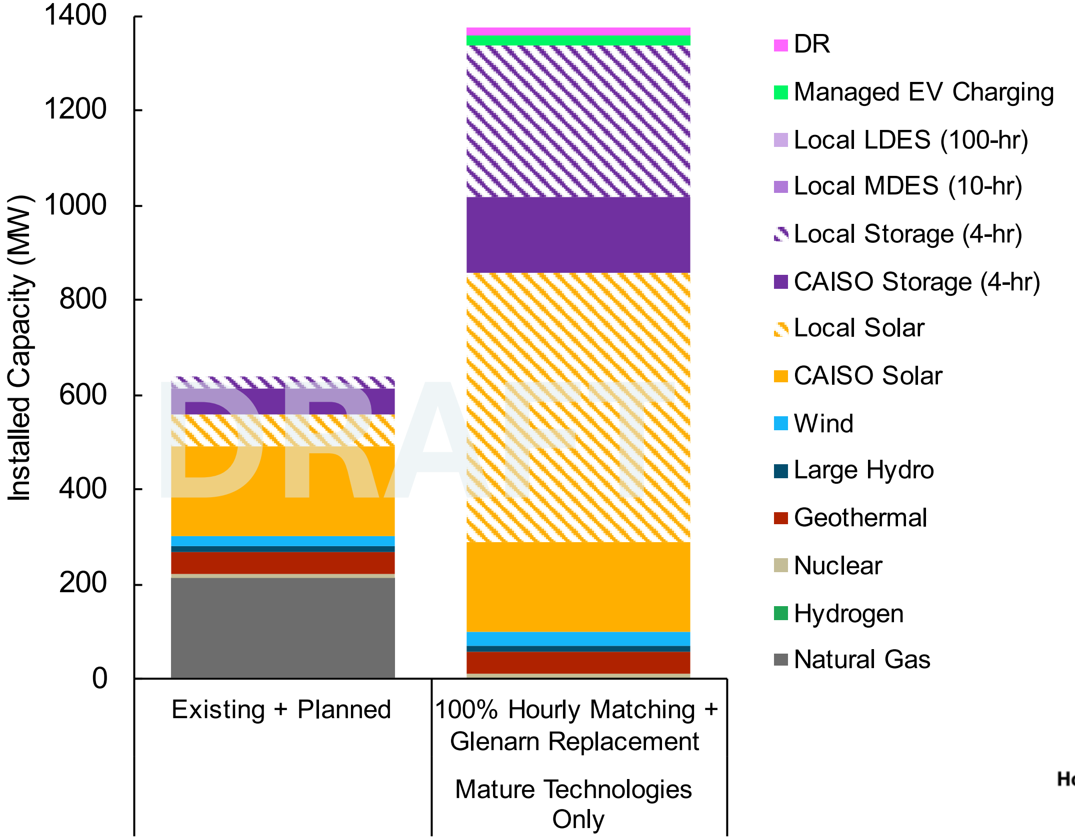
+ **Local solar and storage at significant scale needed to replace Glenarm while maintaining local reliability, resulting in very high incremental costs**
+ **Even with the scale of local resource development, there are still some periods where this portfolio relies on the market to meet PWP needs**

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 100%	Metric 3: 90%*
2031 Incremental Cost:	+$101 million per year		



* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

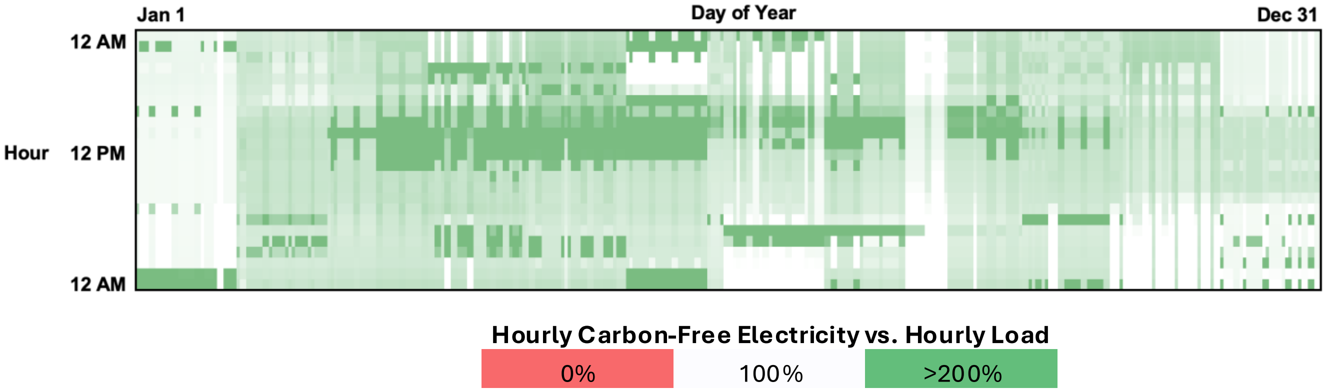
100% Hourly Matching, Mature Technologies Only (Glenarm Replacement)



Initial Learnings & Portfolio Highlights:

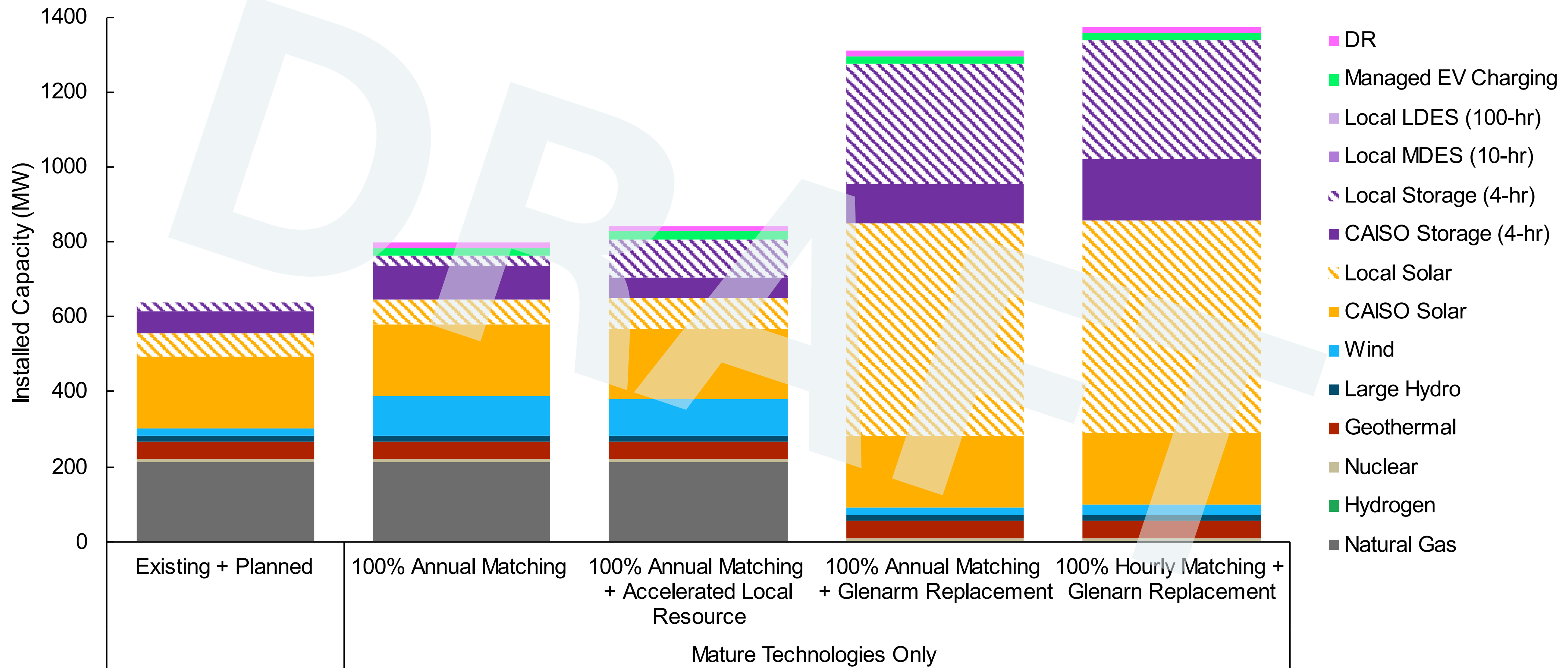
+ Achieving 100% hourly matching requires (1) significant local resource additions to replace Glenarm, (2) additional external resources to eliminate reliance on market, and (3) self-scheduling of energy storage resources to meet PWP needs (rather than maximizing value)

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 100%	Metric 3: 100%*
2031 Incremental Cost:	+$112 million per year		

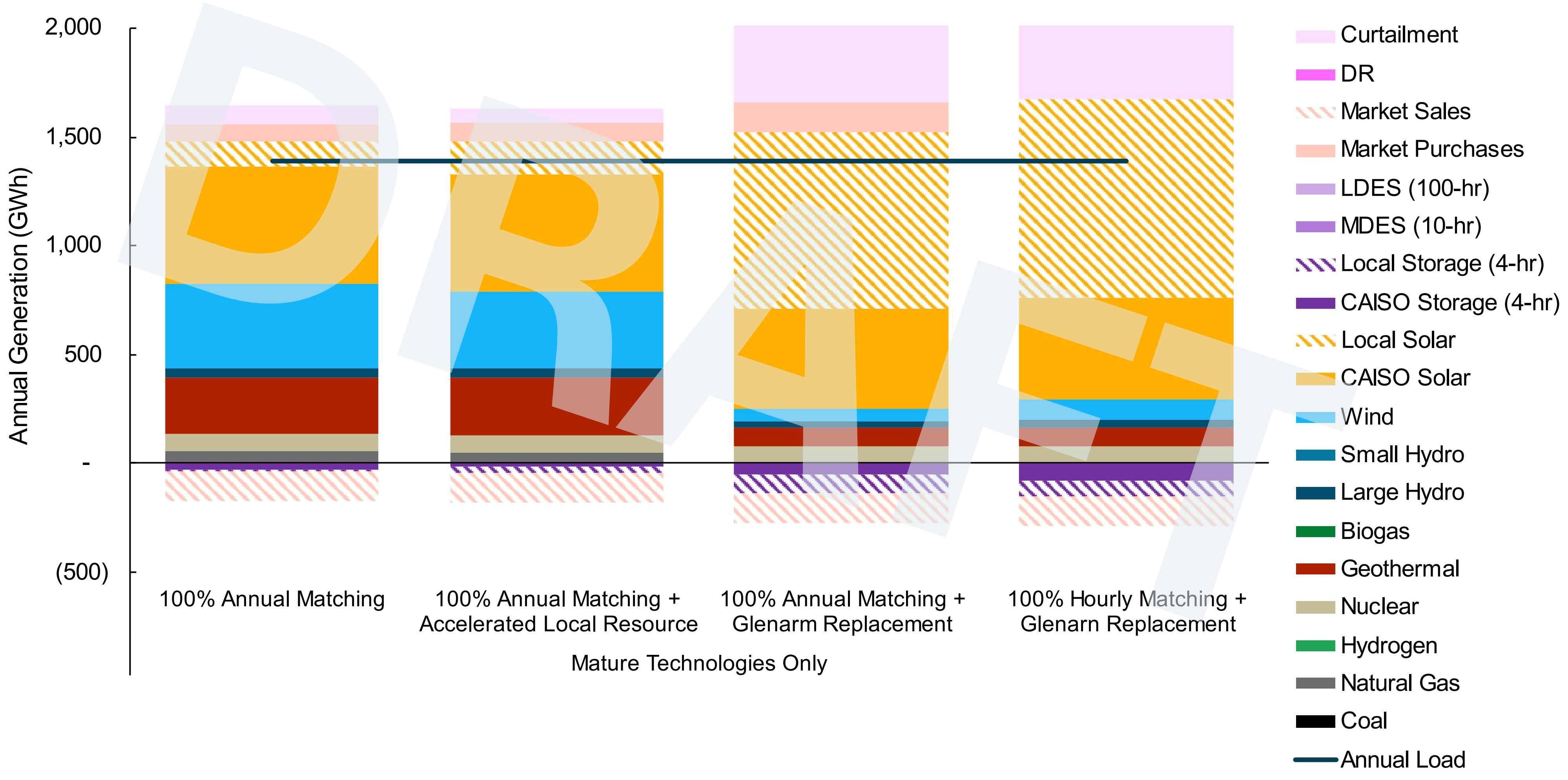


* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

Total Installed Capacity (MW) in 2031

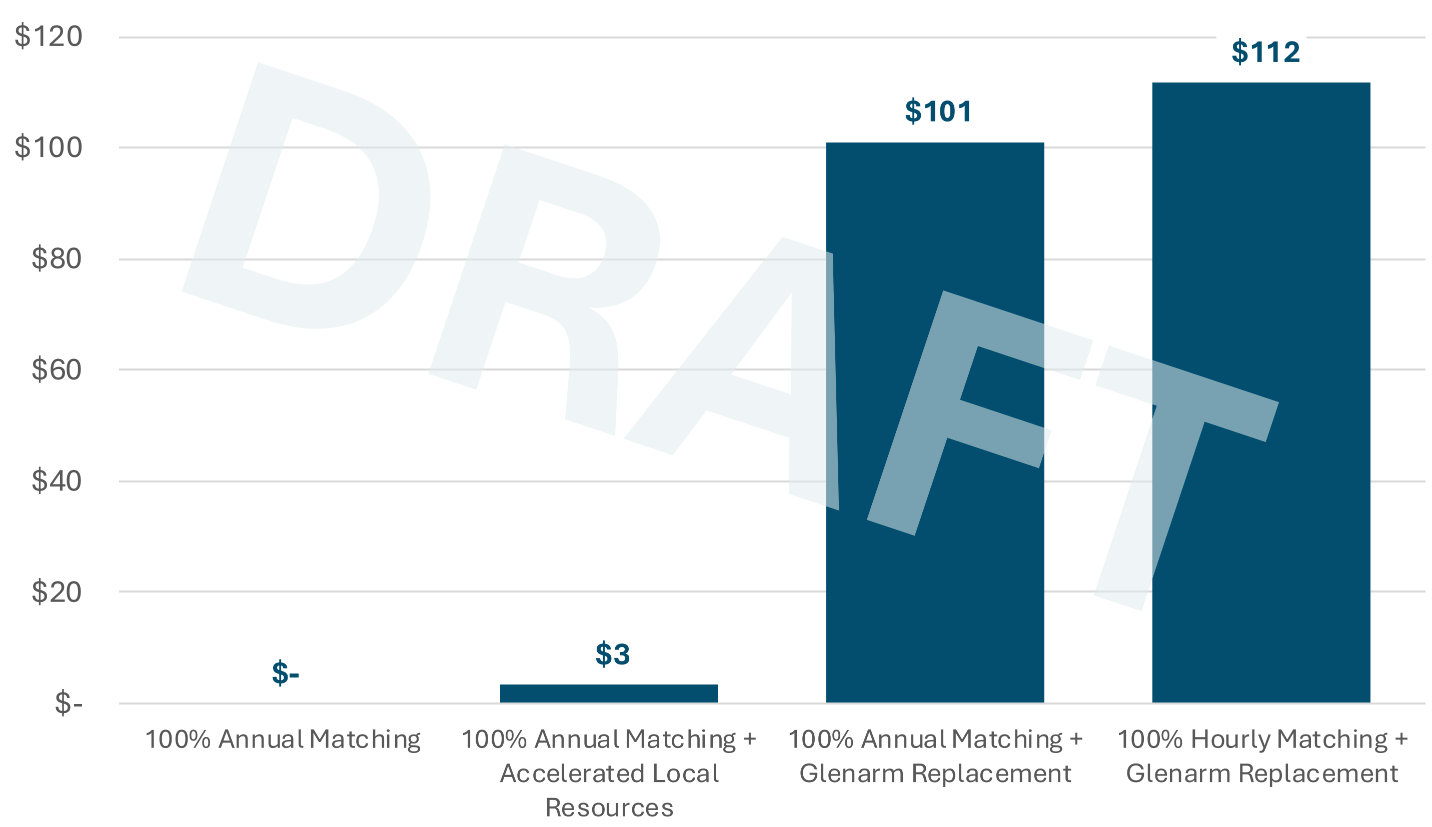


Annual Generation (GWh) in 2031



Relative Total System Costs in 2031, Mature Technologies Only

2031 Relative Incremental Total System Cost
($ million)



Note: PWP's current revenue requirement is approximately $200M. Absent robust public data, costs for developing local parking canopy solar were assumed to comparable to commercial rooftop solar. If parking canopy solar were closer to the cost of residential rooftop solar, the cost for the 100% Annual Matching + Glenarm Replacement case would be $38M higher.

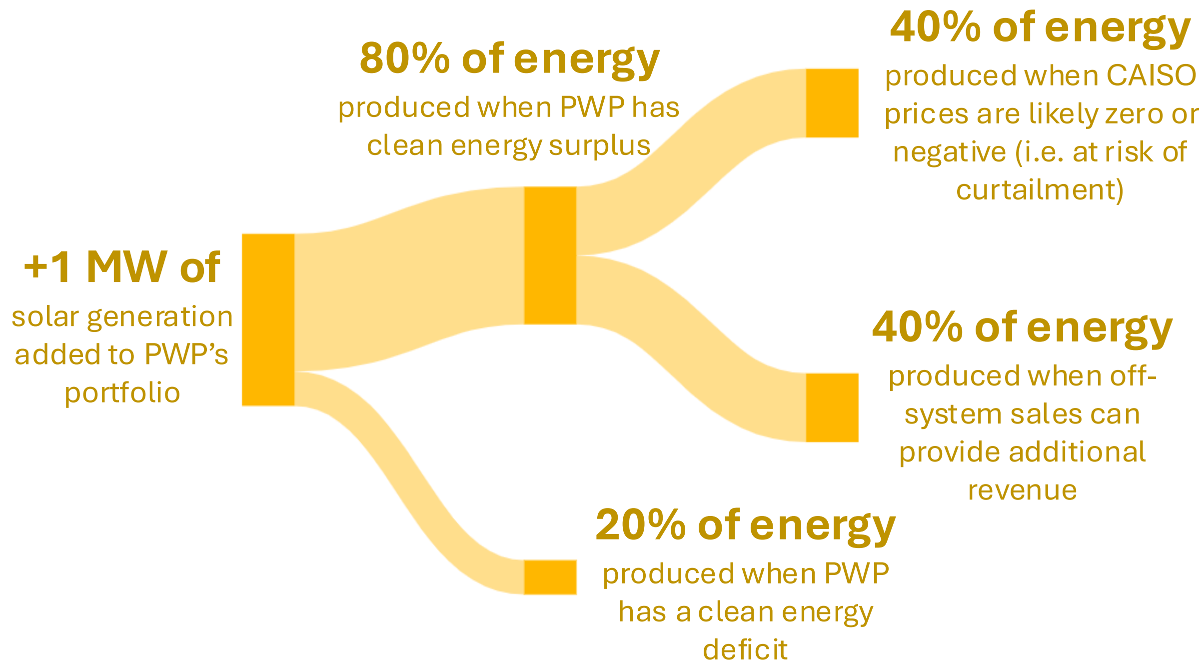
Drivers of Cost Differences Among Cases:

- **Procurement costs for new renewables and storage resources**
  - NOTE: Costs associated with naturally occurring customer adoption of solar & storage are not included in system cost metrics.
- **Fuel and O&M costs for PWP-owned resources**
- **Differences in market purchase costs**

Outstanding Cost Categories to Incorporate:

- **Existing resource fixed costs/PPA costs**
- **Other revenue requirement components (e.g. dx costs)**

Resource Diversity is an Important Consideration to Manage Market & Curtailment Risks



Based on results from 100% Annual Matching, Mature Technologies Only, 2031

- With high levels of procurement of one resource types, there is significant risks for high levels of curtailment of generation that cannot be sold to the market.
- When PWP's has an excess of solar generation, the utility may not be able to sell it to the CAISO market which is highly saturated with solar.

Forecasted Carbon Metrics, 2031, Mature Technologies Only

Metric 1: Share of PWP's **annual retail sales** that is carbon-free
Metric 2: Share of PWP's total **annual generation**[1] that is carbon-free
Metric 3: Share of PWP's **hourly energy needs**[1] that is carbon-free

Metric	Planned + Existing Resources[2]	100% Annual Matching	100% Annual Matching + Accelerated Local Resources	100% Annual Matching + Glenarm Replacement	100% Hourly Matching + Glenarm Replacement
Metric 1	103%	107%	108%	115%	128%
Metric 2	94%	96%	97%	100%	100%
Metric 3	88%	90%	90%	90%	100%

1. Includes retail sales, T&D losses, and storage losses
2. https://pwp.cityofpasadena.net/clean-energy-tracker/

Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel #9

February 26, 2025

Energy+Environmental Economics

Nick Schlag, Partner
Mike Sontag, Director
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Sr. Managing Consultant

Agenda

- **Follow-up on TAP #8**
- **Recap of LTCE Case Studies for Mature Technologies Only**
- **Additional LTCE Case Studies**
  - Long-Duration Energy Storage
  - Glenarm Hydrogen Conversion
- **Fuel price sensitivities**
- **Next steps**

Hydrogen Fuel Cell Analysis

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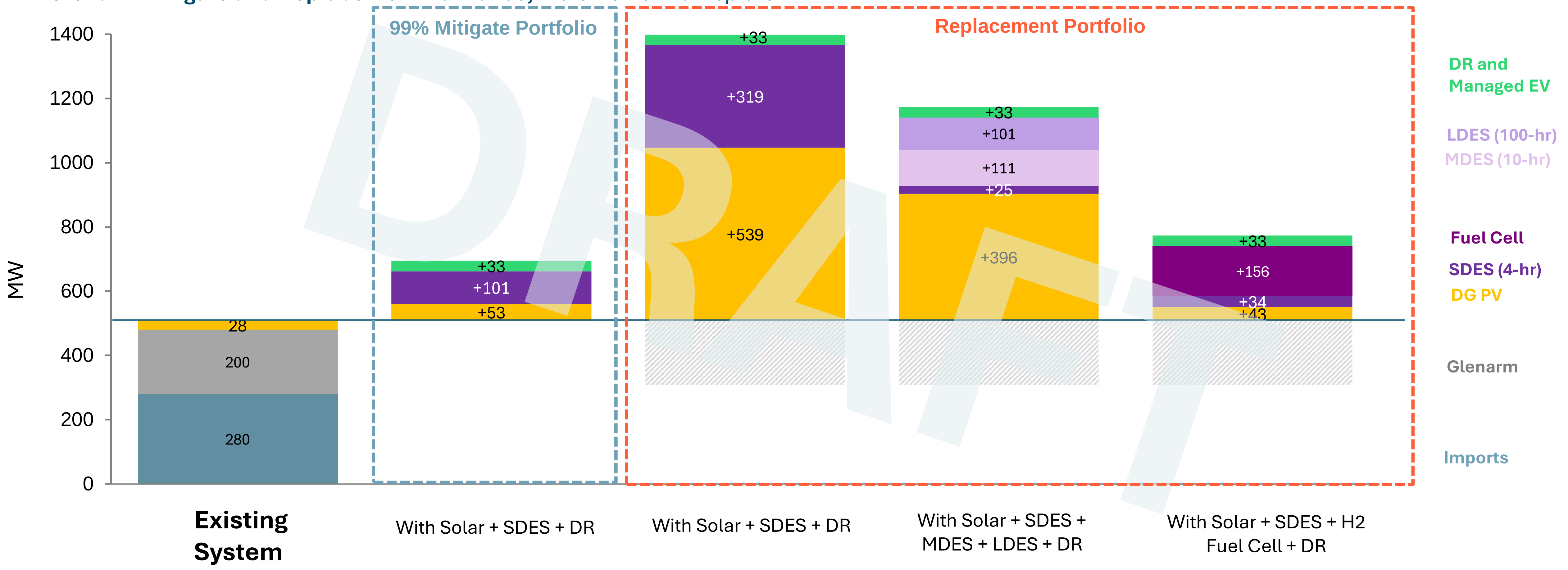
Glenarm Replacement Portfolio with Fuel Cells

Glenarm Mitigate and Replacement Portfolios, *Incremental Nameplate MW*



These values represent the minimum quantities of resources needed to ensure local reliability. Additional local resources will be included in portfolios to the extent that (a) the rate of naturally occurring customer adoption exceeds this level or (b) additional resources are found to be economic in LTCE. E3's modeling indicates that naturally occurring adoption could result in an additional ~35 MW of customer-owned resources by 2031.

Hydrogen consumption for combustion vs fuel cells

	Hydrogen Combustion	Hydrogen Fuel Cell
Nameplate Capacity	200 MW	156 MW
Efficiency (%)	32%	55%
Fuel consumption for 1 hour	16 tons	7 tons
1 Day of Operations		
Run time	8 hours	24 hours
Generation	1.6 GWh	3.7 GWh
Fuel consumption	125 tons	175 tons
Annual Operations		
Capacity Factor	3%	90%
Generation	55 GWh	1,230 GWh
Fuel Consumption	4,155 tons	56,940 tons

At scale, hydrogen fuel cells would consume more fuel than combusting hydrogen in a low-capacity factor generator. Supplying hydrogen for fuel cells would require a dedicated pipeline.

LTCE Modeling Results: Mature Technologies Only

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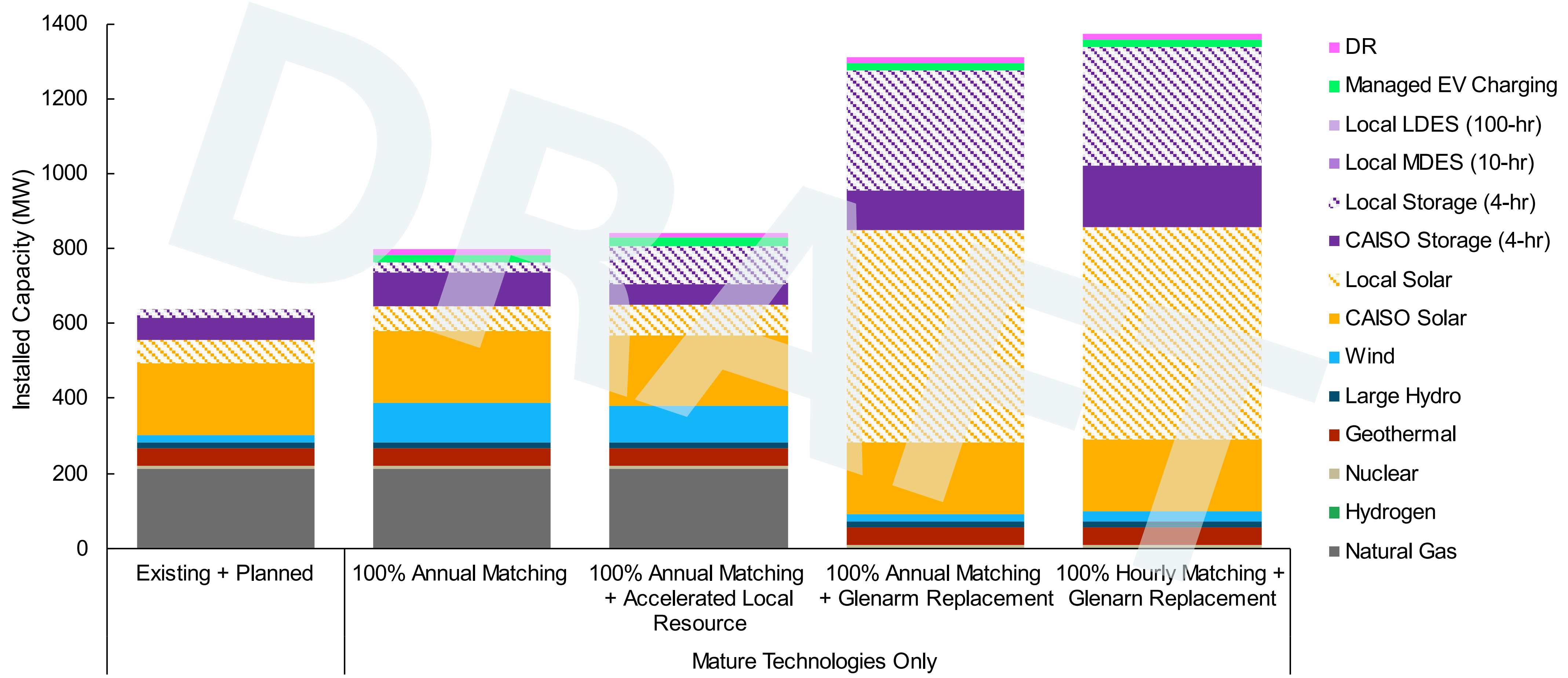
Case-Specific Modeling Assumptions

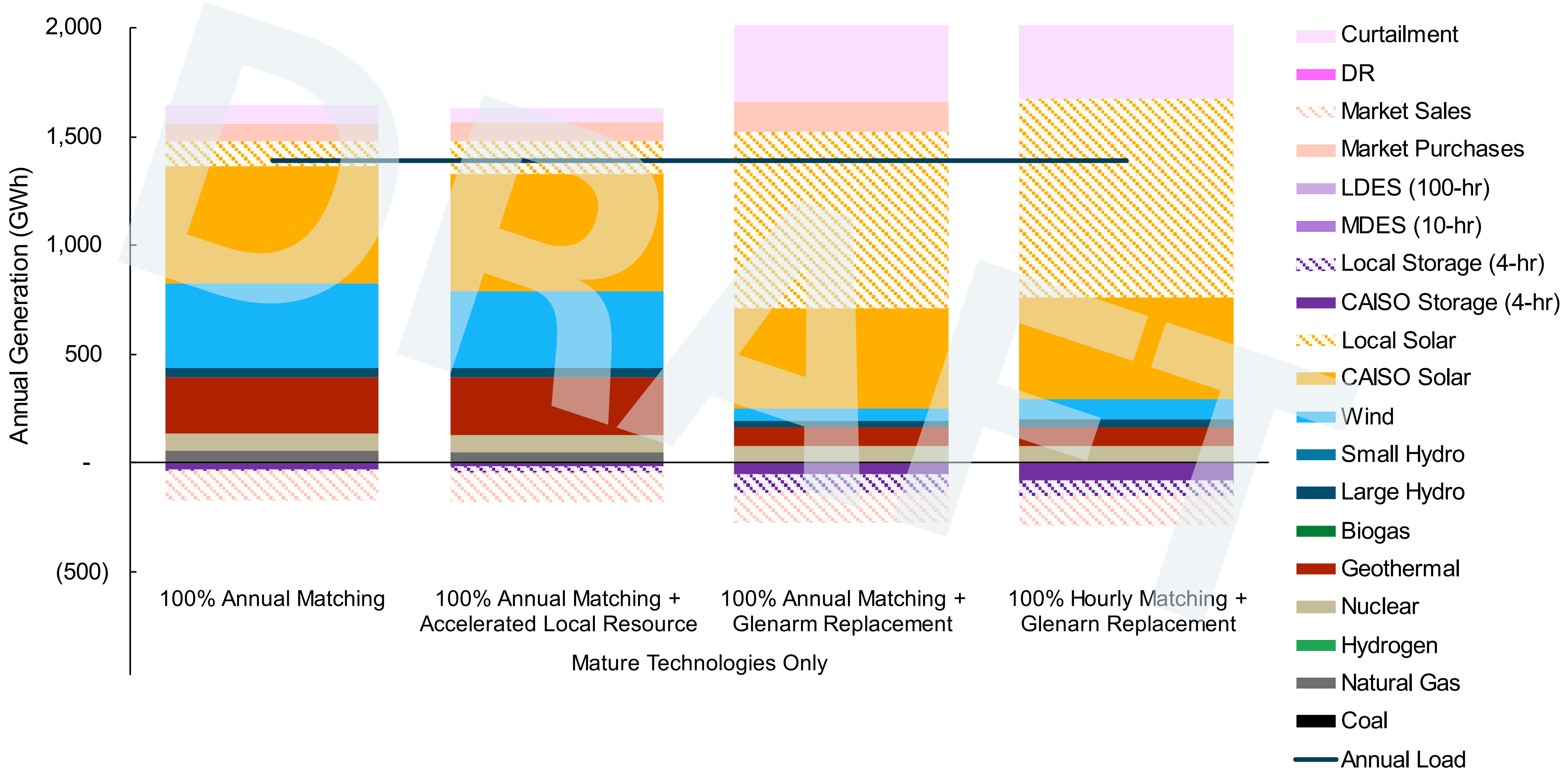
No.	Portfolio Name	Glenarm	Local resource portfolio (2031)	Market Purchases (2031)	
1	100% Annual Matching	Retained*	66 MW local solar 26 MW 4-hr storage	No net market purchases	Mature Technologies Only
2	100% Annual Matching (Accelerated Local Resources)	Retained*	81 MW local solar 101 MW 4-hr storage	No net market purchases	
3	100% Annual Matching (Glenarm Replacement)	Replaced	567 MW local solar 319 MW 4-hr storage	No net market purchases	
4	100% Hourly Matching	Replaced	567 MW local solar 319 MW 4-hr storage	No market purchases	
5	100% Annual Matching (with Hydrogen)	H_2 Conversion	66 MW local solar 26 MW 4-hr storage	No net market purchases	Mature Technologies + Hydrogen
6	100% Hourly Matching (with Hydrogen)	H_2 Conversion	66 MW local solar 26 MW 4-hr storage	No market purchases	
7	100% Annual Matching (with LDES)	Replaced	396 MW local solar, 25 MW 4-hr storage, 101 MW MDES, 111 MW LDES	No net market purchases	Mature Technologies + LDES
8	100% Hourly Matching (with LDES)	Replaced	396 MW local solar, 25 MW 4-hr storage, 101 MW MDES, 111 MW LDES	No market purchases	

*Sensitivity analysis will explore use of renewable natural gas at Glenarm.

Total Installed Capacity (MW) in 2031



Annual Generation (GWh) in 2031



Mature Technologies Only: Initial Learnings and Portfolio Highlights

1. Modest additions of renewable resources and storage by 2031 allow PWP to meet all system needs and serve >100% of annual energy needs with carbon-free generation.
2. Accelerating the development of local resources reduces the need to procure external resources and reduces the operations of Glenarm
3. Local solar and storage at significant scale is needed to replace Glenarm while maintaining local reliability, resulting in very high incremental costs
4. To achieve 100% hourly matching, additional external resources are needed to eliminate reliance on the market and energy storage resources must be self-scheduled to meet PWP's need for clean energy on an hourly basis (rather than maximizing the value of storage resources).

LTCE Modeling Results: Long Duration Storage & Hydrogen

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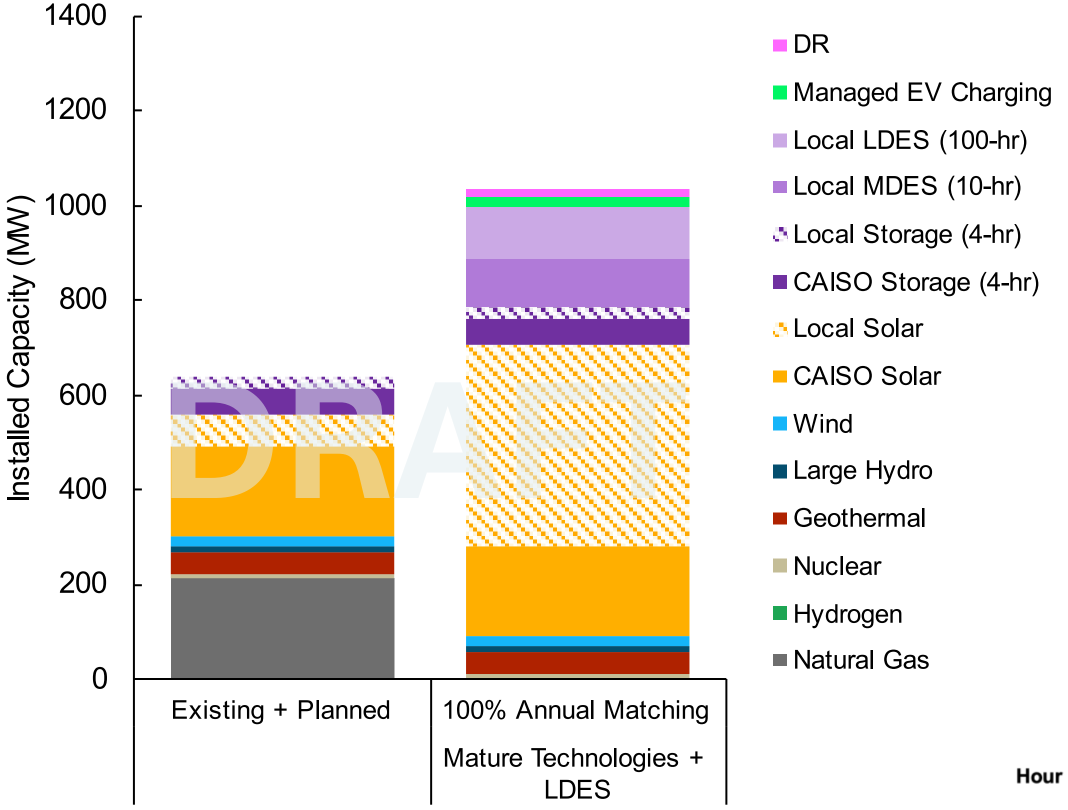
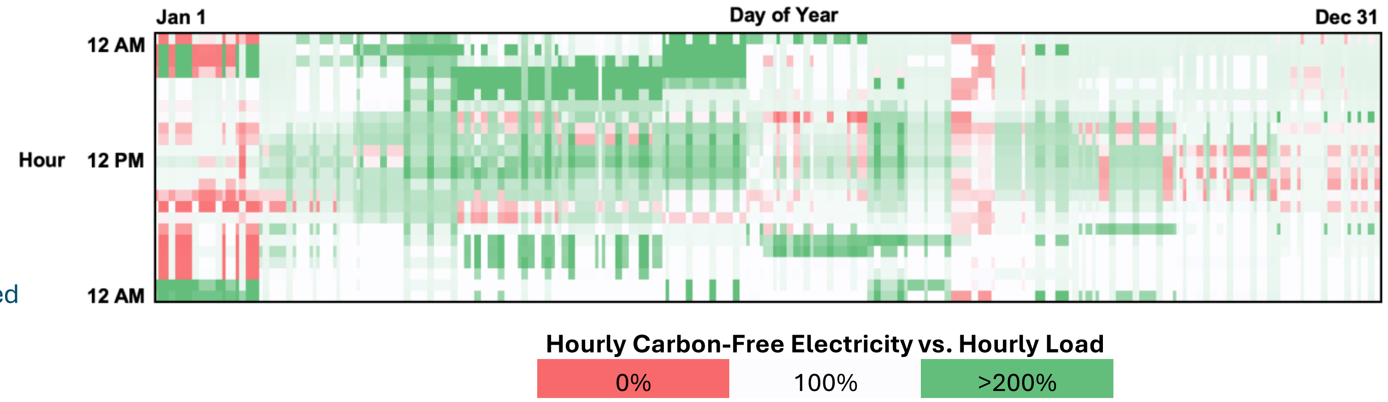
100% Annual Matching, Mature Technologies + LDES



Initial Learnings & Portfolio Highlights:

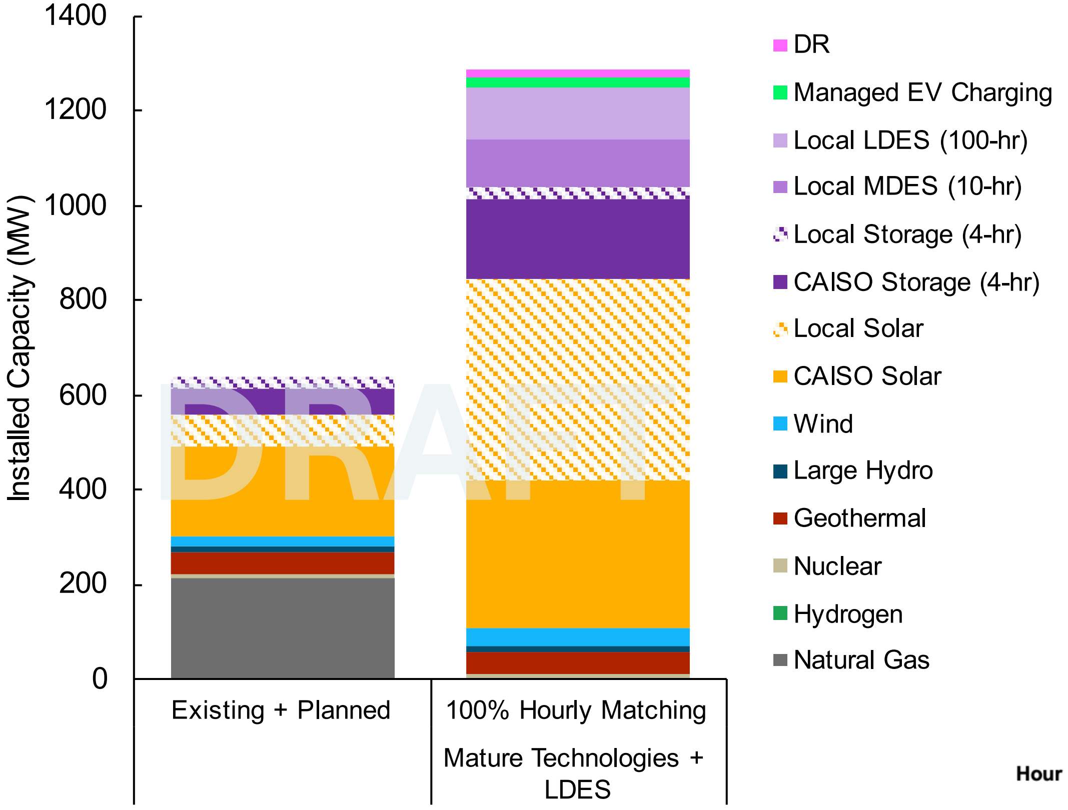
+ **Local solar and storage at significant scale needed to replace Glenarm even with long-duration and medium-duration storage technologies available.**
+ **Even with scale of local resource development, there are still some periods where this portfolio relies on the market to meet PWP needs**

Forecasted Clean Energy Metrics:	**Metric 1:** 100%+	**Metric 2:** 100%	**Metric 3:** 90%*
2031 Incremental Cost:	**+$92 million per year**		



* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

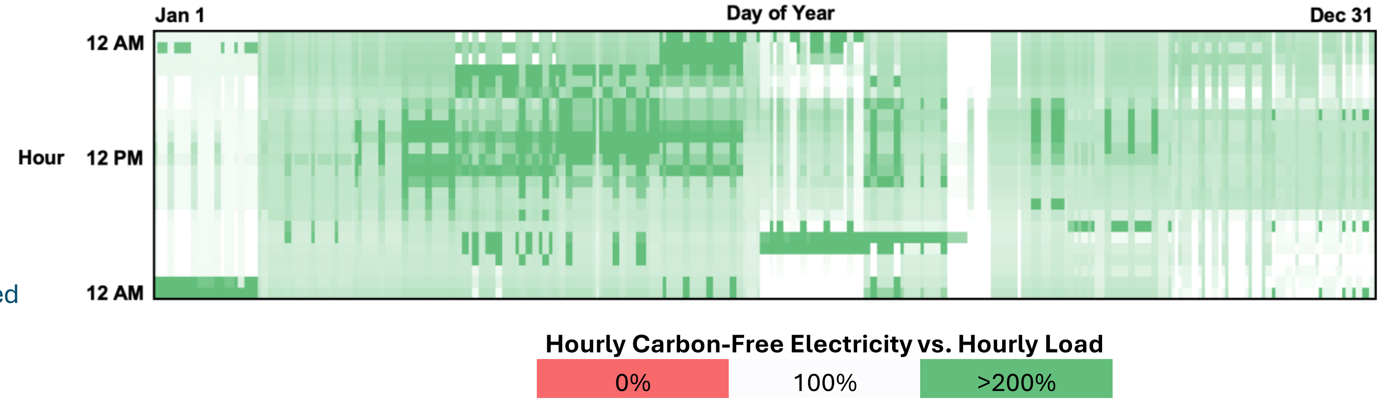
100% Hourly Matching, Mature Technologies + LDES



Initial Learnings & Portfolio Highlights:

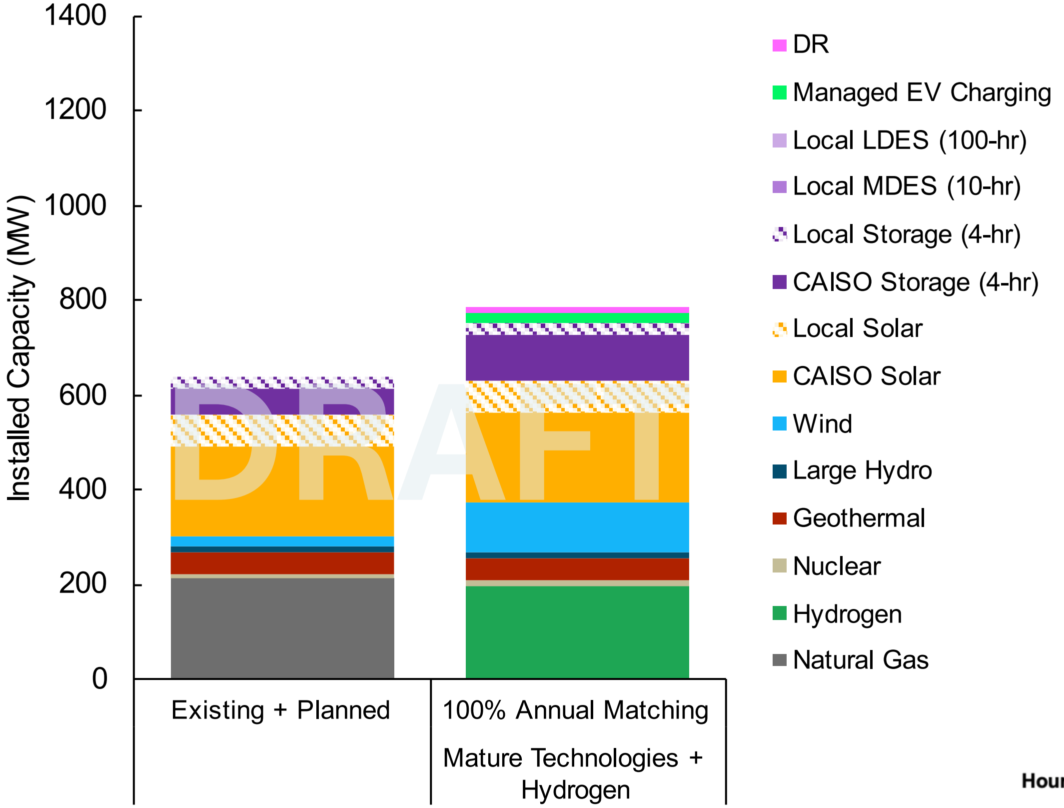
+ Achieving 100% hourly matching requires significant local and external resources to match clean generation with load.
+ Higher incremental cost relative to mature technologies only case indicates that utilizing emerging LDES in 2031 may not be cost-effective.

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 100%	Metric 3: 100%*
2031 Incremental Cost:	+$126 million per year		



* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

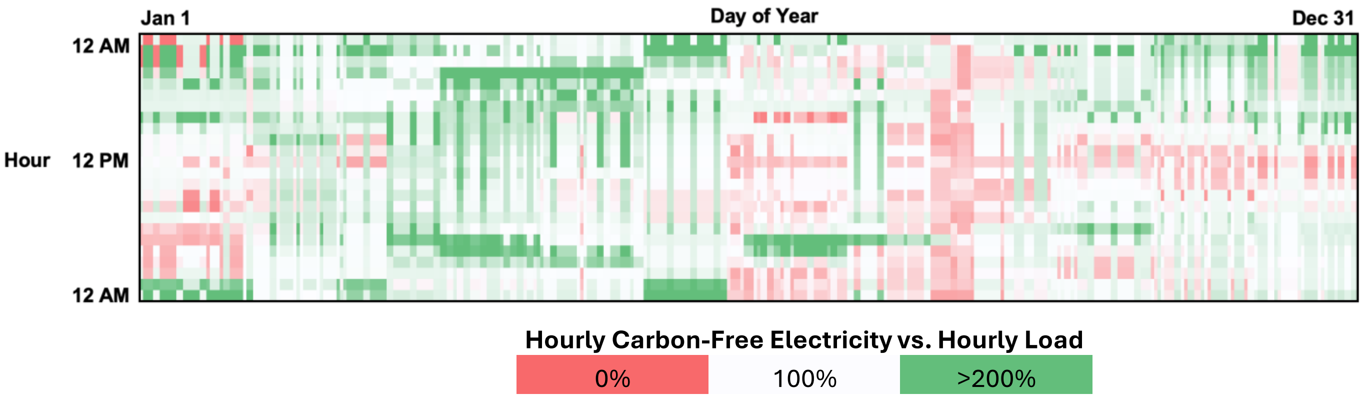
100% Annual Matching, Mature Technologies + Hydrogen Conversion



Initial Learnings & Portfolio Highlights:

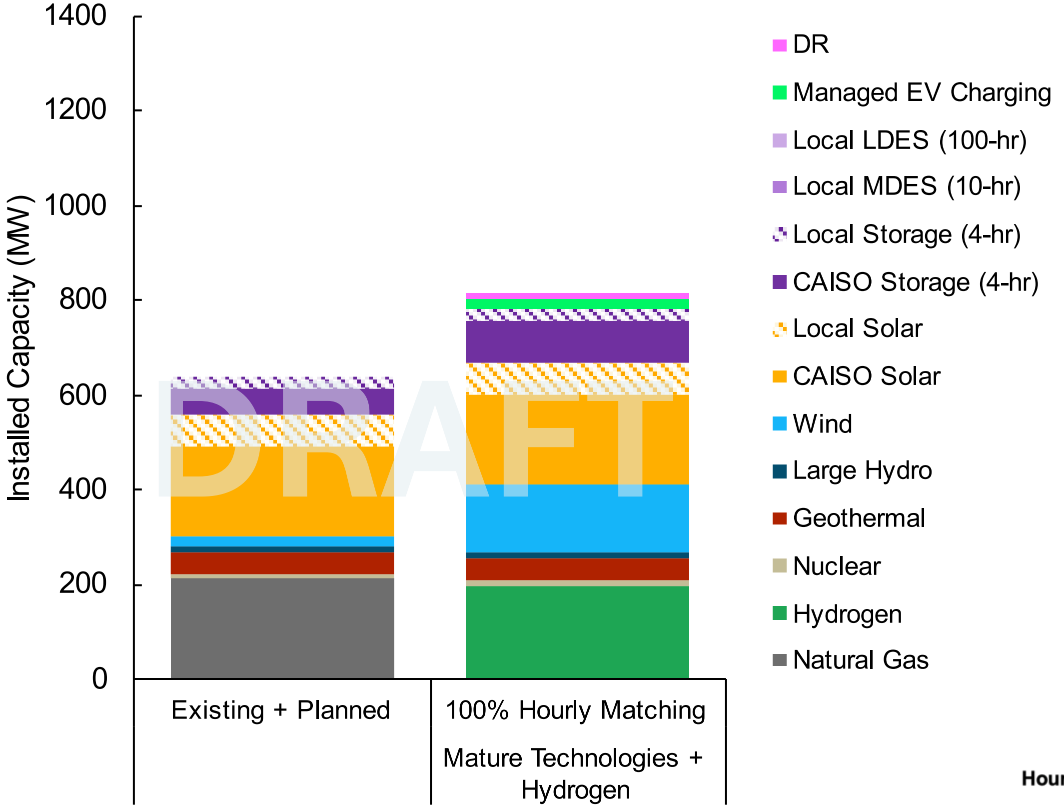
- **With Glenarm retained, a modest incremental additions of renewables and storage allow PWP to meet 100% of annual energy needs with carbon-free sources.**
- **Higher incremental costs are driven primarily by the retrofit costs for Glenarm hydrogen conversion.**

Forecasted Clean Energy Metrics:	**Metric 1:** 100%+	**Metric 2:** 100%	**Metric 3:** 90%*
2031 Incremental Cost:	**+$17 million per year**		



* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

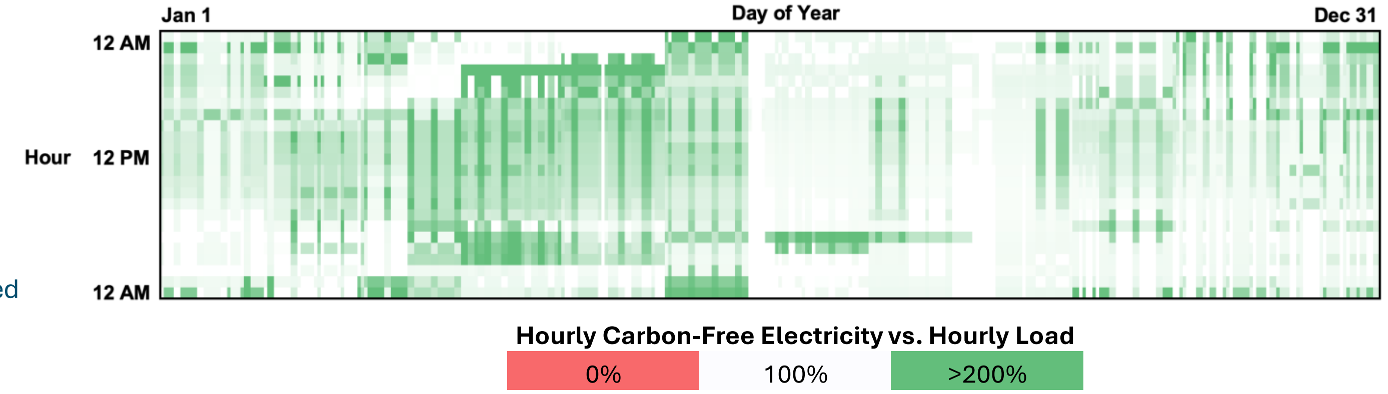
100% Hourly Matching, Mature Technologies + Hydrogen Conversion



Initial Learnings & Portfolio Highlights:

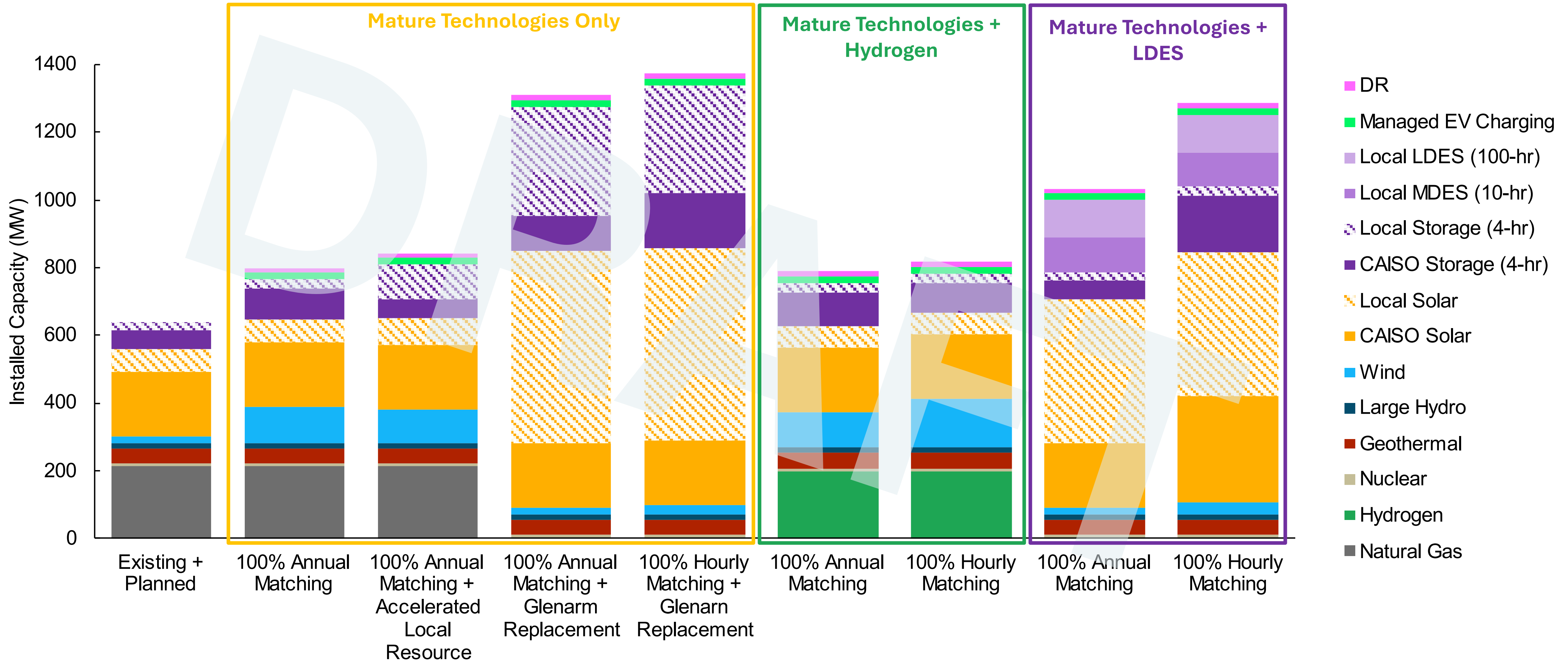
+ Conversion of Glenarm to hydrogen eliminates direct fossil fuel consumption while supporting local reliability needs
+ Lower incremental cost (vs. Mature Technologies Only) indicates potential benefits of emerging technologies – but significant uncertainty remains

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 100%	Metric 3: 100%*
2031 Incremental Cost:	+$28 million per year		

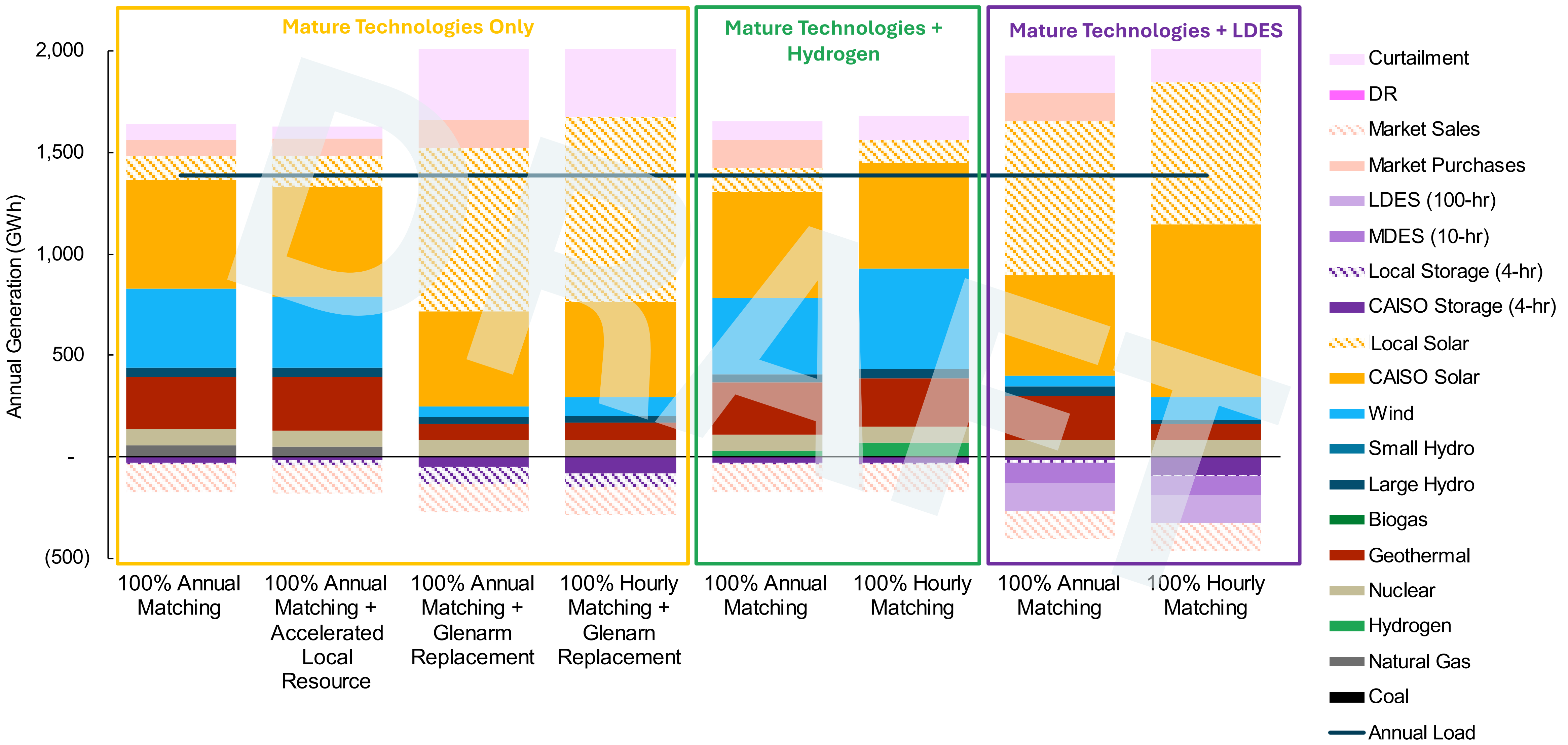


* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

Total Installed Capacity (MW) in 2031



Annual Generation (GWh) in 2031



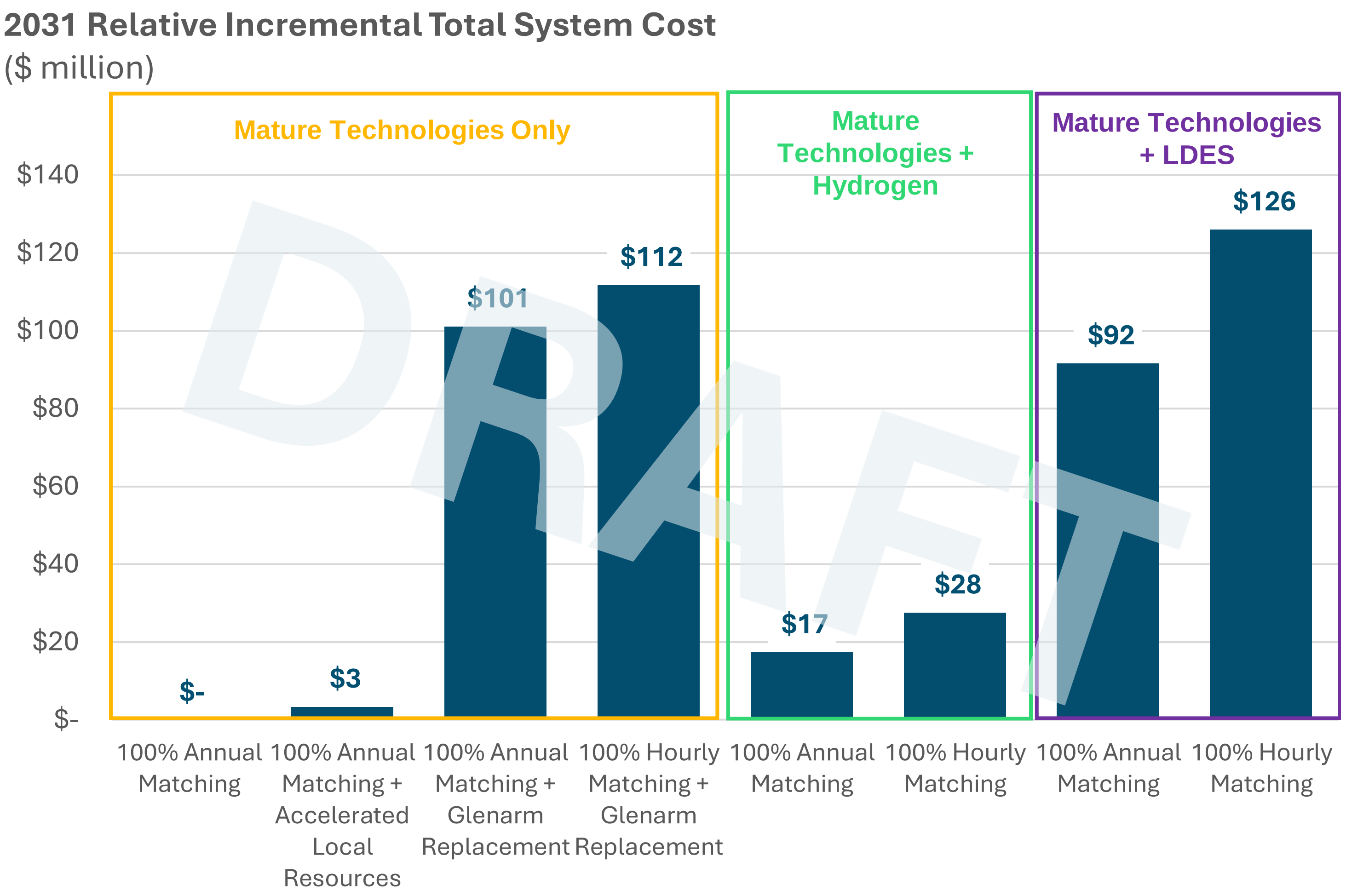
Forecasted Carbon Metrics, 2031

Metric 1: Share of PWP's **annual retail sales** that is carbon-free
Metric 2: Share of PWP's total **annual generation**[1] that is carbon-free
Metric 3: Share of PWP's **hourly energy needs**[1] that is carbon-free

		Mature Technology Only				Mature Technology + Hydrogen		Mature Technology + LDES	
Metric	Planned + Existing Resources[2]	100% Annual Matching	100% Annual Matching + Accelerated Local Resources	100% Annual Matching + Glenarm Replacement	100% Hourly Matching + Glenarm Replacement	100% Annual Matching	100% Hourly Matching	100% Annual Matching	100% Hourly Matching
Metric 1	103%	107%	108%	115%	128%	107%	118%	126%	142%
Metric 2	94%	96%	97%	100%	100%	100%	100%	100%	100%
Metric 3[3]	88%	90%	90%	90%	100%	90%	100%	90%	100%

1. Includes retail sales, T&D losses, and storage losses
2. https://pwp.cityofpasadena.net/clean-energy-tracker/
3. Analysis of metric 3 is under refinement and subject to changed. Values presented for OSP portfolios here represent a lower bound.

Relative Total System Costs in 2031



Note: PWP's current revenue requirement is approximately $200M. Absent robust public data, costs for developing local parking canopy solar were assumed to comparable to commercial rooftop solar. If parking canopy solar were closer to the cost of residential rooftop solar, the cost for the 100% Annual Matching + Glenarm Replacement case would be $38M higher.

Drivers of Cost Differences Among Cases:

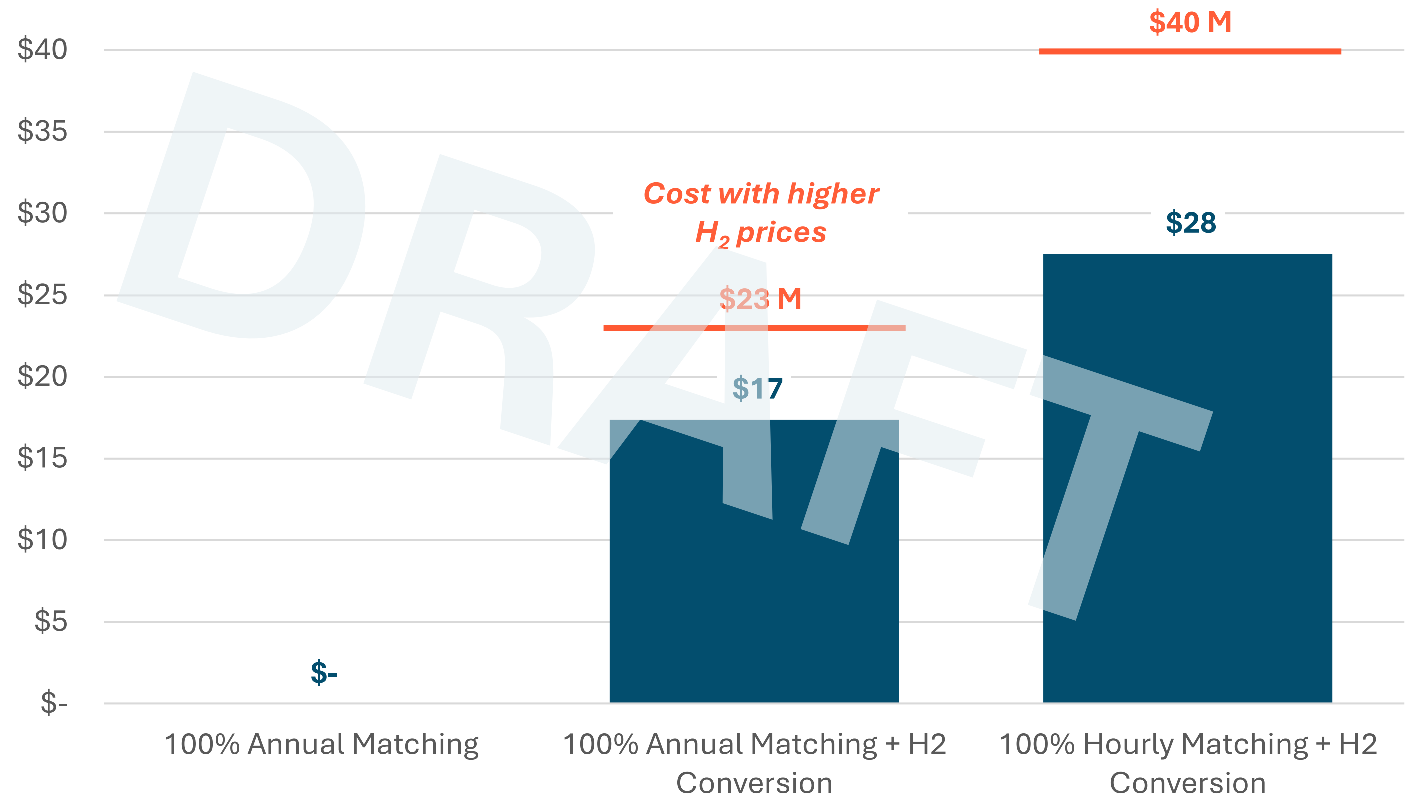
- **Procurement costs for new renewables and storage resources**
  - NOTE: Costs associated with naturally occurring customer adoption of solar & storage are not included in system cost metrics.
- **Fuel and O&M costs for PWP-owned resources**
- **Differences in market purchase costs**

Outstanding Cost Categories to Incorporate:

- **Existing resource fixed costs/PPA costs**
- **Other revenue requirement components (e.g. dx costs)**

Green Hydrogen Cost Sensitivity

2031 Relative Incremental Total System Cost
($ million)



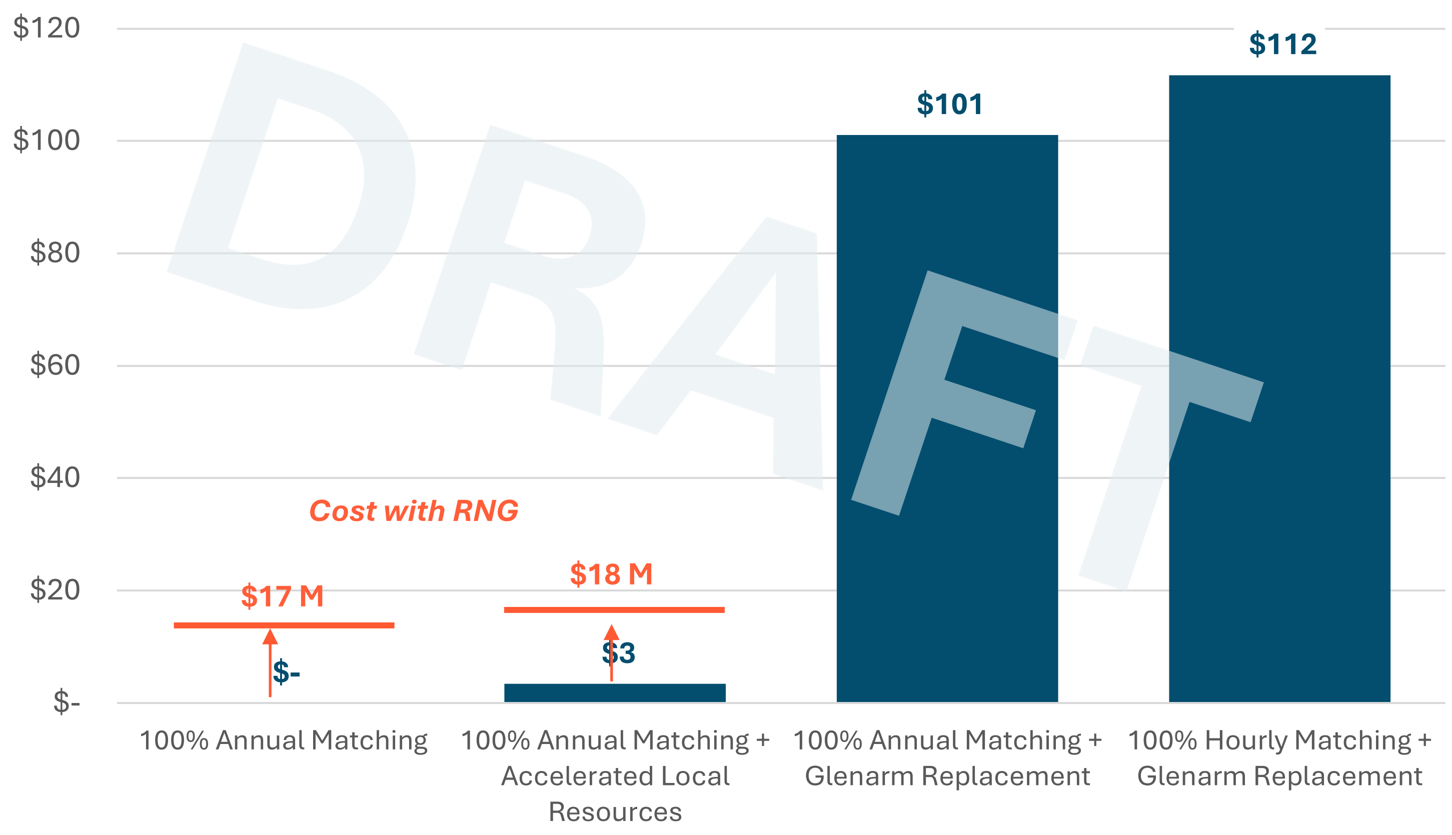
- **With higher hydrogen costs ($31/MMBtu nominal vs $12) in 2031, incremental total system costs could be between $5-13 M/year higher**
  - High marginal fuel prices have lower impact on total costs due to low capacity factors at Glenarm
- **To achieve hourly matching, Glenarm would likely operate more exposing PWP to greater risk if hydrogen fuel prices are higher.**

Annual generation from Glenarm:
200 MW x 2% CF x 8760 hr/yr = 31 GWh/year

Additional cost with high H_2 prices:
31 GWh/year x 9 MMBTu/MWh * ($31/MMBtu - $12/MMBtu) = **$6M**

Cost Sensitivity: Impact of Renewable Natural Gas Procurement

2031 Relative Incremental Total System Cost
($ million)



- **The incremental total system cost of procuring renewable natural gas for Glenarm is small ($15-20 M/year) compared to the costs of replacing Glenarm with a portfolio of local resources.**
- **Adding local resources to reduce Glenarm's operations lowers the incremental fuel costs PWP would incur if purchasing RNG for Glenarm.**

Annual generation from Glenarm:
200 MW x 3% CF x 8760 hr/yr = 56 GWh/year

Approximate incremental cost for RNG in 2031:
56 GWh/year x 9 MMBTu/MWh * ($44/MMBtu RNG - $10/MMBtu Fossil Gas) = **$17M/yr**

Forecasted Carbon Metrics, 2031, with Renewable Natural Gas

Metric 1: Share of PWP's **annual retail sales** that is carbon-free
Metric 2: Share of PWP's total **annual generation**[1] that is carbon-free
Metric 3: Share of PWP's **hourly energy needs**[1] that is carbon-free

Metric	Planned + Existing Resources[2]	100% Annual Matching	100% Annual Matching + Accelerated Local Resources	100% Annual Matching + Glenarm Replacement	100% Hourly Matching + Glenarm Replacement
Metric 1	103%	107% *(112%)*	108% *(112%)*	115%	128%
Metric 2	94%	96% *(100%)*	97% *(100%)*	100%	100%
Metric 3[3]	88%	90% *(94%)*	90% *(94%)*	90%	100%

Values in parenthesis show results if RNG is substituted for natural gas and is counted toward the three clean energy metrics

1. Includes retail sales, T&D losses, and storage losses
2. https://pwp.cityofpasadena.net/clean-energy-tracker/
3. Analysis of metric 3 is under refinement and subject to changed. Values presented for OSP portfolios here represent a lower bound.

Recap and Next Steps

Energy+Environmental Economics

Initial Observations and Takeaways from LTCE Modeling

1. **Current forecasts indicate that PWP has procured carbon-free resources (including existing projects and projects under development) sufficient to match 100% of forecasted retail sales annually (Metric 1).**
   - Range of cases studied illustrate commonly-observed principle that closing the gap between 90-100% for Metrics 2 & 3 becomes increasingly challenging, and cases that achieve "100% hourly matching" exhibit hockey-stick increases in cost
2. **Replacing Glenarm with mature technologies by 2031 while maintaining reliability would require additions of local solar and storage at a level far beyond what is plausibly achievable, resulting in high incremental costs and presenting significant implementation challenges**
   - Despite increasingly infrequent operations, Glenarm currently provides significant reliability value as a firm resource that can (a) operate during extreme events and transmission contingencies and (b) contribute to CAISO local & system resource adequacy needs
   - Scale of solar resources included in replacement portfolios for Glenarm would require utilization of almost all viable parking lots and rooftops across the city, exceeding the naturally occurring adoption of customer solar by an order of magnitude
3. **Development of additional local carbon-free resources provides multiple benefits at limited incremental net cost even if Glenarm is needed for reliability:**
   - Reduced utilization of Glenarm, a benefit magnified if plant is operating using a high marginal cost fuel (e.g. RNG or hydrogen)
   - Improved local system reliability and resilience during extreme events
   - Additional opportunities for community engagement
4. **Emerging technologies may present alternative options to eliminate natural gas use at Glenarm in the long run but require significant technological advances and present additional costs and risks.**
5. **Consideration of PWP's position in the CAISO wholesale market will be important to manage cost and risk**
   - Additional renewable procurement will lead to "oversupply" in some periods (e.g. solar in spring), resulting in increasing risk of curtailment or sales at negative prices
   - Maintaining a small amount of flexibility to purchase from the market (while meeting 100% of *annual* needs with carbon-free energy) allows PWP to maximize the value of its resources and reduce costs relative to an "hourly matching" strategy that eliminates all reliance on the market

Next Steps

- Refinement of cases presented today
- Additional portfolio sensitivity analyses (e.g. transmission expansion)
- Technology cost sensitivities
- Cost impacts analyses

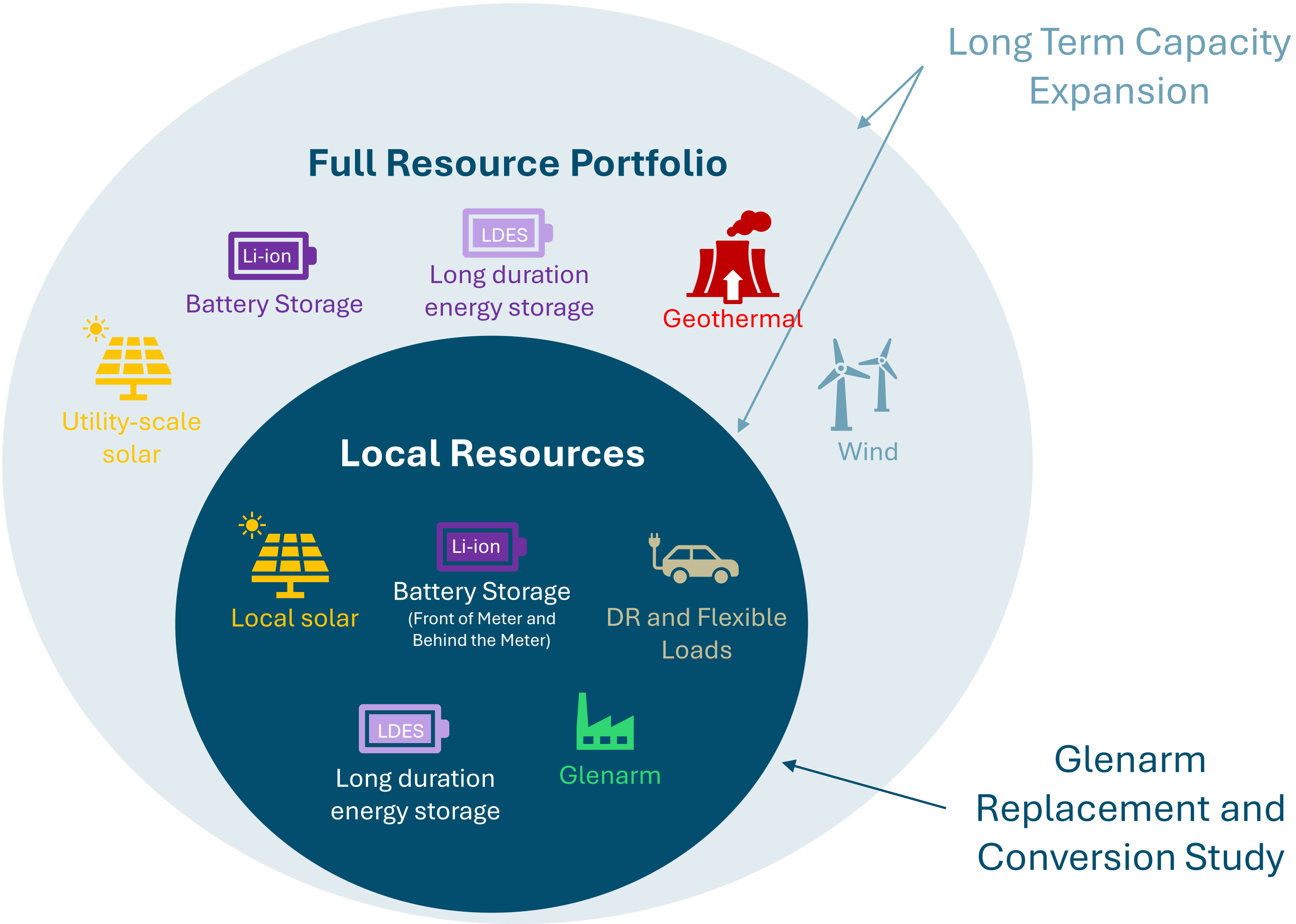
Appendix

Energy+Environmental Economics

Portfolio Development Process

Portfolio development process comprises two phases of analysis:

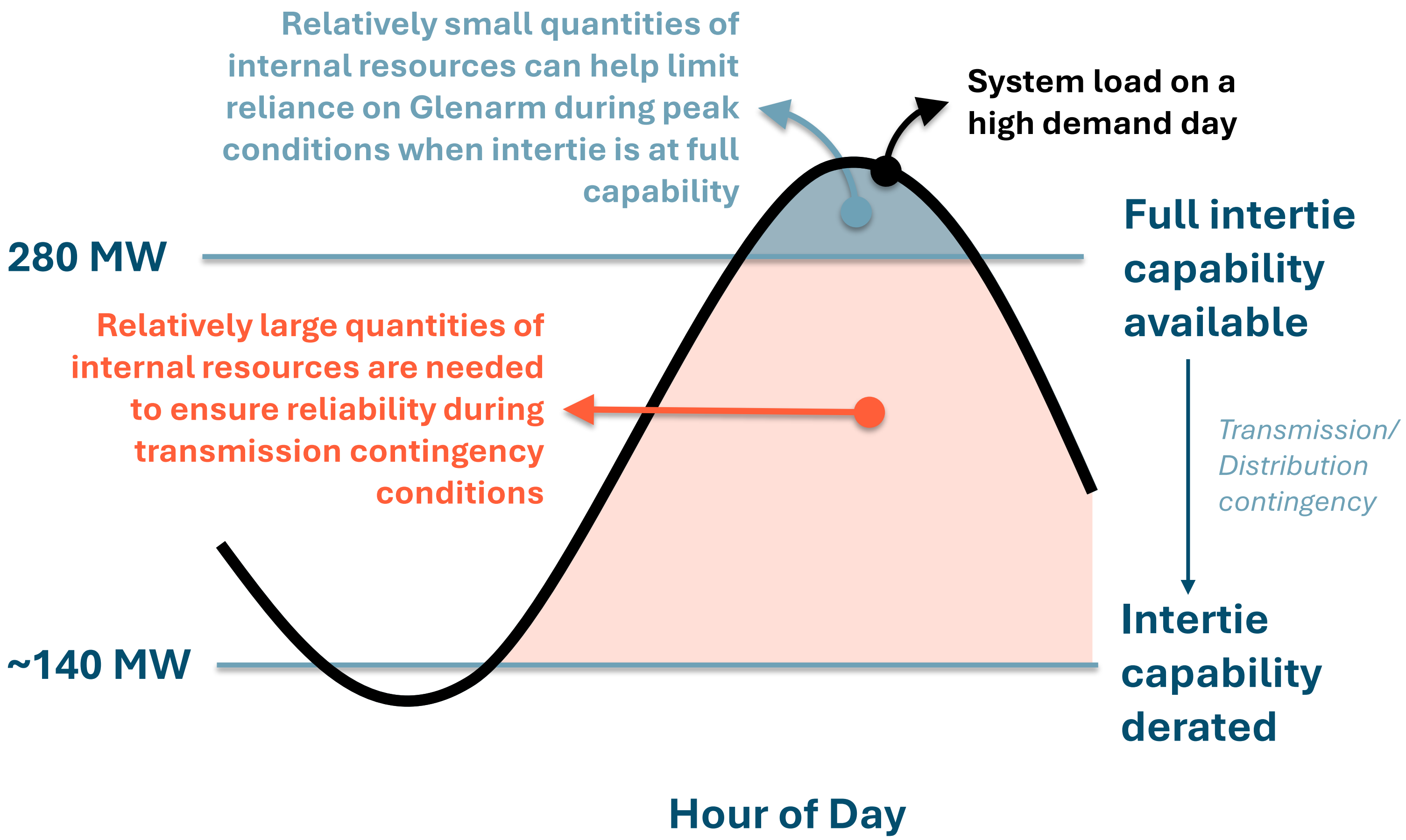
1. **Glenarm Replacement and Conversion Study: Identify a range of internal resource solutions to meet local reliability needs of PWP system given limitations of transmission system**
   - Focus on a single specific challenge on the path to Resolution 9977 goals
   - **Not yet considering relative cost of different options**
2. **Long-Term Capacity Expansion: Create complete resource portfolios that consider objectives of clean energy, reliability, affordability, and equity**
   - Focus on holistic view of resource portfolio to support Resolution 9977 goals



Visualizing Reliability Needs for Internal Generation

Maintaining reliability in Pasadena's service territory requires internal resources that can meet needs under a range of extreme conditions:

1. **During peak demand conditions (above import capability)**
2. **During transmission or distribution contingencies that reduce intertie capability**



Three Frames for Internal Reliability Analysis

Augment Glenarm	What internal resources are needed to meet growing loads while **maintaining reliability if Glenarm remains in service**?
Mitigate Glenarm	*What additional internal resources can **mitigate the need to operate Glenarm** under "normal" operating conditions (i.e. when import capability is available up to full 280 MW)?*
Replace Glenarm	What are the total resource needs to **maintain reliability even in the event of transmission contingency**?

Internal resources considered

Solar

Storage

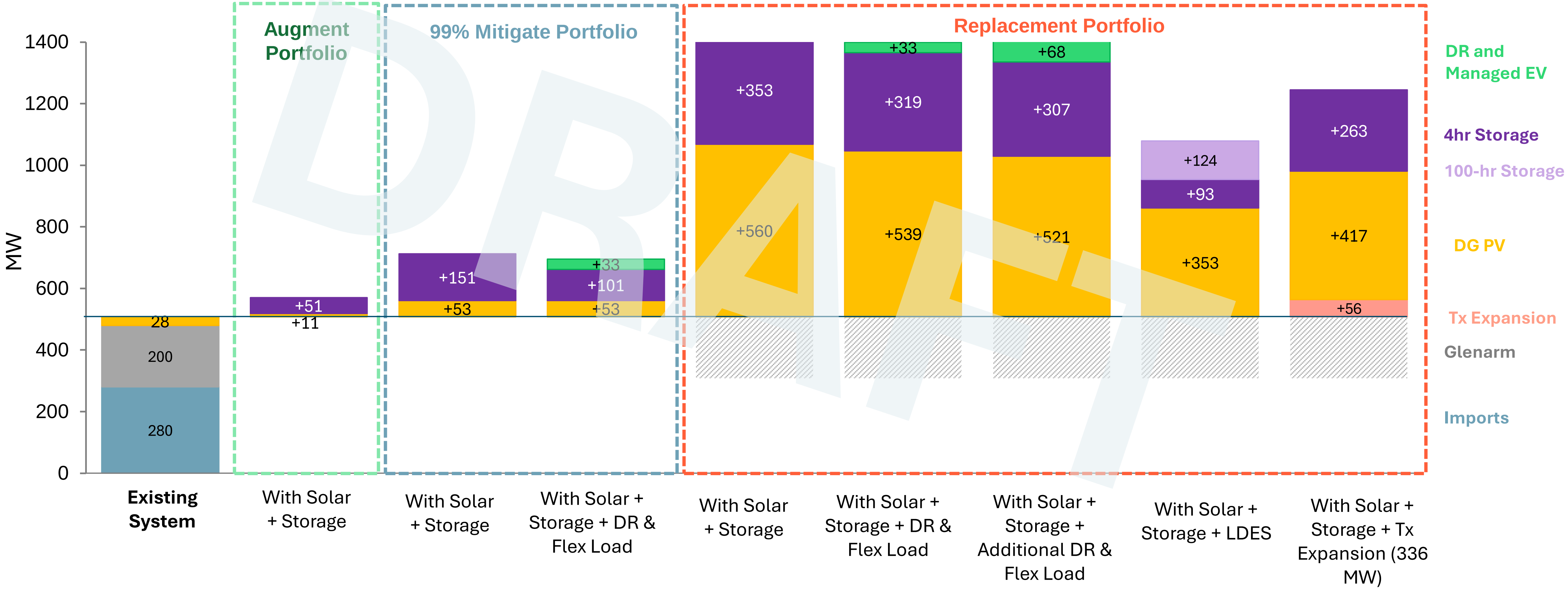
Increased Load Flexibility & Managed Charging

Long Duration Storage

Sensitivities also explore increased import capability

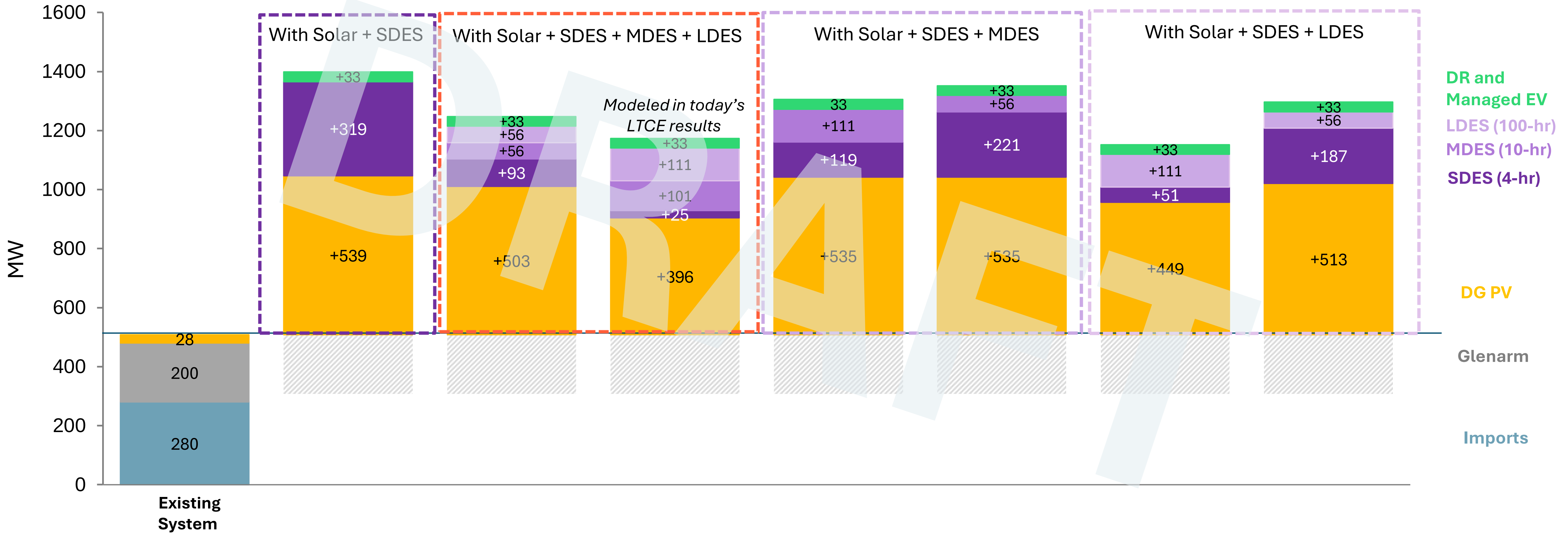
Reminder of Glenarm Replacement Analysis Presented at Last TAP Meeting

Glenarm Augment, Mitigate, and Replacement Portfolios, *Incremental Nameplate MW*



These values represent the minimum quantities of resources needed to ensure local reliability. Additional local resources will be included in portfolios to the extent that (a) the rate of naturally occurring customer adoption exceeds this level or (b) additional resources are found to be economic in LTCE. E3's modeling indicates that naturally occurring adoption could result in an additional ~35 MW of customer-owned resources by 2031.

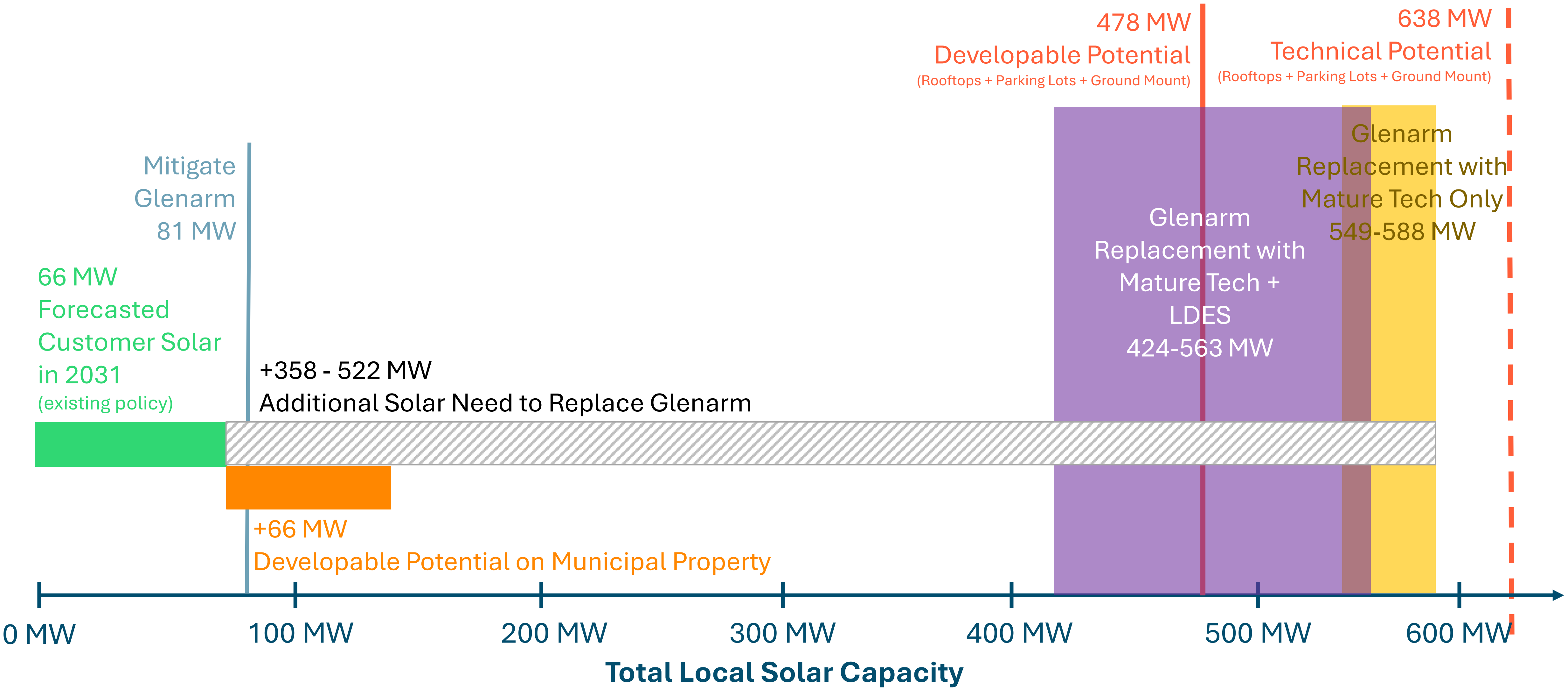
Glenarm Replacement Portfolio Summary with MDES and LDES



These values represent the minimum quantities of resources needed to ensure local reliability. Additional local resources will be included in portfolios to the extent that (a) the rate of naturally occurring customer adoption exceeds this level or (b) additional resources are found to be economic in LTCE. E3's modeling indicates that naturally occurring adoption could result in an additional ~35 MW of customer-owned resources by 2031.

LDES = Long-Duration Energy Storage
MDES = Medium-Duration Energy Storage
SDES = Short-Duration Energy Storage

Scale of Local Solar Need and Resource Potential



Evaluating Options to Supply Hydrogen at Glenarm

On-site storage of trucked in hydrogen or on-site production of hydrogen at Glenarm are not viable options for 100% conversion due to scale of plant fuel needs

Land use requirements for on-site hydrogen storage or production are prohibitive.

Delivering hydrogen to Glenarm would require…

To store fuel supply for…	1 day	3 days
Tons of H2 Fuel	375	1,125
Acres for storage	25	75
Truck trips to fill storage tank	375	1,125

To produce hydrogen on-site…

To generate enough fuel within a summer week for..	1 day	3 days
MW of electolyzers	125	375
Acres for electrolyzers	<1	<1
MW of solar for electrolysis	300	900
Acres for solar for electrolysis	1,650	5,000
Acres for storage	25	75

50-100% of existing system peak load.

Ground-mount PV potential in Pasadena is ~10 MW.

Long-Term Capacity Expansion Modeling Overview

Objective Function

Investment Costs
- New resources
- New transmission (optional)

\+

Fixed Costs
- Renewables
- Energy storage
- Thermal

\+

Variable Costs
- Variable O&M*
- Fuel Costs
- Market purchases

*Operation and Maintenance

Decisions

Investments

System Operations

Constraints

- Clean energy targets
- Resource adequacy requirements
- Resource Limits
- Operations
- Transmission

Common Assumptions Across Cases Modeled in LTCE

Load Forecast	Customer Resources	Existing Portfolio	Transmission	Resource Potential
2031 peak demand: **360 MW** *(reflects managed EV charging)*	Adoption of customer resources by 2031 based on current NEM structure: Solar: **65 MW** Storage: **1 MW**	All resources currently owned or under contract to PWP included across portfolios *(retirement dates vary across cases)*	**280 MW** import limit at TM Goodrich, expanding to 336 MW by 2035	External resource options informed by CPUC IRP planning assumptions; internal resource options informed by preparatory studies

Resource Costs	Commodity Pricing	Clean Energy	Local Reliability	Resource Adequacy
Informed by the OSP New and Emerging Tech Study	Natural gas, carbon allowance, and CAISO wholesale electricity prices based on E3 fundamentals-based forecast	All portfolios include *at least* enough carbon-free energy to meet PWP's annual energy needs by 2031	All portfolios include a minimum requirement for local resources informed by LOLP modeling	All portfolios must meet future RA requirements based on "marginal ELCC" accreditation framework

Topology for Capacity Expansion Model

Utility Load	
2031 Peak Demand[5]	361 MW
Owned & Contracted Resources	
Glenarm Power Plant	198 MW
Windsor Reservoir Solar	0.7 MW
Glenarm BESS[2]	25 MW
2031 Customer-Owned Resources	
Customer-Owned Solar	66 MW
Customer Owned Storage	1 MW
Candidate Resource Options	
Local Solar PV	
Local Battery Storage (4hr)	
Local Mid Duration Storage (10hr)[3]	
Local Long Duration Storage (100hr)[3]	
Demand Response	
Load Flexibility	
Green Hydrogen[3]	

Local PWP System

TM Goodrich
Receiving Station

280 MW limit
(expanding to 336 MW by 2035)

External CAISO System

Owned & Contracted Resources	
Palo Verde Nuclear	10 MW
Intermountain Power Plant[1]	108 MW
Magnolia Power Plant	14 MW
Chiquita Canyon Landfill Gas[1]	7 MW
Puente Hills Landfill Gas[1]	13 MW
Hoover Hydro	15 MW
Azusa Hydro	15 MW
Calwind[2]	20 MW
Coso Geothermal[2]	10 MW
Geysers Geothermal[2]	25 MW
Antelope Big Sky Ranch Solar	7 MW
Big Sky Summer Solar	7 MW
Columbia 2 Solar	3 MW
Kingbird Solar	20 MW
Bonanza Solar[2]	105 MW
Grace Solar[2]	50 MW
Bonanza BESS[2]	55 MW
Candidate Resource Options	
Utility-Scale Solar PV	
Wind (California)	
Wind (Out of State)	
Geothermal	
Battery Storage (4hr)	
Mid Duration Storage (10hr)[3]	
Long Duration Storage (100hr)[3]	
Wholesale Energy Market	
CAISO Wholesale Market (SP15)	

Notes:
1. Resources with established plans for retirement or contract expirations prior to end of 2030
2. Resources not yet online today
3. Candidate resources included in a select set of portfolios
4. Based on 2023 IRP forecast.
5. Based on 2023 IRP forecast with blended EV charging developed by E3.

Three Core Case Studies to Achieve Resolution 9977 Goals

Case Studies	New Resources Considered to Meet Resolution 9977 Goals					
Mature Technologies Only	Solar PV	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	
Mature Technologies + Green Hydrogen	Solar PV	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	Green Hydrogen (H_2) Conversion at Glenarm
Mature Technologies + Long-Duration Storage	Solar PV	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	Long-Duration Energy Storage

Common methods & assumptions across all three case studies:

- Natural gas combustion at Glenarm ceases by end of 2030 (either converted to H_2 or replaced)
- No reliance on wholesale market purchases ("24x7 carbon free electricity")
- Quantities of each resource optimized in each case study to meet reliability needs and carbon-free objectives

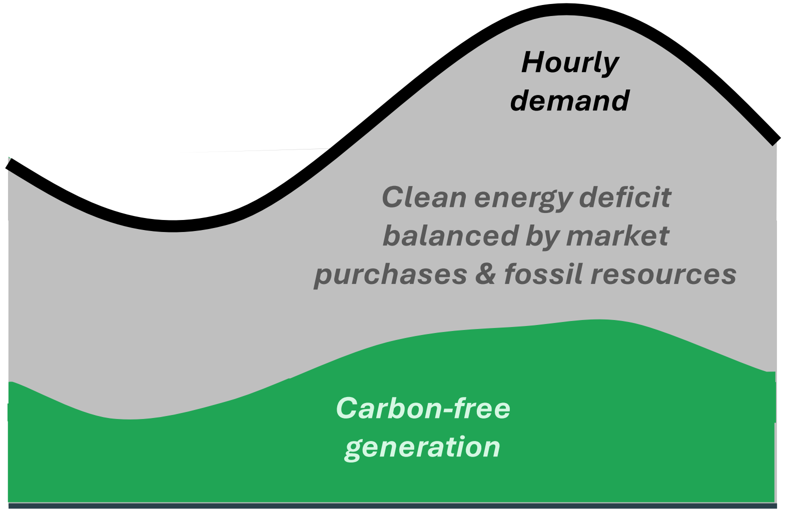
Additional variations explored to provide PWP and City Council with robust analyses to inform the Optimized Strategic Plan:

+ **"Accelerated Local Resources": What are the comparative impacts of portfolios that accelerate the deployment of local resources while maintaining Glenarm Power Plant as a backup for reliability?**
+ **Timing: How does each strategy change if transition to carbon-free occurs less rapidly?**
  - Opportunity to synchronize transition with transmission expansion
  - More plausible timelines for technology readiness for emerging technologies
+ **Markets: How does short-term market transaction flexibility impact these case studies?**
+ **Renewable Natural Gas: What are the cost impacts of utilizing RNG to reduce carbon emissions from Glenarm?**

Different Procurement Strategies Will Lead to Large Differences in PWP's Position in the CAISO Market

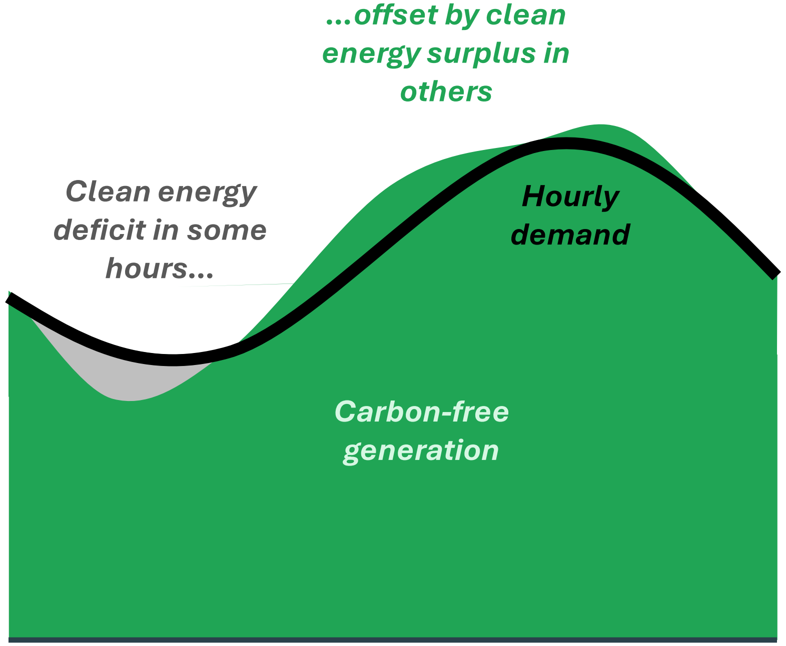
Current Portfolio (2025)

Utility has a ***short market position***, relying on market purchases (and fossil resources) to serve a portion of load in all hours



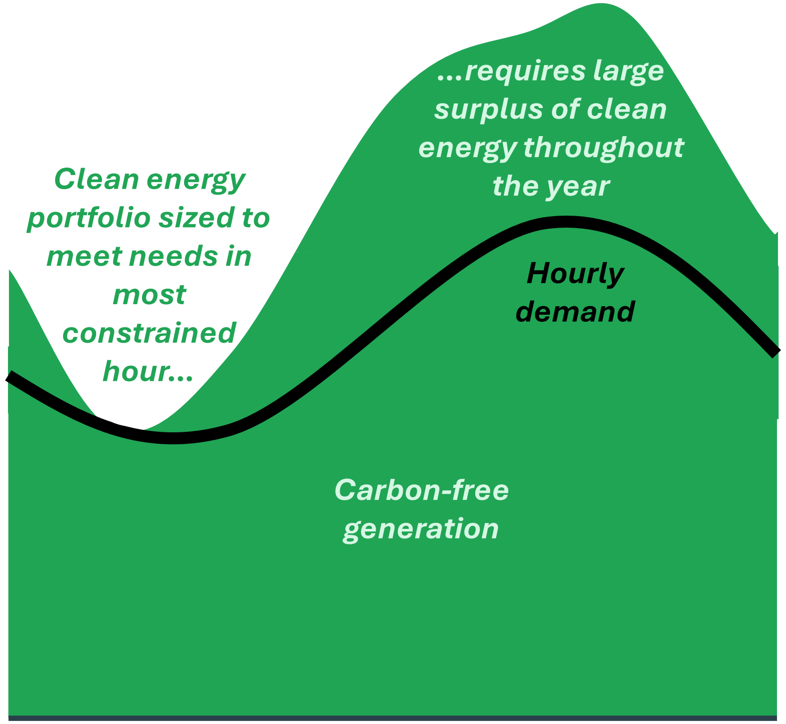
"100% Annual Matching"

Utility maintains a ***balanced market position***, offsetting market purchases with sales of surplus clean energy



"100% Hourly Matching"

Utility takes a ***long market position***, resulting in significant off-system sales and/or curtailment so carbon-free resources can meet load in most constrained periods



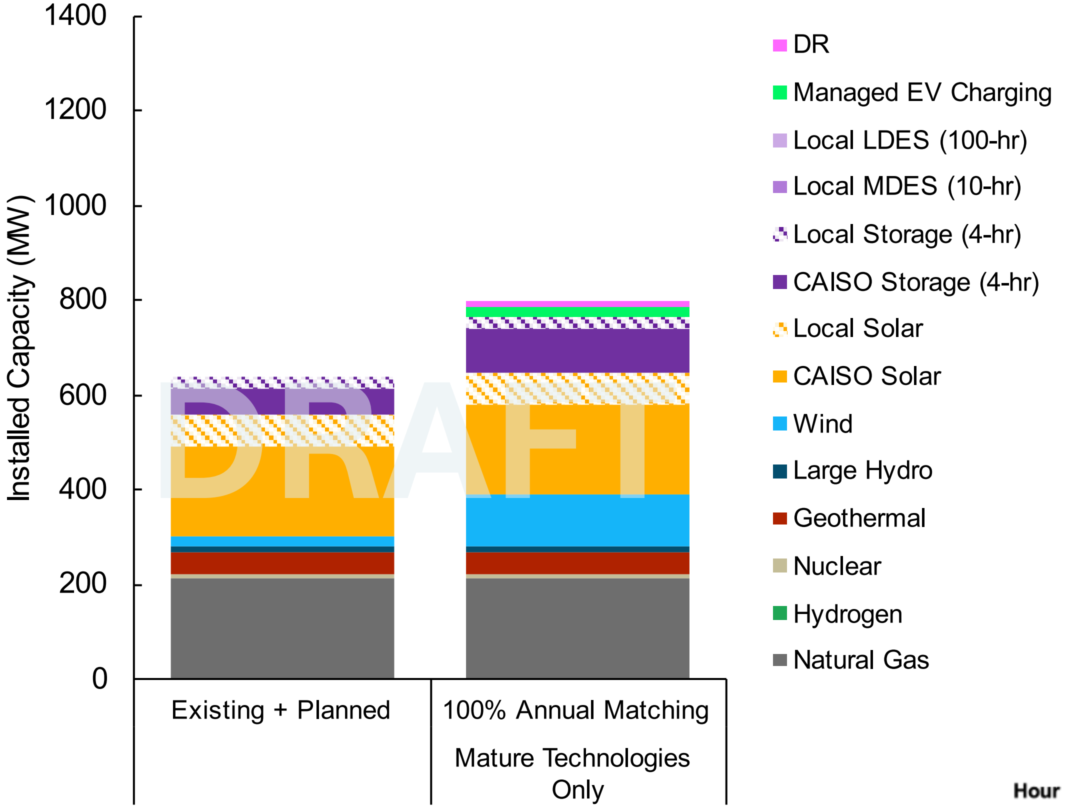
Figures are illustrative – not a modeling result

Relative Incremental Cost Metric

<u>Cost metrics presented today:</u>

- **Incremental costs include the following components:**
  - Fixed Operations and Maintenance for existing utility-owned generation
  - Operating costs (fuel, operations and maintenance) for new and existing resources
  - Procurement costs for new resources
  - Market purchases and sales
  - Transmission Access Charge
- **Costs are presented relative to the lowest cost case (100% Annual Matching)**
- **Costs reflect annual costs in 2031 to serve loads; additional on-going costs are associated with the portfolio in each case study**
- ***Next steps: Calculate total system cost including existing or embedded costs and develop average system cost metrics***

100% Annual Matching, Mature Technologies Only

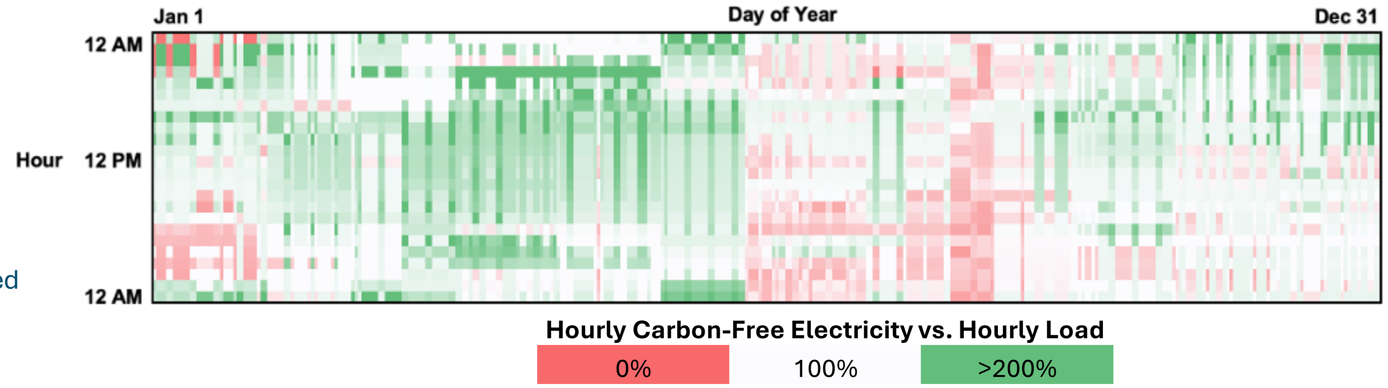


* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

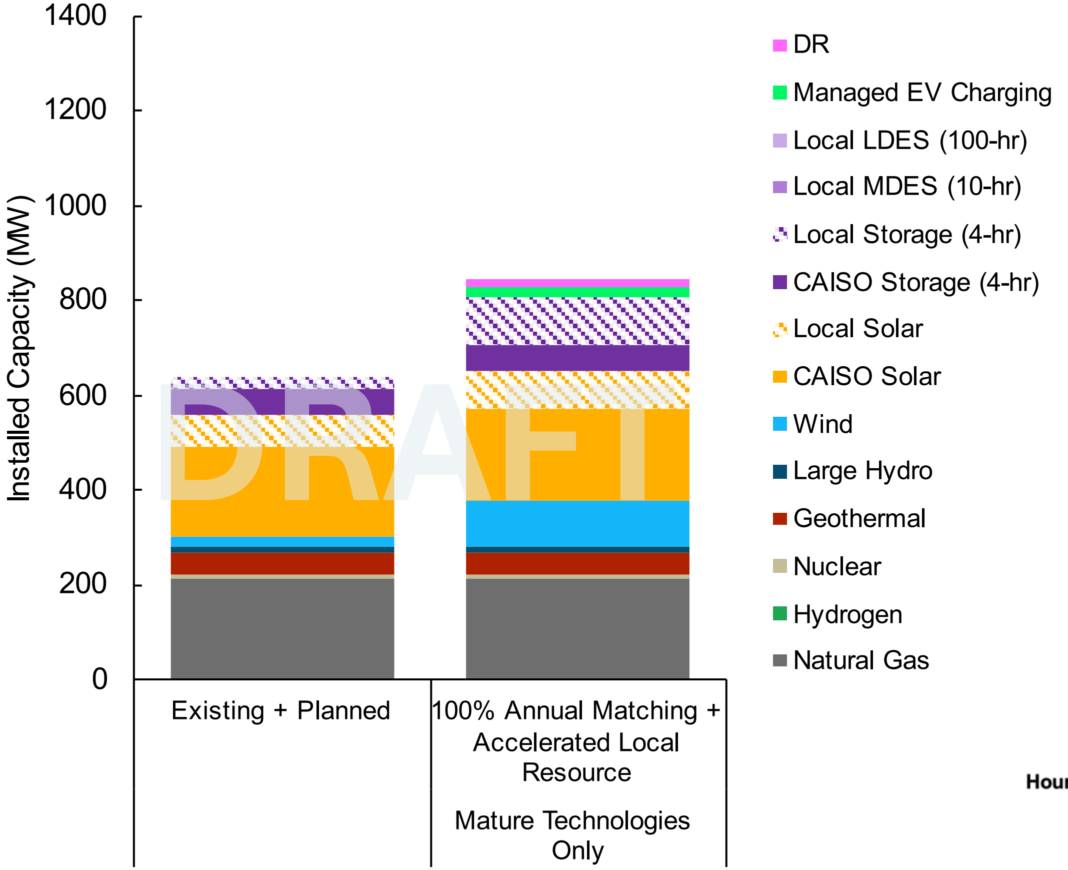
Initial Learnings & Portfolio Highlights:

+ Modest incremental additions of renewables and storage allow PWP to meet 100% of annual energy needs with carbon-free sources
+ Glenarm retained and operated infrequently for local reliability
+ "Annual matching": sales of surplus carbon-free resources offset market purchases and limited Glenarm operations (mostly summer)

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 96%	Metric 3: 90%*
2031 Incremental Cost:	+$0 million per year		



100% Annual Matching, Mature Technologies Only (Accelerated Local Resources)

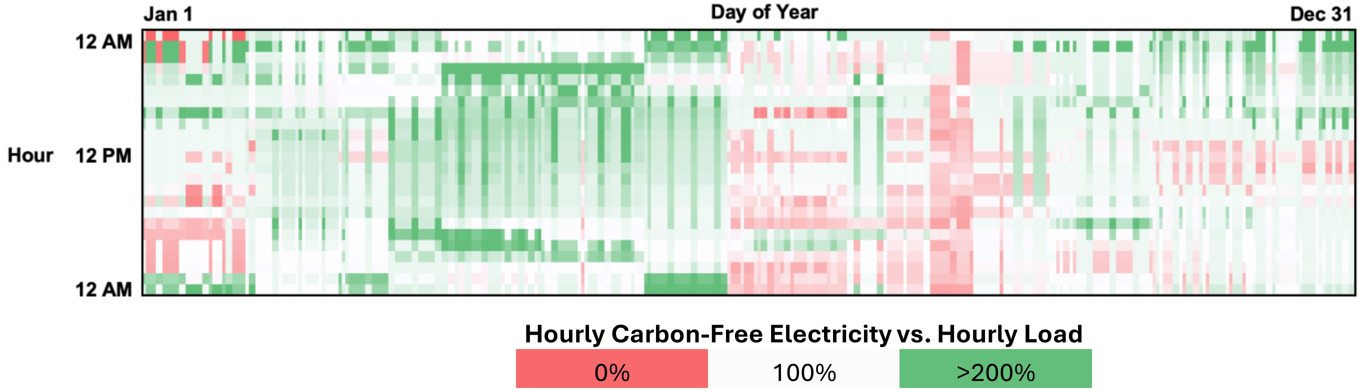


* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

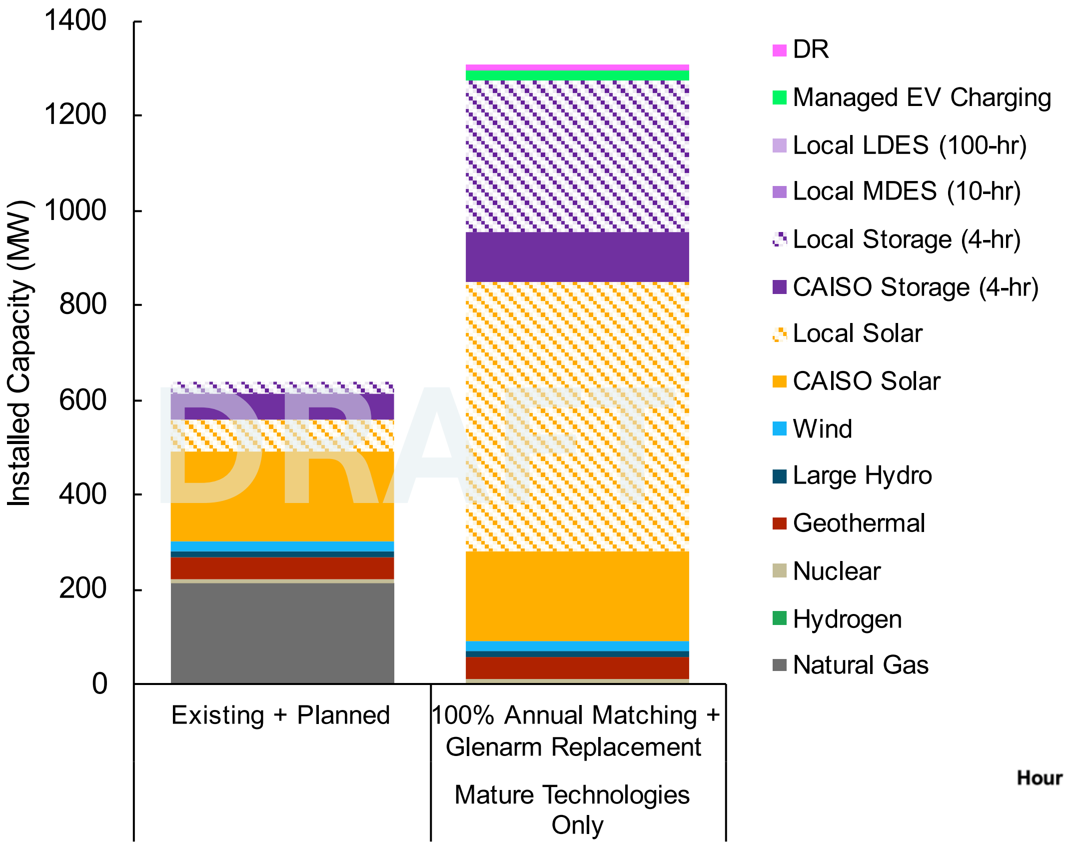
Initial Learnings & Portfolio Highlights:

- Increased focus on local solar & storage development further reduces frequency of Glenarm's use to meet local reliability needs and reduces imports from CAISO at limited incremental cost
- Increased internal resource development reduces level of external resources developed

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 97%	Metric 3: 90%*
2031 Incremental Cost:	+$3 million per year		



100% Annual Matching, Mature Technologies Only (Glenarm Replacement)

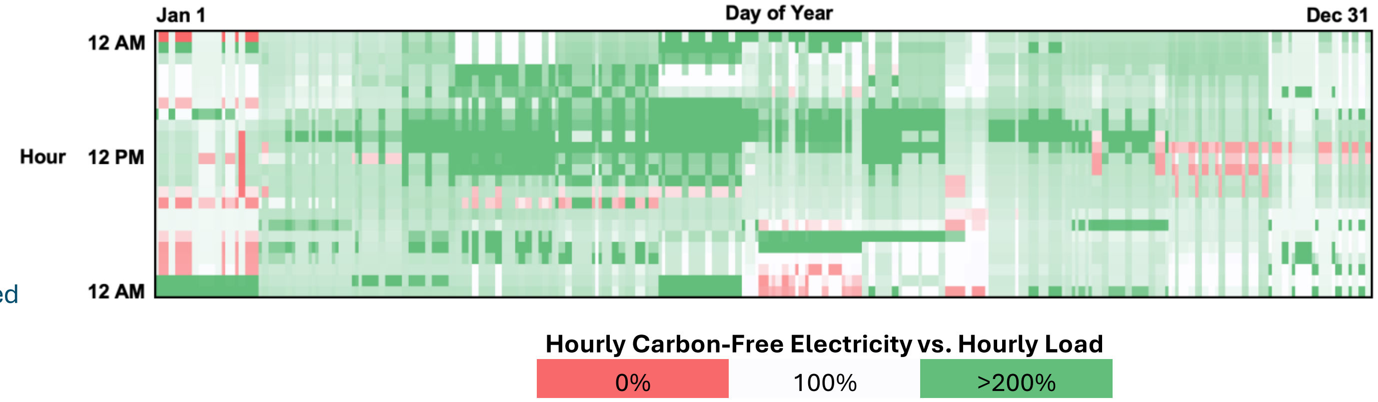


* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

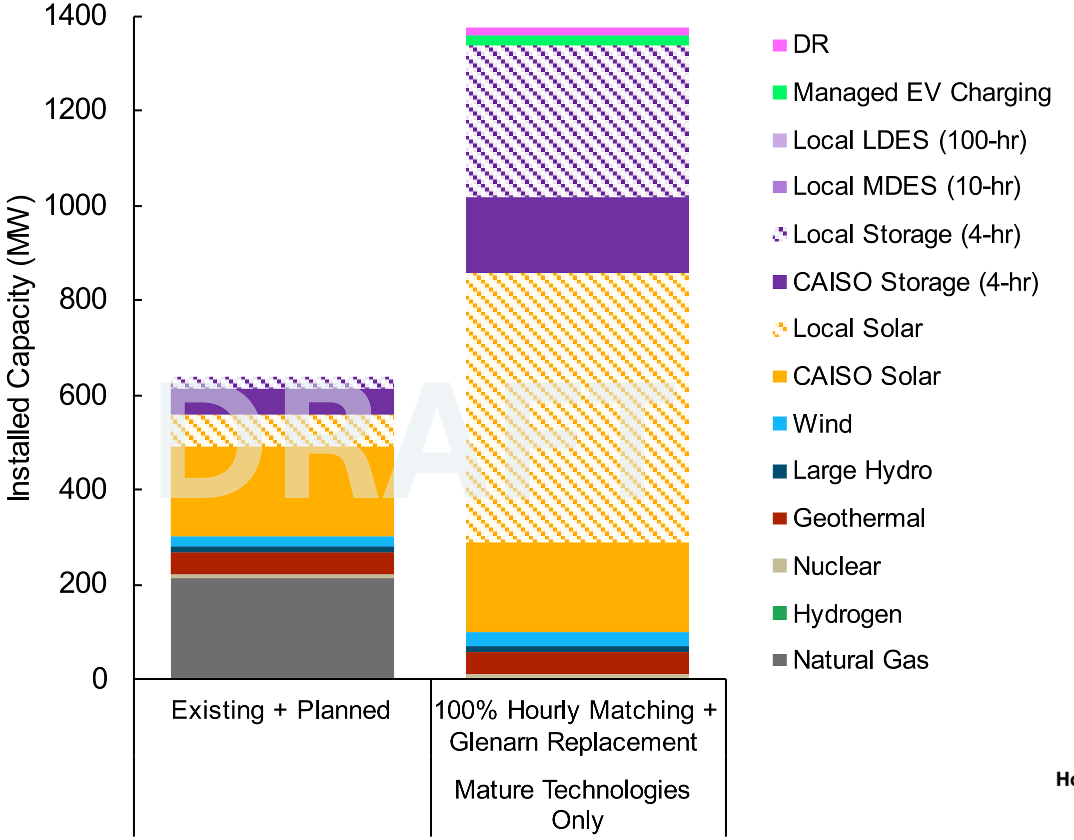
Initial Learnings & Portfolio Highlights:

- **Local solar and storage at significant scale needed to replace Glenarm while maintaining local reliability, resulting in very high incremental costs**
- **Even with the scale of local resource development, there are still some periods where this portfolio relies on the market to meet PWP needs**

Forecasted Clean Energy Metrics:	Metric 1: 100%+	Metric 2: 100%	Metric 3: 90%*
2031 Incremental Cost:	+$101 million per year		



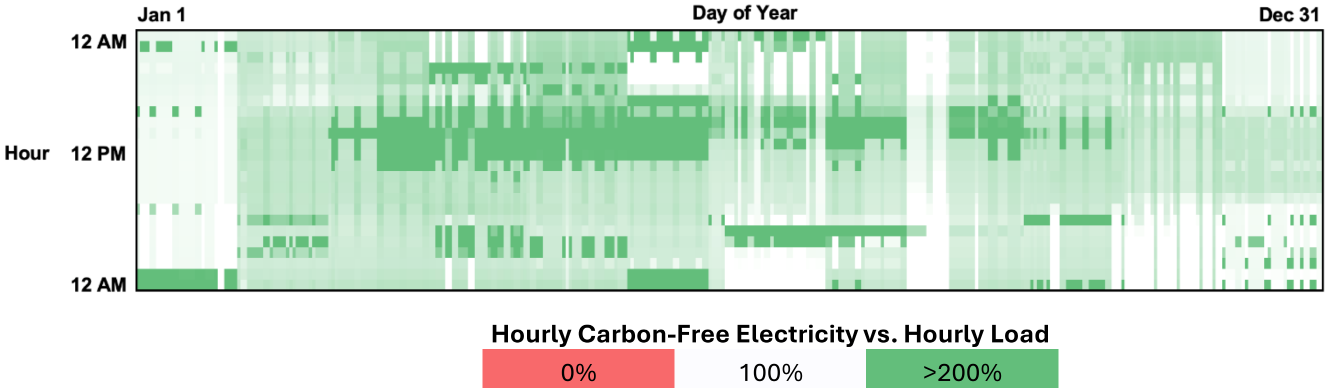
100% Hourly Matching, Mature Technologies Only (Glenarm Replacement)



Initial Learnings & Portfolio Highlights:

+ **Achieving 100% hourly matching requires (1) significant local resource additions to replace Glenarm, (2) additional external resources to eliminate reliance on market, and (3) self-scheduling of energy storage resources to meet PWP needs (rather than maximizing value)**

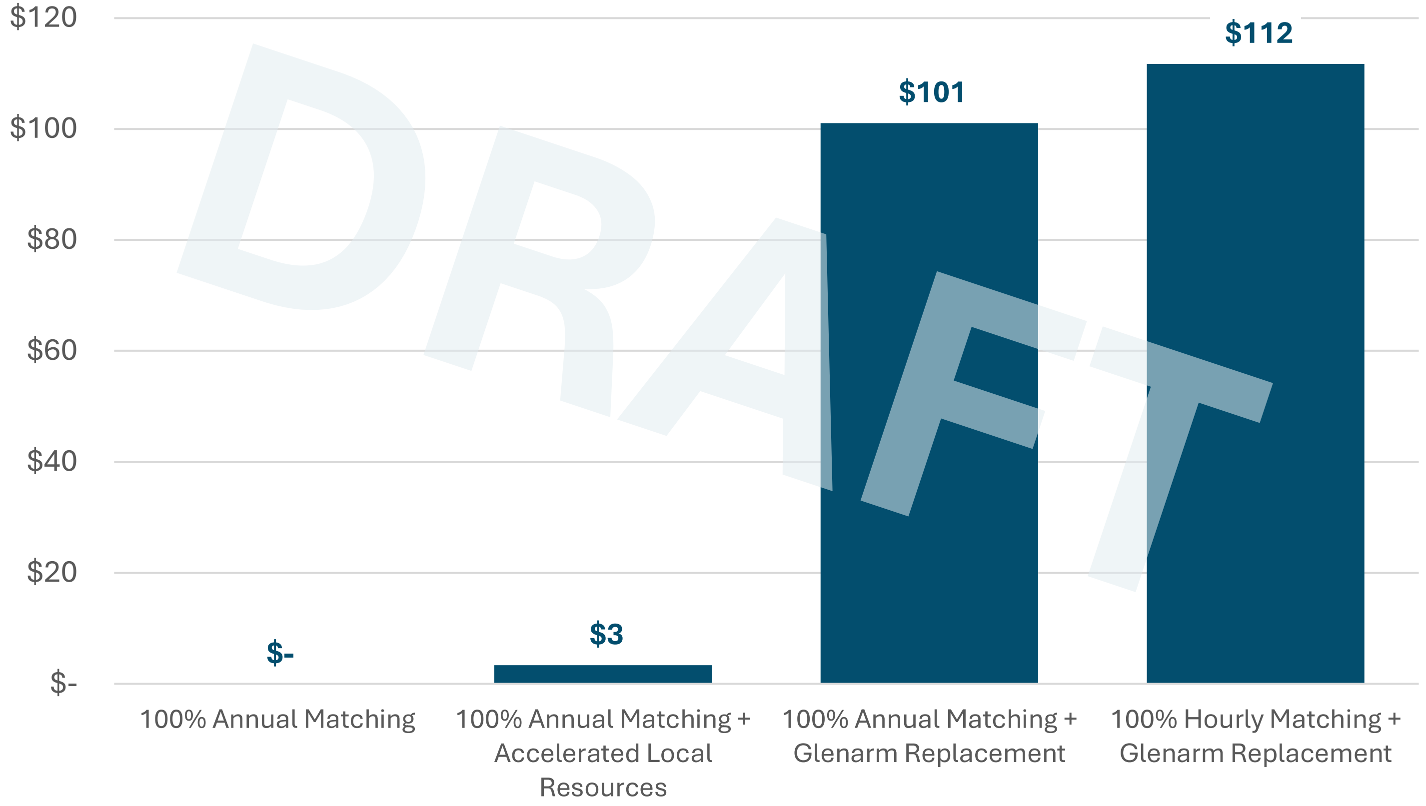
Forecasted Clean Energy Metrics:	**Metric 1:** 100%+	**Metric 2:** 100%	**Metric 3:** 100%*
2031 Incremental Cost:	**+$112 million per year**		



* Metric 3 calculated based on limited deterministic set of conditions represented in long-term capacity expansion modeling. Real world results would necessarily vary and likely be lower due to a broader set of potential conditions.

Relative Total System Costs in 2031, Mature Technologies Only

2031 Relative Incremental Total System Cost
($ million)



Note: PWP's current revenue requirement is approximately $200M. Absent robust public data, costs for developing local parking canopy solar were assumed to comparable to commercial rooftop solar. If parking canopy solar were closer to the cost of residential rooftop solar, the cost for the 100% Annual Matching + Glenarm Replacement case would be $38M higher.

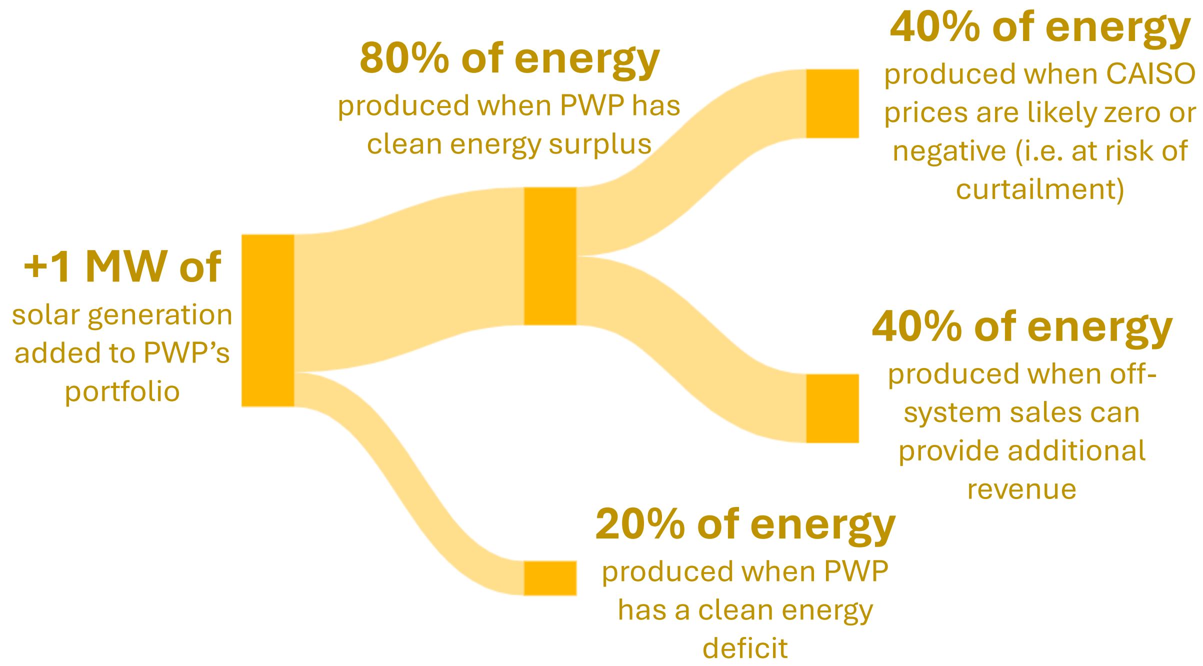
Drivers of Cost Differences Among Cases:

- **Procurement costs for new renewables and storage resources**
  - NOTE: Costs associated with naturally occurring customer adoption of solar & storage are not included in system cost metrics.
- **Fuel and O&M costs for PWP-owned resources**
- **Differences in market purchase costs**

Outstanding Cost Categories to Incorporate:

- **Existing resource fixed costs/PPA costs**
- **Other revenue requirement components (e.g. dx costs)**

Resource Diversity is an Important Consideration to Manage Market & Curtailment Risks



Based on results from 100% Annual Matching, Mature Technologies Only, 2031

- **With high levels of procurement of one resource types, there is significant risks for high levels of curtailment of generation that cannot be sold to the market.**
- **When PWP's has an excess of solar generation, the utility may not be able to sell it to the CAISO market which is highly saturated with solar.**

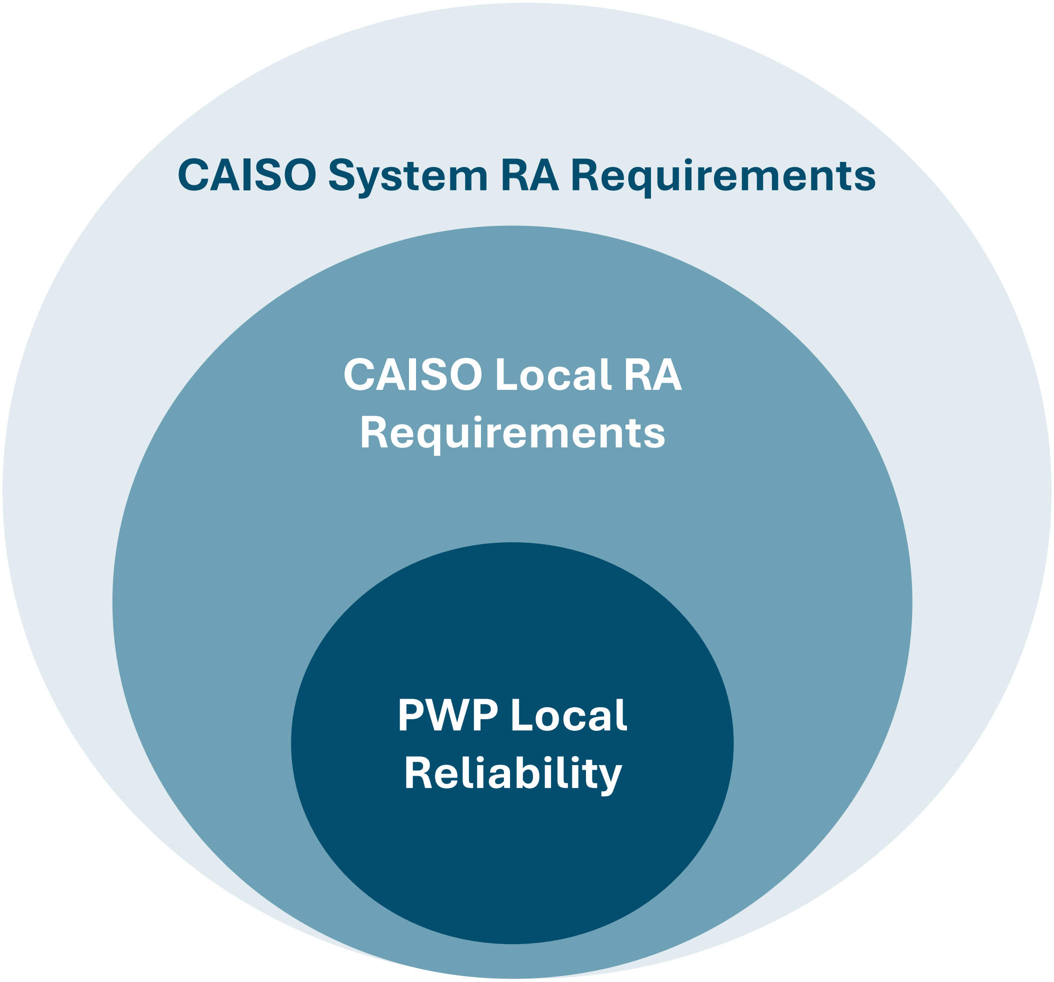
Forecasted Carbon Metrics, 2031, Mature Technologies Only

Metric 1: Share of PWP's **annual retail sales** that is carbon-free
Metric 2: Share of PWP's total **annual generation**[1] that is carbon-free
Metric 3: Share of PWP's **hourly energy needs**[1] that is carbon-free

Metric	Planned + Existing Resources[2]	100% Annual Matching	100% Annual Matching + Accelerated Local Resources	100% Annual Matching + Glenarm Replacement	100% Hourly Matching + Glenarm Replacement
Metric 1	103%	107%	108%	115%	128%
Metric 2	94%	96%	97%	100%	100%
Metric 3[3]	88%	90%	90%	90%	100%

1. Includes retail sales, T&D losses, and storage losses
2. https://pwp.cityofpasadena.net/clean-energy-tracker/
3. Analysis of metric 3 is under refinement and subject to changed. Values presented for OSP portfolios here represent a lower bound.

Multiple Layers of Reliability Requirements



Potential solutions contribute differently to meeting PWP's reliability needs and obligations

	PWP Local Reliability	CAISO Local RA	CAISO System RA
Internal Resources	✓	✓	✓
Transmission Upgrades	✓	×	×
External Resources *(in LCR Zones in SCE TAC)*	×	✓	✓
External Resources *(outside LCR Zones)*	×	×	✓

Marginal ELCCs for the OSP

Variable and energy limited resources have ELCCs that generally decline over time as more are added to the portfolio leading to saturation effects.

Resource	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045
Utility-Scale Solar	12%	13%	13%	12%	12%	11%	11%	8%	6%	12%
Short Duration Storage	64%	60%	56%	53%	50%	47%	44%	36%	28%	15%
Mid Duration Storage	66%	62%	59%	58%	56%	56%	56%	59%	56%	30%
Long Duration Storage	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
In-State Wind	11%	11%	11%	11%	11%	11%	11%	11%	11%	11%
Out-of-State Wind	23%	23%	23%	22%	22%	21%	21%	20%	19%	19%
Geothermal	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
Gas or Hydrogen CT	83%	83%	83%	83%	83%	83%	83%	83%	83%	83%

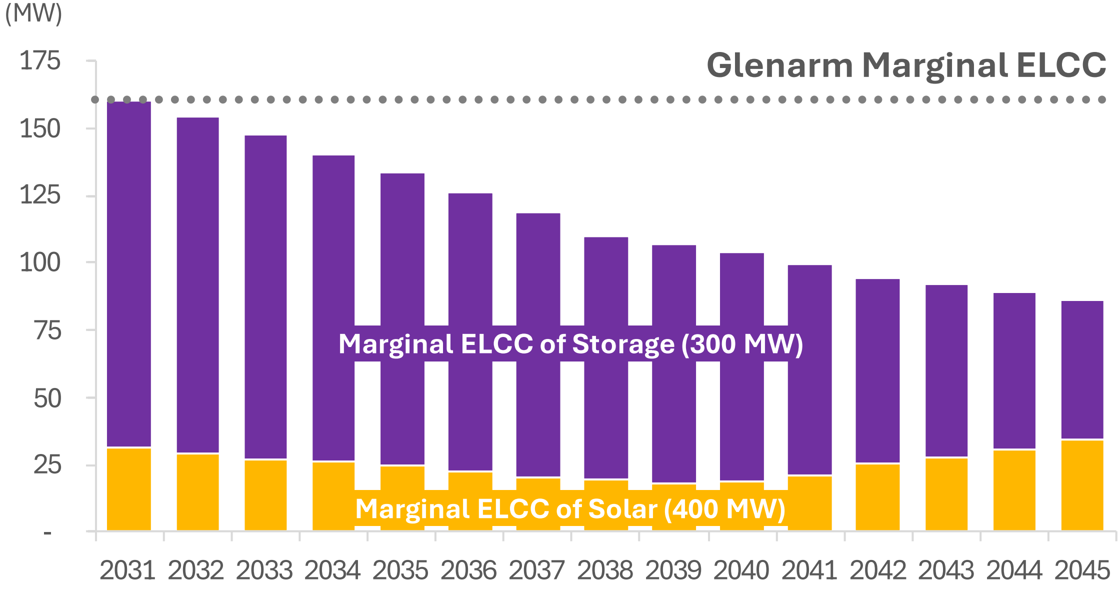
Firm resources like geothermal and gas CTs generally have higher ELCCs that do not decline over time.

Marginal ELCC assumptions used in PWP OSP derived from modeling results in CPUC Integrated Resource Planning proceeding

Long-Term Resource Adequacy Risks Associated with Solar & Storage Replacement

+ As penetration of variable & storage resources increases across CAISO, marginal ELCCs decline (particularly for energy storage)
+ As a result, capacity accredited to solar & storage replacement portfolio that initially has the same accreditation as Glenarm may decline significantly below that value over time.
+ Long-term declines in capacity accreditation of solar & storage replacement portfolio means that increasing quantities of additional resources may be needed to meet CAISO RA obligations

Marginal ELCC of Solar & Storage Replacement Resources Over Time



Illustrative portfolio of solar and storage

Pasadena's Carbon Metrics

Metric 1: Share of PWP's **annual retail sales** that is carbon free

$$\frac{\text{Forecasted Annual Carbon} - \text{Free Generation}}{\text{Forecasted Annual Load}}$$

Metric 2: Share of PWP's total **annual generation**[1] that is carbon free

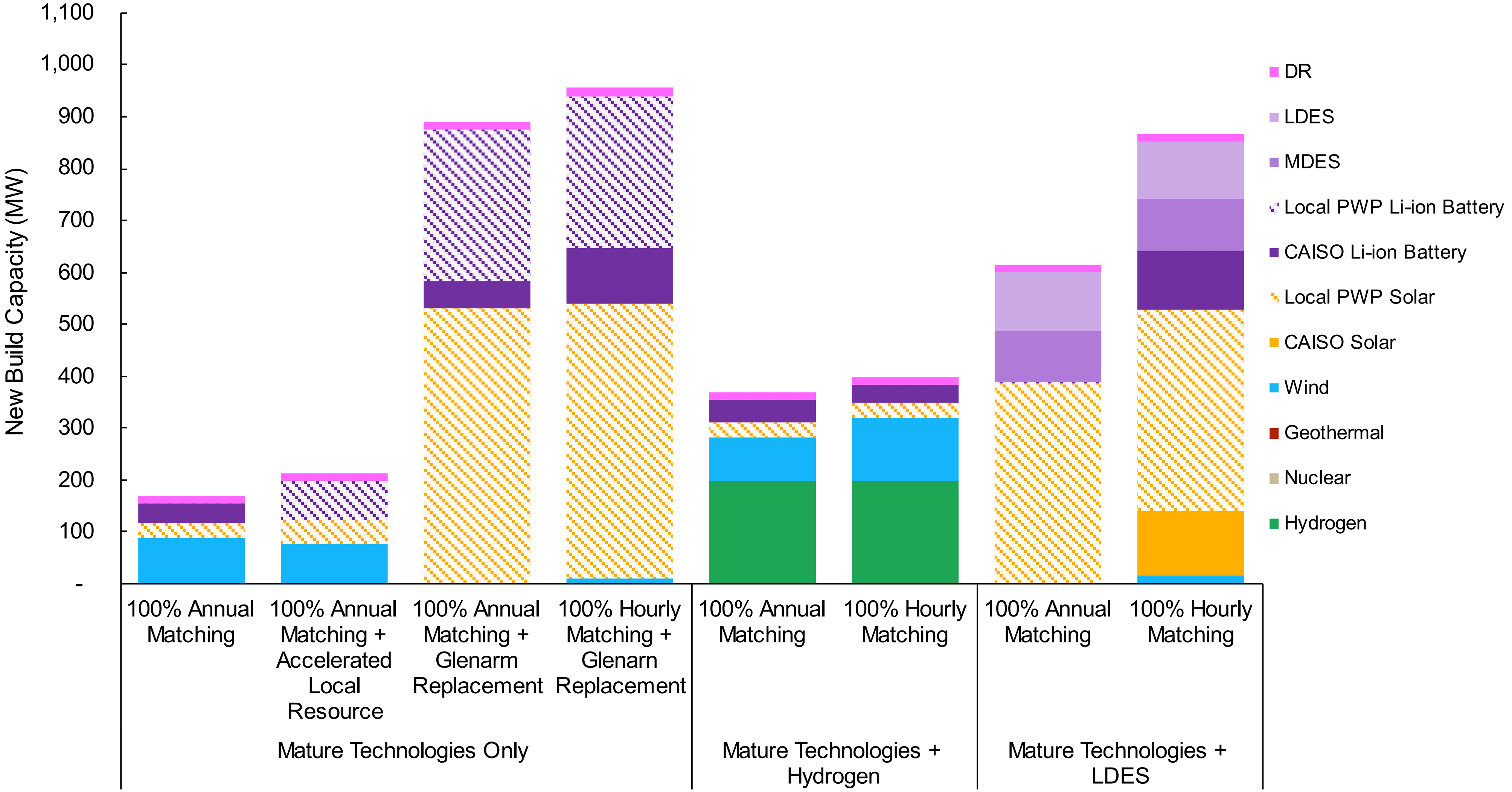
$$\frac{\text{Forecasted Total Carbon} - \text{Free Generation}}{\text{Forecasted Total of All Generation}}$$

Metric 3: Share of PWP's **hourly energy needs**[1] that is carbon free

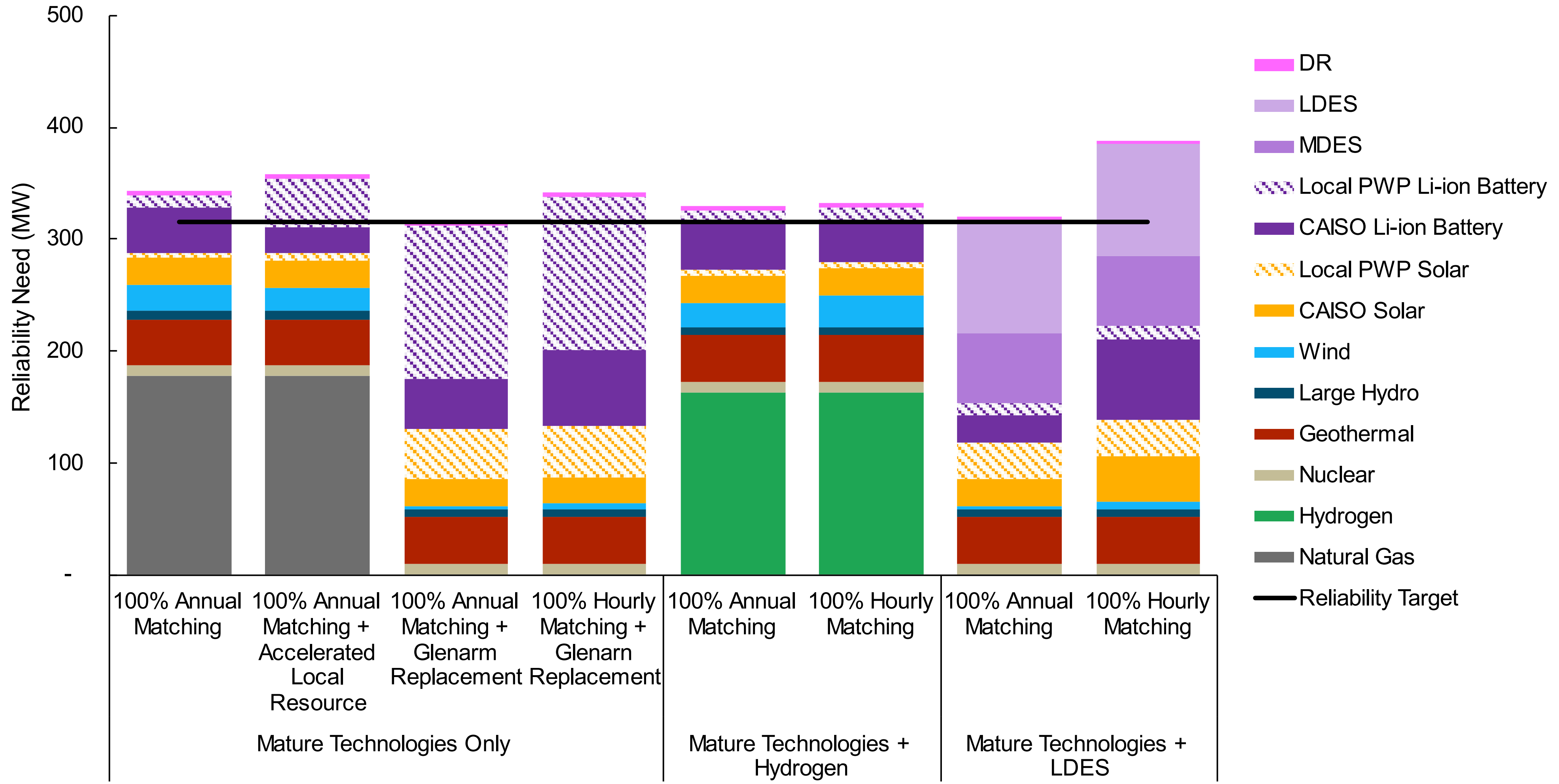
$$\frac{\text{Forecasted Carbon} - \text{Free Generation Capped at Hourly Load Forecast}}{\text{Forecasted Annual Load}}$$

1. Includes retail sales, T&D losses, and storage losses
2. https://pwp.cityofpasadena.net/clean-energy-tracker/

Cumulative Capacity Additions (MW) 2025-2031



CAISO System Resource Adequacy (MW) in 2031



Insights & Initial Learnings from Glenarm Replacement and Conversion Study.

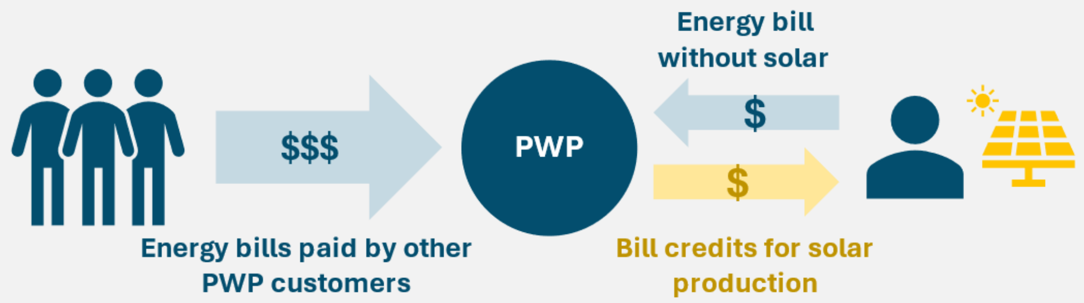
1. **If Glenarm remains in service, the need for additional resources to meet growing loads is relatively modest and is largely consistent with resources already procured by PWP and naturally occurring customer adoption of solar.**
2. **Replacing Glenarm with a combination of internal renewables, storage, and demand-side resources requires new internal generation resources at a significant scale that approaches technical potential.**
   - Sizing of replacement portfolio largely driven by need to maintain reliability during (a) transmission contingency conditions even when (b) solar output is limited (short-term cloudy days)
   - Demand-side resources, emerging longer-duration storage technologies and incremental transmission upgrades can reduce scale of resource needs. None offer a “silver bullet” solution to the challenge of replacing firm generation.
   - A larger transmission upgrade, potentially constructed in the 2030s, could reduce the challenge of replacing Glenarm.
   - Consistent with broader literature and experience in the industry showing that meeting reliability needs without “firm” resources (short-term resources that can be dispatched on demand for as long as needed) is prohibitively challenging.
3. **While the scale of resources needed to replace Glenarm entirely is significant, smaller quantities of new internal resources can reduce the reliance on Glenarm except for the most extreme conditions.**
4. **Full hydrogen conversion of Glenarm requires significant infrastructure developments that are beyond PWP’s control and are unlikely to built before 2030.**
   - RNG may be an effective short-term substitute for natural gas while longer-term options for replacement or conversion remain uncertain.

Treatment of Local Solar & Storage Costs in Total System Cost

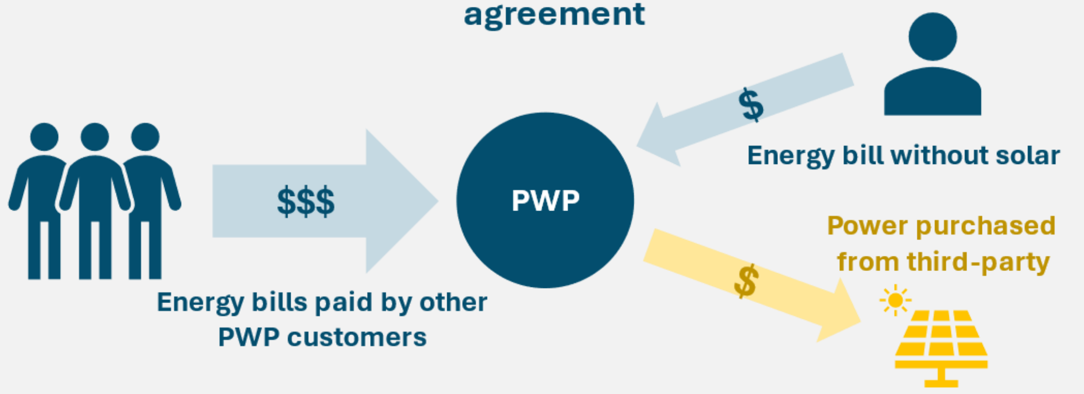
- **Installation costs for solar and storage systems naturally adopted by customers in response to current rate design are not included in Total System Cost metric**
- **For additional local resources *beyond* this level of naturally occurring adoption, costs for solar and storage are included in Total System Cost**
- **There are multiple mechanisms that PWP could utilize to procure or develop additional local resources**
  - Bill credits (as with current Net Energy Metering)
  - Direct incentives to customers
  - Feed-in tariffs
  - Power purchase agreements with third party developers
  - Utility ownership
- **All mechanisms require some financial incentive – in some cases explicit, in others implicit – to the counterparty making the investment that impacts costs borne by other utility customers**
- **Including costs for solar and storage at a level that would allow the owner to recover the costs of the investment over its lifetime represents a *lower bound*of the potential size of the the financial incentive and corresponding impact to PWP customers**

Whether implicit or explicit, remuneration provided to solar owner impacts costs to serve other PWP customers

Example: Implicit compensation through bill credits



Example: Explicit compensation through power purchase agreement



Development of an Optimized Strategic Plan for Pasadena Water and Power

Technical Advisory Panel #10

March 27, 2025

Energy+Environmental Economics

Nick Schlag, Partner
Mike Sontag, Director
Nathan Lee, Sr. Managing Consultant
Michaela Levine, Sr. Managing Consultant

Agenda

- Increasing Metric 3
- Additional case studies
- Distribution study methodology
- Next steps

Defining "Optimized Strategic Plan"

The Optimized Strategic Plan is…

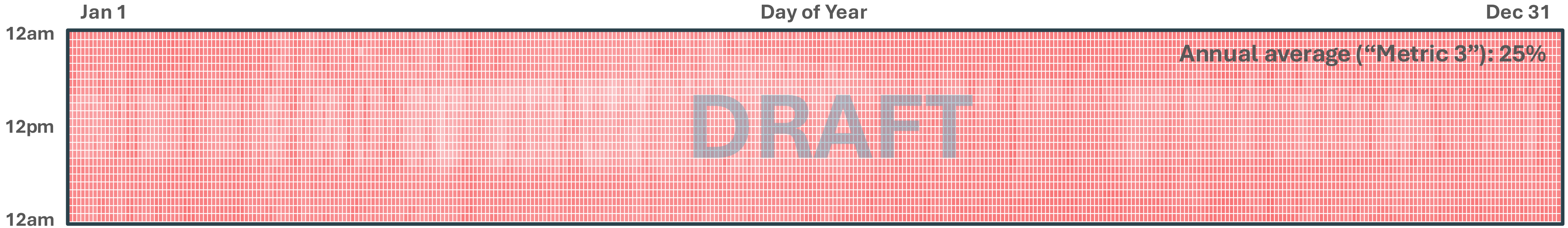
…a roadmap that lays out the key steps and future decision points that will best position PWP to achieve its goal to source all electricity from carbon-free sources by the end of 2030 while maintaining reliability and limiting cost impacts to customers

The Optimized Strategic Plan will…

…consider how new generation resources, investments in transmission and distribution infrastructure, and customer programs can facilitate transition to Pasadena's carbon-free goal

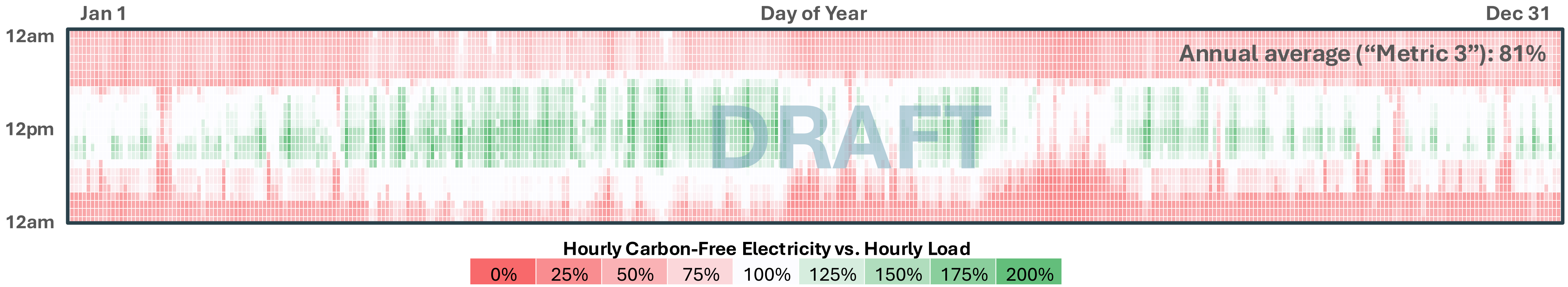
Balance of Carbon-Free Energy Resources based on Currently Executed Contracts

2025 Carbon-Free Electricity Supply



2031 Carbon-Free Electricity Supply (Executed Contracts Only)

Additions: Coso Geothermal (10 MW), Geysers Geothermal (25 MW), Bonanza Solar/BESS (105 MW/55MW), Glenarm BESS (25 MW), Calwind (20 MW)

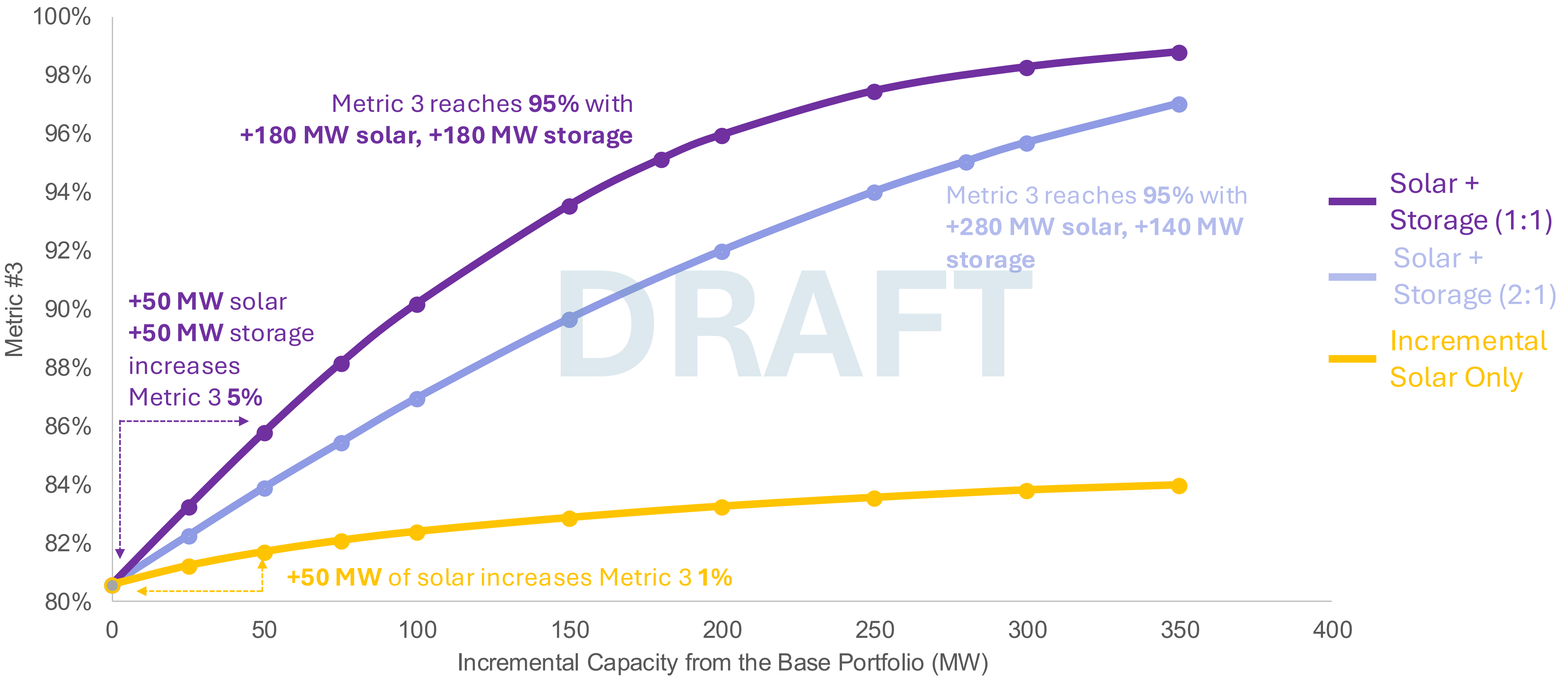


Resource Options Available to Close the Gap on Metric 3

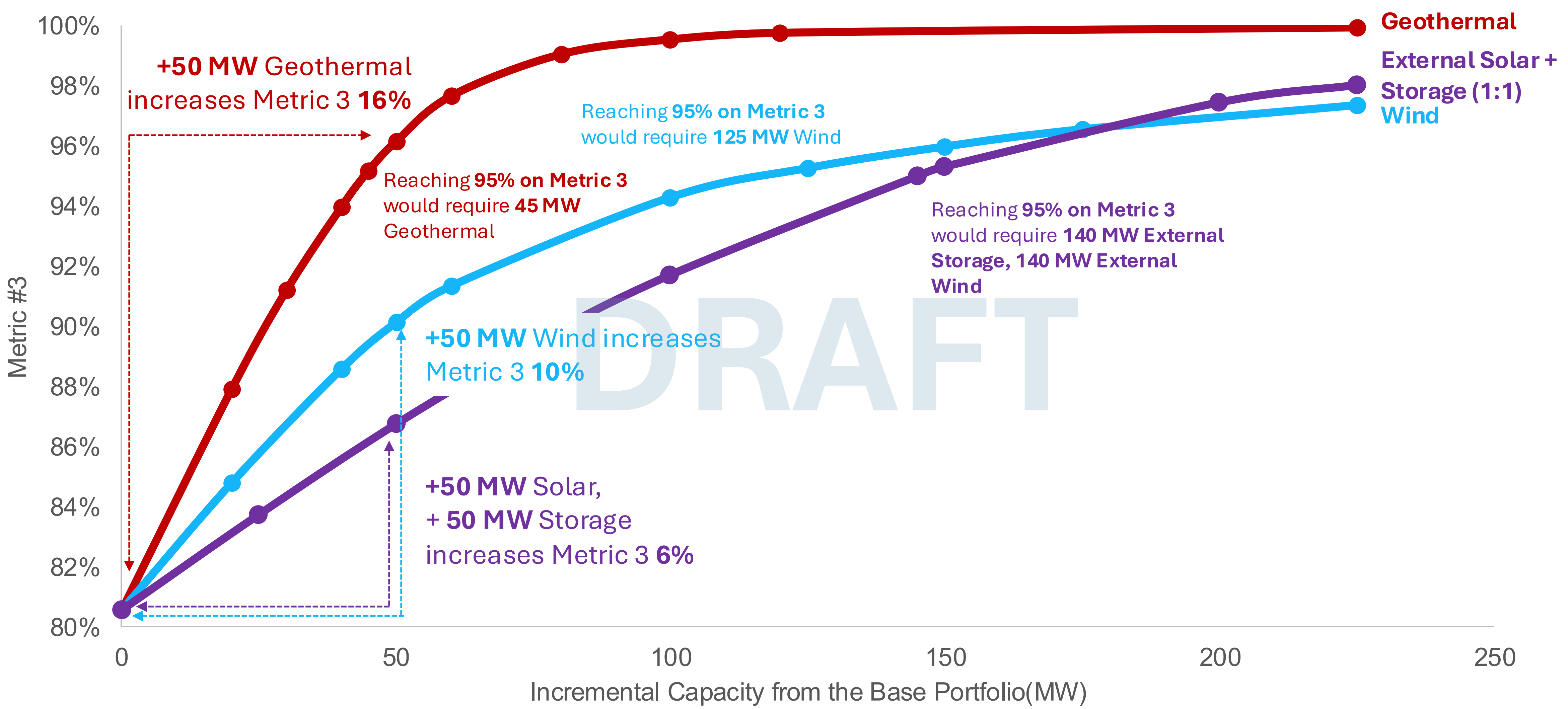
Multiple options for carbon-free generation and storage resources exist to increase Metric 3 and each have their own considerations or limitations.

	Local	External
Solar	✓	✓
Wind		✓
Geothermal		✓
Battery Storage (4-hr)	✓	✓
Demand Response	✓	
Managed EV Charging	✓	
Mid Duration Storage (10-hr)	✓	✓
Long Duration Storage (100-hr)	✓	✓
H_2-Fired Gas Turbine	✓	✓
H_2 Fuel Cell	✓	

Closing the Gap: Internal Renewable Resource Options



Closing the Gap: External Renewable Resource Options



Analysis Summary

1. **Additions of both local and external carbon-free resources to PWP's portfolio can increase Metric 3.**
2. **No single resource type is required for PWP to increase Metric 3 toward 100%, but PWP cannot approach 100% on Metric 3 by adding variable generation (solar and wind) alone.**
3. **Adding increasing amounts of one resource type to PWP's portfolio has a diminishing impact on increasing in Metric 3.**
   - Clean firm resources such as geothermal can increase Metric 3 significantly with relatively smaller incremental capacity additions but also exhibit diminishing increases with further capacity additions.
4. **A diverse portfolio of resources can increase Metric 3 with lower total capacity additions.**

Additional Case Studies

Energy+Environmental Economics

Three Core Case Studies to Achieve Resolution 9977 Goals

Case Studies	New Resource Options to Meet 2030 Goals					
Mature Technologies Only	Solar PV *(Distributed & Utility)*	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	
Mature Technologies + Green Hydrogen	Solar PV *(Distributed & Utility)*	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	Green Hydrogen (H_2) Conversion at Glenarm
Mature Technologies + Long-Duration Storage	Solar PV *(Distributed & Utility)*	Land-Based Wind	Geother-mal	Load Flexibility	Battery Storage	Long-Duration Energy Storage

Common methods & assumptions across all three case studies:

- Natural gas combustion at Glenarm ceases by end of 2030 (either converted to H_2 or replaced)
- No reliance on wholesale market purchases ("24x7 carbon free electricity")
- Quantities of each resource optimized in each case study to meet reliability needs and carbon-free objectives

Additional variations explored to provide PWP and City Council with robust analyses to inform the Optimized Strategic Plan:

+ **"Accelerated Distributed Energy Resources (DER)": What are the comparative impacts of portfolios that accelerate the deployment of DER while maintaining Glenarm Power Plant as a backup for reliability?**
+ **Timing: How does each strategy change if transition to carbon-free occurs less rapidly?**
  - Opportunity to synchronize transition with transmission expansion
  - More plausible timelines for technology readiness for emerging technologies
+ **Markets: How does short-term market transaction flexibility impact these case studies, if PWP's owned and contracted generation is carbon-free?**

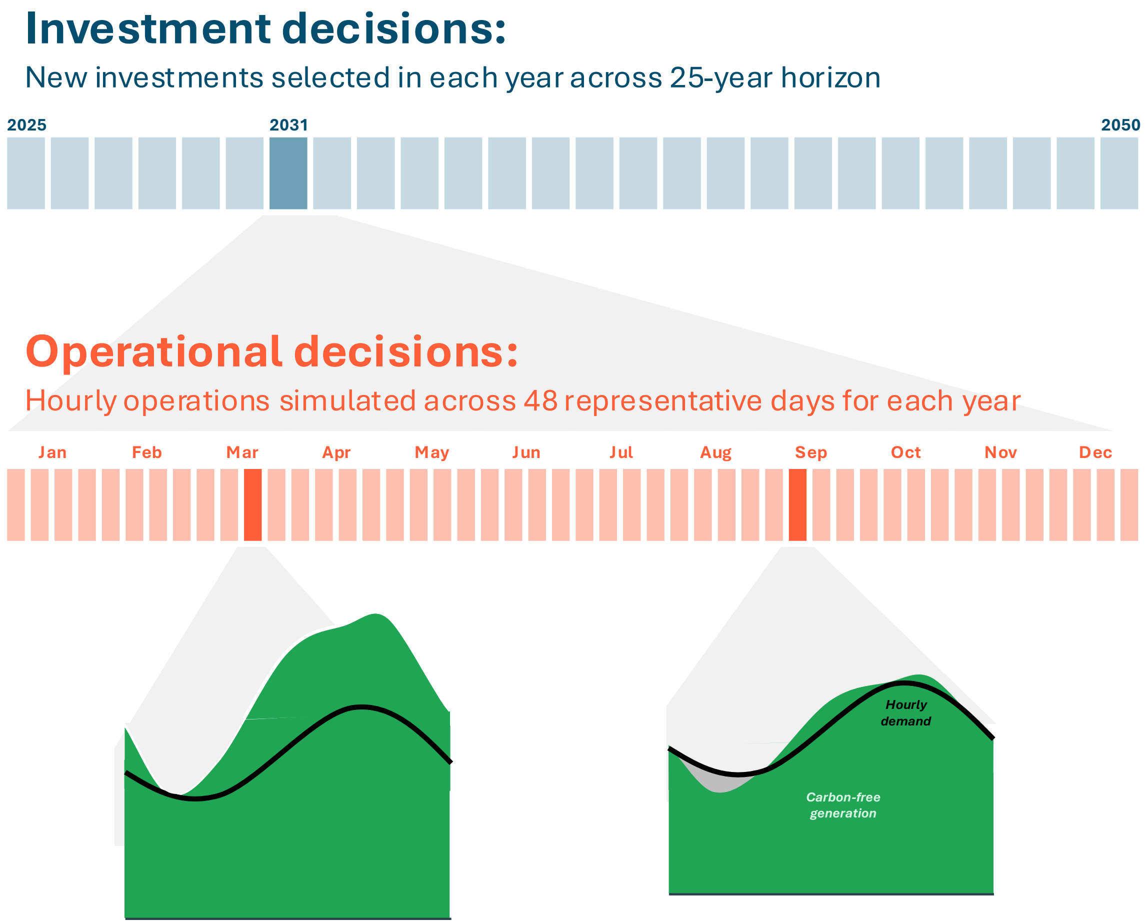
Using Long Term Capacity Expansion to Develop Portfolios

<u>Mathematical optimization problem:</u>

Minimize NPV Investment Costs + Operating Costs

Subject to constraints:

- **Minimum requirements for local resources**
- **Resource adequacy requirements**
- **Carbon-free energy targets**
- **Plant-specific operational limitations**
  - Thermal: Maximum power, ramp rate
  - Storage: Maximum power, state of charge
  - Renewables: hourly availability



Topology for Capacity Expansion Model

Utility Load	
2030 Peak Demand[5]	361 MW
Owned & Contracted Resources	
Glenarm Power Plant	198 MW
Windsor Reservoir Solar	0.7 MW
Glenarm BESS[2]	25 MW
Existing Customer-Owned Resources	
Customer-Owned Solar	28 MW
Customer Owned Storage	1 MW
Candidate Resource Options	
Distributed Solar PV	
Battery Storage (4hr)	
Mid Duration Storage (10hr)[3]	
Long Duration Storage (100hr[3]	
Demand Response	
Load Flexibility	
Green Hydrogen[3]	

Local PWP System

TM Goodrich
Receiving Station

280 MW limit
(expanding to 336 MW by 2035)

External CAISO System

Owned & Contracted Resources	
Palo Verde Nuclear	10 MW
Intermountain Power Plant[1]	108 MW
Magnolia Power Plant	14 MW
Chiquita Canyon Landfill Gas[1]	7 MW
Puente Hills Landfill Gas[1]	13 MW
Hoover Hydro	15 MW
Azusa Hydro	15 MW
Calwind[2]	20 MW
Coso Geothermal[2]	10 MW
Geysers Geothermal[2]	25 MW
Antelope Big Sky Ranch Solar	7 MW
Big Sky Summer Solar	7 MW
Columbia 2 Solar	3 MW
Kingbird Solar	20 MW
Bonanza Solar[2]	105 MW
Grace Solar[2]	50 MW
Bonanza BESS[2]	55 MW
Candidate Resource Options	
Utility-Scale Solar PV	
Wind (California)	
Wind (Out of State)	
Geothermal	
Battery Storage (4hr)	
Mid Duration Storage (10hr)[3]	
Long Duration Storage (100hr)[3]	
Wholesale Energy Market	
CAISO Wholesale Market (SP15)	

Notes:
1. Resources with established plans for retirement or contract expirations prior to end of 2030
2. Resources not yet online today
3. Candidate resources included in a select set of portfolios
4. Based on 2023 IRP forecast.
5. Based on 2023 IRP forecast with blended EV charging developed by E3.

Case Studies Previously Presented

Technology Set	Portfolio Name	Glenarm	Total Minimum Local Resource Portfolio (2031)	Market Purchases (2031)
Mature Technologies Only	100% Annual Matching	Retained	66 MW local solar 26 MW 4-hr storage	No net market purchases
	100% Annual Matching (Accelerated Local Resources)	Retained	81 MW local solar 101 MW 4-hr storage	No net market purchases
	100% Annual Matching (Glenarm Replacement)	Replaced	567 MW local solar 319 MW 4-hr storage	No net market purchases
	100% Hourly Matching (Glenarm Replacement)	Replaced	567 MW local solar 319 MW 4-hr storage	No market purchases
+ Hydrogen Conversion	100% Annual Matching (with Hydrogen)	H_2 Conversion	66 MW local solar 26 MW 4-hr storage	No net market purchases
	100% Hourly Matching (with Hydrogen)	H_2 Conversion	66 MW local solar 26 MW 4-hr storage	No market purchases
+ Long Duration Energy Storage	100% Annual Matching (with LDES)	Replaced	424 MW local solar, 26 MW 4-hr storage, 101 MW MDES, 111 MW LDES	No net market purchases
	100% Hourly Matching (with LDES)	Replaced	424 MW local solar, 26 MW 4-hr storage, 101 MW MDES, 111 MW LDES	No market purchases

New Case Studies, Case-Specific Modeling Assumptions

Technology Set	Portfolio Name	Glenarm	Total Minimum Local Resource Portfolio (2031)	Market Purchases (2031)
Mature Technologies Only	100% Annual Matching	Retained	66 MW local solar 26 MW 4-hr storage	No net market purchases
	100% Annual Matching (Accelerated Local Resources)	Retained	81 MW local solar 101 MW 4-hr storage	No net market purchases
	100% Annual Matching (Accelerated Local Resources Plus)	Retained	130 MW local solar 125 MW 4-hr storage	No net market purchases
	100% Hourly Matching (Accelerated Local Resources)	Retained	81 MW local solar 101 MW 4-hr storage	No market purchases
	100% Hourly Matching (Accelerated Local Resources Plus)	Retained	130 MW local solar 125 MW 4-hr storage	No market purchases
	100% Annual Matching (Glenarm Replacement)	Replaced	567 MW local solar 319 MW 4-hr storage	No net market purchases
	100% Hourly Matching (Glenarm Replacement)	Replaced	567 MW local solar 319 MW 4-hr storage	No market purchases

Portfolio and Metric Comparison

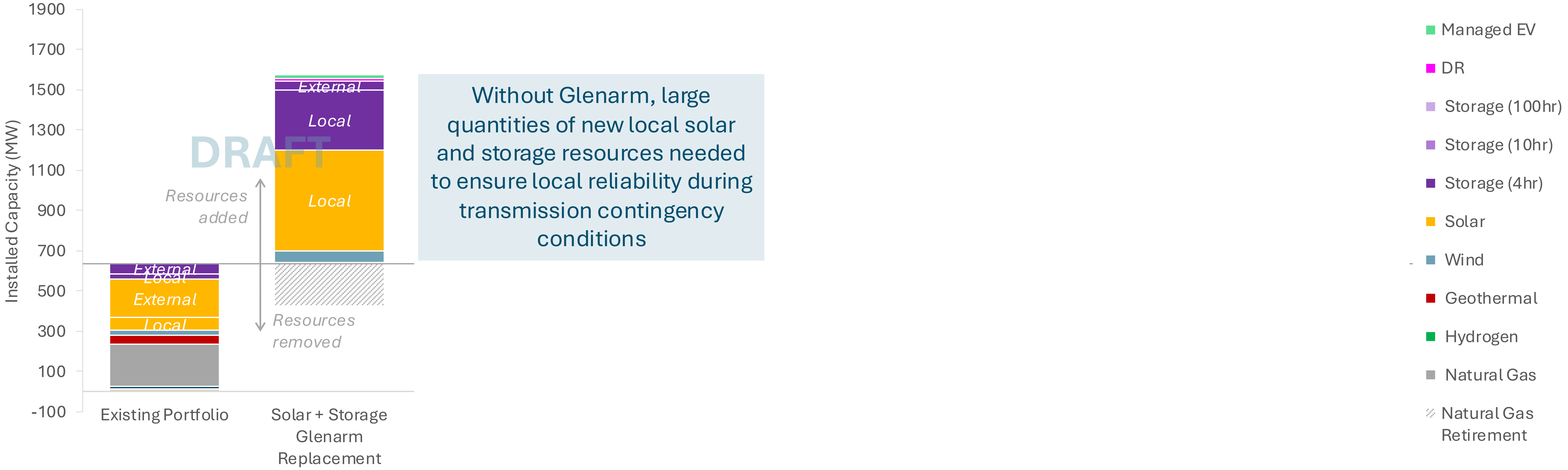
	Current 2031 Resource Portfolio*
Metric 1	86%
Metric 2	78%
Metric 3	83%

*Metrics currently reported on the PWP clean energy tracker for Owned/Contracted resources

Note: Metric calculations are based on a single deterministic year of normal weather conditions and do not capture events where transmission or distribution contingencies would require Glenarm to operate to ensure local reliability. Actual outcomes may vary due to impacts of natural year-to-year weather variability, transmission and distribution contingencies, and dispatch instructions provided by CAISO.

Portfolio and Metric Comparison

	Current 2031 Resource Portfolio*	Portfolios Designed to Meet 100% of *Hourly* Needs *(Glenarm Replaced/Converted)*
Metric 1	86%	167%
Metric 2	78%	100%
Metric 3	83%	100%



Without Glenarm, large quantities of new local solar and storage resources needed to ensure local reliability during transmission contingency conditions

*Metrics currently reported on the PWP clean energy tracker for Owned/Contracted resources

Note: Metric calculations are based on a single deterministic year of normal weather conditions and do not capture events where transmission or distribution contingencies would require Glenarm to operate to ensure local reliability. Actual outcomes may vary due to impacts of natural year-to-year weather variability, transmission and distribution contingencies, and dispatch instructions provided by CAISO.

Portfolio and Metric Comparison

	Current 2031 Resource Portfolio*	Portfolios Designed to Meet 100% of *Hourly* Needs *(Glenarm Replaced/Converted)*	
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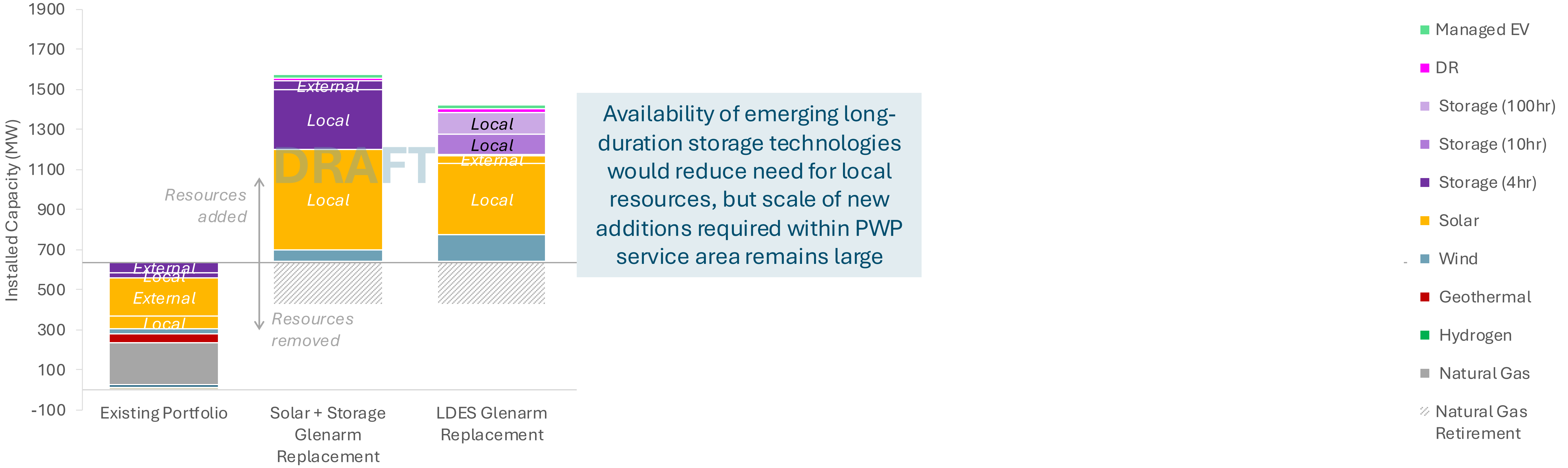


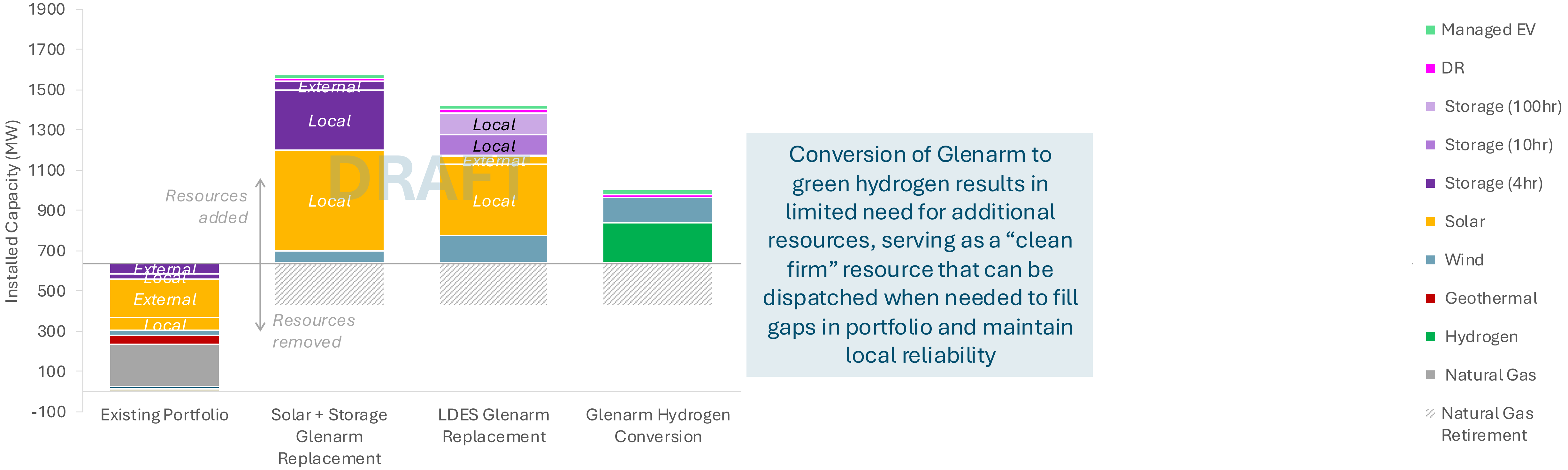
Availability of emerging long-duration storage technologies would reduce need for local resources, but scale of new additions required within PWP service area remains large

*Metrics currently reported on the PWP clean energy tracker for Owned/Contracted resources

Note: Metric calculations are based on a single deterministic year of normal weather conditions and do not capture events where transmission or distribution contingencies would require Glenarm to operate to ensure local reliability. Actual outcomes may vary due to impacts of natural year-to-year weather variability, transmission and distribution contingencies, and dispatch instructions provided by CAISO.

Portfolio and Metric Comparison

	Current 2031 Resource Portfolio*	Portfolios Designed to Meet 100% of *Hourly* Needs *(Glenarm Replaced/Converted)*		
Metric 1	86%	167%	183%	127%
Metric 2	78%	100%	100%	100%
Metric 3	83%	100%	100%	100%



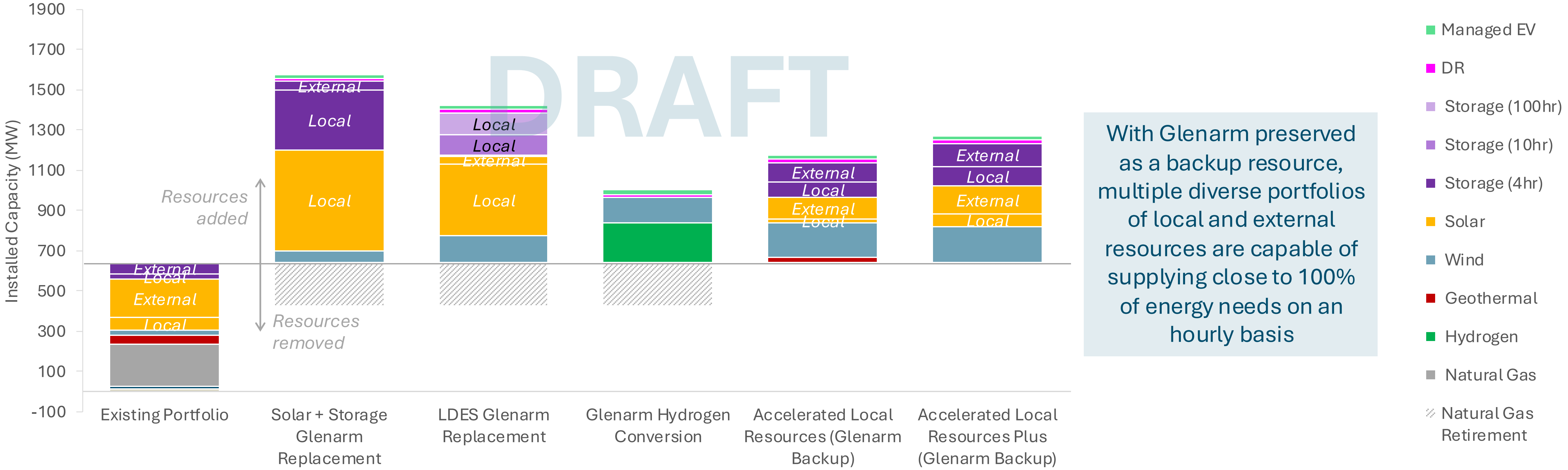
Conversion of Glenarm to green hydrogen results in limited need for additional resources, serving as a "clean firm" resource that can be dispatched when needed to fill gaps in portfolio and maintain local reliability

*Metrics currently reported on the PWP clean energy tracker for Owned/Contracted resources

Note: Metric calculations are based on a single deterministic year of normal weather conditions and do not capture events where transmission or distribution contingencies would require Glenarm to operate to ensure local reliability. Actual outcomes may vary due to impacts of natural year-to-year weather variability, transmission and distribution contingencies, and dispatch instructions provided by CAISO.

Portfolio and Metric Comparison

	Current 2031 Resource Portfolio*	Portfolios Designed to Meet 100% of *Hourly* Needs *(Glenarm Replaced/Converted)*			Portfolios Designed to Meet 100% of *Hourly* Needs *(Glenarm as Backup)*	
Metric 1	86%	167%	183%	127%	170%	171%
Metric 2	78%	100%	100%	100%	100%	100%
Metric 3	83%	100%	100%	100%	100%	100%



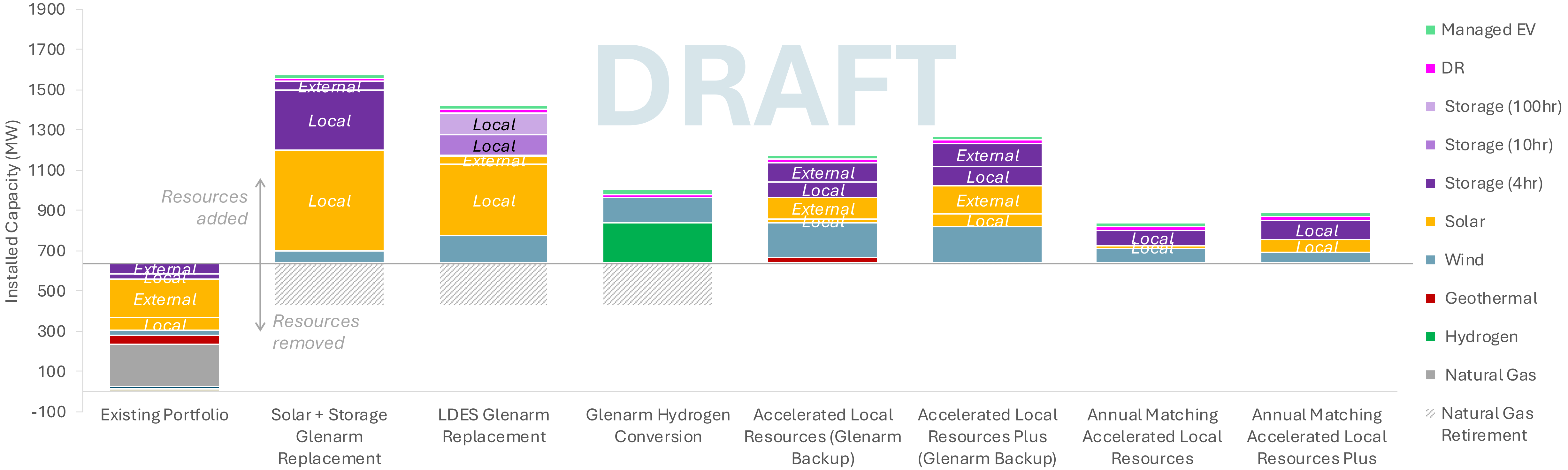
With Glenarm preserved as a backup resource, multiple diverse portfolios of local and external resources are capable of supplying close to 100% of energy needs on an hourly basis

*Metrics currently reported on the PWP clean energy tracker for Owned/Contracted resources

Note: Metric calculations are based on a single deterministic year of normal weather conditions and do not capture events where transmission or distribution contingencies would require Glenarm to operate to ensure local reliability. Actual outcomes may vary due to impacts of natural year-to-year weather variability, transmission and distribution contingencies, and dispatch instructions provided by CAISO.

Portfolio and Metric Comparison

	Current 2031 Resource Portfolio*	Portfolios Designed to Meet 100% of *Hourly* Needs (*Glenarm Replaced/Converted*)			Portfolios Designed to Meet 100% of *Hourly* Needs (*Glenarm as Backup*)		Portfolios Designed to Meet 100% of *Annual* Needs (*Glenarm Reduced Operations*)	
Metric 1	86%	167%	183%	127%	170%	171%	108%	108%
Metric 2	78%	100%	100%	100%	100%	100%	96%	96%
Metric 3	83%	100%	100%	100%	100%	100%	94%	95%

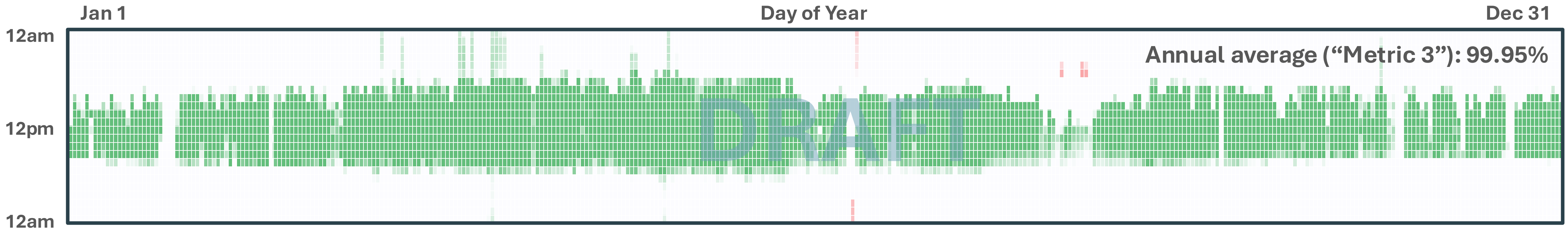


*Metrics currently reported on the PWP clean energy tracker for Owned/Contracted resources

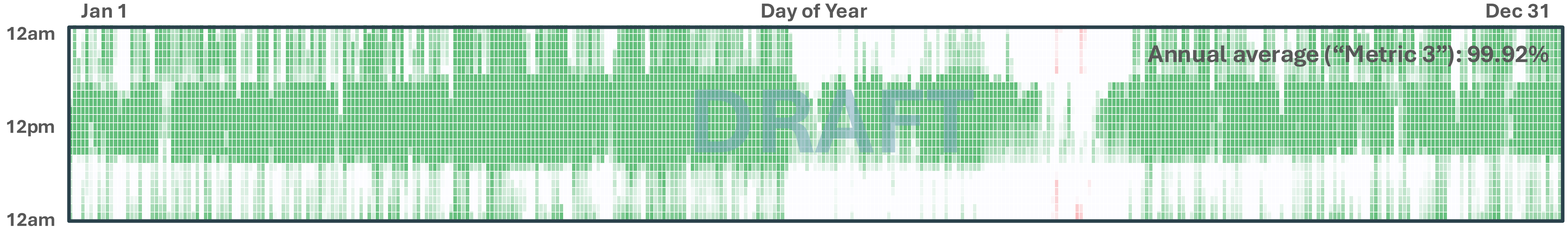
Note: Metric calculations are based on a single deterministic year of normal weather conditions and do not capture events where transmission or distribution contingencies would require Glenarm to operate to ensure local reliability. Actual outcomes may vary due to impacts of natural year-to-year weather variability, transmission and distribution contingencies, and dispatch instructions provided by CAISO.

2031 Balance of Carbon-Free Energy Resources

Glenarm Replacement Solar + Storage Only



Accelerated Local Resources + Glenarm Backup



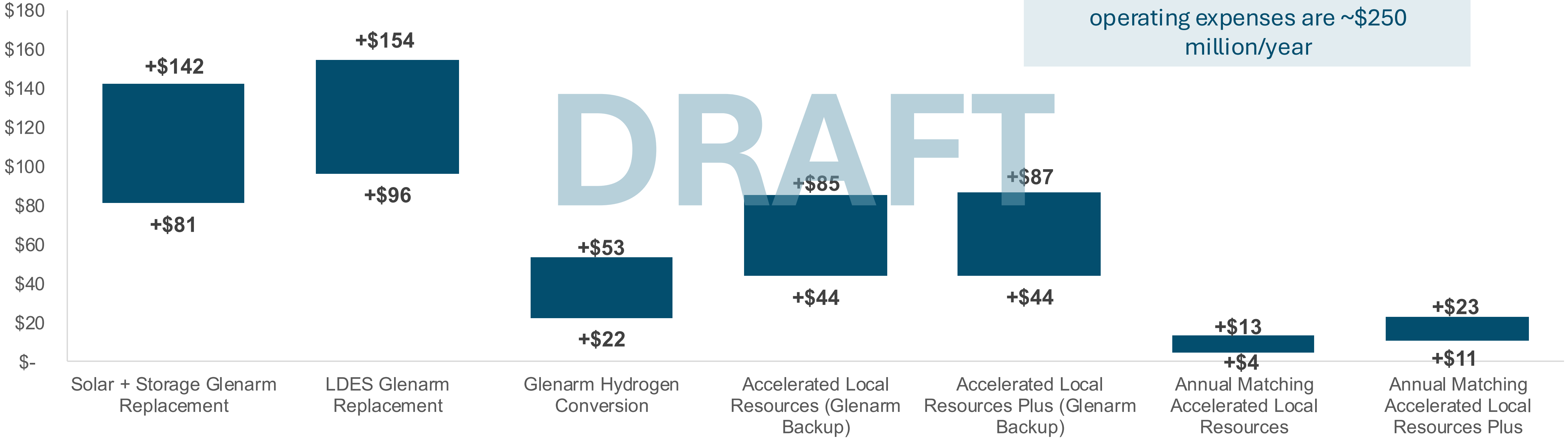
Hourly Carbon-Free Electricity vs. Hourly Load

0%	25%	50%	75%	100%	125%	150%	175%	200%

Portfolio Cost Comparison

	Portfolios Designed to Meet 100% of *Hourly* Needs (*Glenarm Replaced/Converted*)			Portfolios Designed to Meet 100% of *Hourly* Needs (*Glenarm as Backup*)		Portfolios Designed to Meet 100% of *Annual* Needs (*Glenarm Reduced Operations*)	
Metric 1	167%	183%	127%	170%	171%	108%	108%
Metric 2	100%	100%	100%	100%	100%	96%	96%
Metric 3	100%	100%	100%	100%	100%	94%	95%

2031 Relative Incremental Total System Cost
($ million per year)



Note: PWP's current power fund operating expenses are ~$250 million/year

Note: Incremental cost measured relative to a "least-cost" portfolio designed to meet 100% of Pasadena's annual energy needs with carbon-free resources

Summary of Portfolio Analyses

	Portfolios Designed to Meet 100% of *Hourly* Needs *(Glenarm Replaced/Converted)*			Portfolios Designed to Meet 100% of *Hourly* Needs *(Glenarm as Backup)*		Portfolios Designed to Meet 100% of *Annual* Needs *(Glenarm Reduced Operations)*	
	Solar-Storage Replacement	**LDES Replacement**	**Hydrogen Conversion**	**Accel Local Resources**	**Accel Local Resources Plus**	**Accel Local Resources**	**Accel Local Resources Plus**
New Resource Needs by 2031							
New Renewables (MW)	563	531	129	326	380	87	114
New Storage (MW)	339	215	-	173	214	76	100
New DR & Load Flex (MW)	35	37	35	35	36	35	35
Clean Energy Metrics by 2031							
Metric 1 (%)	167%	183%	127%	170%	171%	108%	108%
Metric 2 (%)	100%	100%	100%	100%	100%	96%	96%
Metric 3 (%)	100%	100%	100%	100%	100%	94%	95%
Relative Costs in 2031							
Incremental Cost ($M/yr)	+$81-142	+$96-154	+$22-53	+$44-85	+$44-87	+$4-13	+$11-23
Other Considerations	Higher risk (red, orange, light green, dark green) Lower risk						
Siting & Land Availability	red	red	dark green	dark green	light green	dark green	light green
Technology Readiness	light green	red	red	light green	light green	light green	light green
Upstream Infrastructure Need	light green	light green	red	light green	light green	light green	light green
Wholesale Market Exposure	orange	orange	light green	orange	orange	dark green	dark green
Resource Adequacy Risk	red	orange	light green	dark green	dark green	light green	light green
Local Resilience	red	orange	light green	light green	dark green	light green	dark green

Note: Metric calculations are based on a single deterministic year of normal weather conditions and do not capture events where transmission or distribution contingencies would require Glenarm to operate to ensure local reliability. Actual outcomes may vary due to impacts of natural year-to-year weather variability, transmission and distribution contingencies, and dispatch instructions provided by CAISO.

Analysis Findings: Opportunities and Challenges

<u>Opportunities:</u>

1. **A wide range of new resource options can contribute to meeting Pasadena's clean energy goals under Resolution 9977**
   - Local solar and storage, demand-side flexibility, external renewables and storage, and additional emerging technologies may all play a role
   - Analysis does not indicate a specific "need threshold" for any single type of resource to meet Pasadena's goals
   - There are multiple viable portfolios of resources that can meet any prescribed clean energy target, and the least-cost option among them will depend upon a range of market factors that are uncertain today
2. **By relieving the local reliability constraint, maintaining Glenarm as a backup resource unlocks additional opportunities to diversify Pasadena's supply of carbon-free energy with external renewables and storage resources, reducing costs to integrate additional resources**
   - Wind, geothermal, and utility-scale solar & storage are all selected as least-cost resources in multiple cases with Glenarm in the portfolio
   - Retaining Glenarm in the near-term creates an opportunity to leverage emerging technologies that may not be commercially viable by 2031.

<u>Challenges:</u>

1. **The OSP case studies illustrate three contrasting visions for how Pasadena could fully decarbonize its power supply on an hourly basis, but each one faces at least one significant technical barrier to implementation**
   - **Land constraints** and **local siting challenges** pose challenges in portfolios that replace Glenarm
   - **Lack of technology readiness** is likely to limit the feasibility of portfolios including long-duration storage or hydrogen by 2031
2. **How the city chooses to meet local reliability needs within the city even under stress conditions has significant ramifications on the portfolio composition and cost**
   - Portfolios that seek to replace Glenarm with carbon-free resources result in large needs for new local resource capacity, where options for diversity are limited
   - All portfolios that maintain Glenarm in some form as a firm resource in the load pocket exhibit lower costs than portfolios in which it is retired

Distribution study methodology

Energy+Environmental Economics

Distribution Study Process Overview

Define system-wide scenarios of DER adoption → Geospatially downscale DER forecasts to distribution feeders → Quantify bounds of potential distribution system costs

Distribution System Study Scenarios

Net Energy Metering

Managed light-duty EV charging

Demand Response

Solar (66 MW)
NEM forecast for customer solar

Storage (26 MW)
NEM forecast for customer storage (1 MW) + Utility-scale storage (25 MW)

Accelerated Local Resources

Managed light-duty EV charging

Demand Response

Solar (130 MW)
Accelerated adoption of customer solar

Storage (127 MW)
Accelerated adoption of customer storage (51 MW) + Utility-scale storage (75 MW)

Glenarm Replacement

Managed light-duty EV charging

Demand Response

Solar (567 MW)
All technical solar potential (rooftop + parking + ground mount)

Storage (319 MW)
Customer storage (119 MW) + Utility-scale storage (200 MW)

Forecasting Anywhere Overview

1. Determine technical potential
- Inputs: Parcels; Businesses; Parking lots
- Outputs: *# of chargers, square footage, MW capacity*

Tells you where DERs could be installed

2. Calculate propensity (likelihood) to adopt
- Inputs: Businesses; Proximity to POI; Existing adoption; Income
- Outputs: *Propensity score*

3. Determine local level adoption
Allocate utility-level adoption forecast
- Inputs: Power Supply Forecast; OSP Glenarm Study Results; OSP Customer Solar Forecast
- Outputs: *Units adopted*

Tells you where DERs are likely to be located

4. Geospatial aggregation
Feeder area
- Inputs: Power Delivery Diagram
- Outputs: *Units adopted*

5. Calculate load impacts
- Inputs: Hourly load shapes
- Outputs: *Hourly, annual, peak load impact*

6. Data, reports, visualizations

Legend: Model Step | *Inputs* | Outputs

Next Steps

- **Collect and incorporate feedback from MSC and TAP on portfolio development phase**
- **Cost impacts phase**
  - Cost impacts study
    - Transition to electric rate study
  - Distribution system analysis
- **Synthesis and plan development**

Appendix

Energy+Environmental Economics

Power supply cost break down, 2031

$ Million/Year	100% Annual Matching	Solar + Storage Glenarm Replacement	LDES Glenarm Replacement	Glenarm Hydrogen Conversion	Accelerated Local Resources (Glenarm Backup)	Accelerated Local Resources Plus (Glenarm Backup)	Annual Matching Accelerated Local Resources	Annual Matching Accelerated Local Resources Plus
Existing Utility-Owned Generation Fixed O&M	$12 - $12	$0 - $0	$ 0- $0	$0 - $0	$11 - $11	$11 - $11	$12 - $12	$12 - $12
Generic New Resources	$18 - $23	$165 - $230	$174 - $237	$59 - $84	$103 - $150	$104 - $151	$30 - $43	$37 - $54
Generic New Solar	$0 - $0	$103 - $129	$73 - $92	$0 - $0	$13 - $21	$25 - $37	$3 - $4	$13 - $16
Local	$0 - $0	$103 - $129	$69 - $86	$0 - $0	$3 - $4	$13 - $16	$3 - $4	$13 - $16
External	$0 - $0	$0 - $0	$3 - $6	$0 - $0	$9 - $17	$12 - $21	$0 - $0	$0 - $0
Generic Storage	$0 - $0	$45 - $82	$62 - $98	$0 - $0	$23 - $42	$29 - $52	$10 - $18	$13 - $24
Local	$0 - $0	$39 - $71	$61 - $97	$0 - $0	$10 - $18	$13 - $24	$10 - $18	$13 - $24
External	$0 - $0	$6 - $11	$ - $1	$0 - $0	$13 - $23	$15 - $28	$0 - $0	$0 - $0
Generic New Other	$18 - $22	$16 - $20	$40 - $48	$59 - $84	$68 - $87	$50 - $63	$16 - $21	$11 - $14
Operating Costs (Fuel, CO_2, O&M)	$10 - $10	$1 - $1	$1 - $1	$11 - $11	$1 - $1	$1 - $1	$8 - $8	$8 - $8
Market Purchases (Revenues)	($4) – ($4)	($32) – ($32)	($35) – ($35)	($12) – ($12)	($37) – ($37)	($36) – ($36)	($10) – ($10)	($9) – ($9)
Transmission Access Charge (TAC)	$27 - $27	$10 - $10	$19 - $19	$27 - $27	$28 - $28	$27 - $27	$27 - $27	$25 - $25

Note: The table above shows only components of the power supply cost that differ between case studies.

Metric 3 Calculation

Calculate the net carbon-free generation in each hour:

$$\text{Net Carbon-Free Generation}_H = \text{Carbon-Free Generation}_H + \text{Storage Discharge}_H - \text{Storage Charge}_H,$$

Cap net carbon-free generation at load in each hour, sum each hour of the year, divide by annual load:

$$\frac{\text{Sum(Minimum[Net Carbon-Free Generation}_H\text{, Load}_H\text{] for H in 1...8760)}}{\text{Annual Load}}$$