CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Net Positive Resilient All-Electric Affordable Housing at the Corona Station Residence in Petaluma

September 2024 | CEC-500-2024-095

PREPARED BY:

Angelica Chow
Herb Yaptinchay
Kayla Bortolon
Electric Power Research Institute (EPRI)
Primary Authors

Michael Ferreira
Project Manager
California Energy Commission

Agreement Number: EPC-21-028

Anthony Ng
Branch Manager
TECHNOLOGY INNOVATION AND ENTREPRENEURSHIP BRANCH

Jonah Steinbuck, Ph.D.
Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

The researchers on this project first acknowledge and thank the California Energy Commission for support of this research and development effort with its technical guidance and funding support. Special thanks go to the Commission Agreement Managers, Molly O'Hagan and Michael Ferreira, as well as Branch Manager Anthony Ng for guiding and supporting the team toward the project's successful completion.

The team acknowledges and thanks the following people and organizations for their support of the many aspects of this project:

- City of Petaluma: Jared Hall and Kevin McDonnell
- Redwood Energy: Sean Armstrong and Emily Higbee
- The Danco Group: McKenzie Dibble, Chris Dart, and Dan Johnson
- Larsen & Toubro USA: Dr. Arindam Maitra, Russell Griffith, and Robinder Sarang
- PAE Engineers: Alper Erten and Kirsten Robinson
- Mithun: Mary Telling and Claire McConnell
- The Rahus Institute: Tor Allen
- Electric Power Research Institute: Ram Ravikumar, Morgan Smith, Dr. Vis Ananth, Ben Clarin, Sara Beaini, Mazen Daher, Aaron Tam, and Evan Giarta

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

To address California's goal of reducing greenhouse gas emissions and mitigate the statewide housing crisis, innovations are needed to rethink the design and construction of affordable housing within California. The purpose of the California Energy Commission Next EPIC Challenge is to create an affordable, zero-emissions, mixed-use development. The Electric Power Research Institute and the project team designed a zero net energy, affordable multifamily mixed-use community called Meridian at Corona Station in Petaluma, California, using community engagement strategies and innovative electrification, electric vehicle charging, a renewable microgrid, an alternative standby interconnection, and nature-based/non-energy solutions.

Building energy modeling estimates an impactful energy and emissions performance of improved building energy efficiency with reduced energy use intensity and greenhouse gas intensity. The building design is modeled to achieve a 90-percent reduction in operational carbon emissions and approximately a 40-percent reduction in embodied carbon. From a cost analysis, the project is designed to eliminate the energy burden for residential tenants. The project includes 100-percent affordable housing and 25-percent supportive housing for individuals experiencing homelessness. The project's approach aims to create a feasible and scalable multifamily housing design that promotes clean energy distributed energy resources deployment with a renewable microgrid of solar and battery storage that can power the entire community for 95 percent of the year with a unidirectional standby connection with the utility for the remainder of the year. The project also features a scalable community engagement approach and nature-based/non-energy related design features that highlight the community's and the city of Petaluma's needs and priorities. The next steps include the construction, occupation, analysis of results, and knowledge transfer of Meridian at Corona Station's best practices to field demonstrate a mixed-use development design and approach that reduces building emissions while mitigating climate change and positively impacting communities.

Keywords: Mixed-use development, affordable housing, multifamily, zero net energy, community resilience, climate change, decarbonization, clean energy, energy efficiency

Please use the following citation for this report:

EPRI (Electric Power Research Institute). 2024. *Net Positive Resilient All-Electric Affordable Housing at the Corona Station Residence in Petaluma.* California Energy Commission. Publication Number: CEC-500-2024-095.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Background

To address the urgent need to reduce greenhouse gas emissions and combat rising housing costs and a housing deficit, innovations are needed to ensure that all Californians have access to safe, healthy, affordable, and desirable living environments. As part of the California Energy Commission Next Electric Program Investment Charge Challenge, the Electric Power Research Institute and the project team have designed a zero net energy mixed-use, affordable housing community in Petaluma, California.

Meridian at Corona Station (Meridian) in Petaluma, California, is an all-electric, transit-integrated, affordable and supportive multifamily housing development focused on the security, sustainability, and resilience of its community and the greater city of Petaluma. Meridian consists of 131 affordable housing units, including 33 supportive housing units and mixed-use office spaces. The community features important elements benefitting the community: open green space, outdoor recreational amenities, an electric food truck restaurant garden, and an adjacent new Sonoma-Marin Area Rail Transit train and electric bus terminal that enables access to the rest of the North Bay. The community is designed as a low-carbon and climate-resilient development focused on positive, equitable outcomes for low-income residents. The community integrates energy-efficient technologies, ecologically friendly elements, bidirectional electric vehicle chargers, and advanced construction practices to minimize greenhouse gas emissions and increase access to clean energy and electric vehicle charging, helping meet California's clean energy, net-zero emissions, and electric vehicle goals.

Project Purpose and Approach

The project aims to design a mixed-use development that is affordable, equitable, climate-resilient, cost-competitive, and emissions-free. The project design fulfills and exceeds metrics proposed by the California Energy Commission and the project team on affordability, smart growth, emissions-free, scalability, grid-interactivity, and resilience. When designing any affordable housing community, it is important to understand the community and its needs as well as to find opportunities for design strategies that best meet community goals. For the design of Meridian, the project team interviewed local community members, community-based organizations, and city of Petaluma officials. Through this effort, the project team aligned the project design with Petaluma's Climate Ready by 2030 Goal, community concerns with hazardous events due to climate change, and the integration of nature-based solutions. To address the emissions-free aspect, the project features a zero net energy design: a solar + battery microgrid with enough capacity to power the community for 95 percent of the year with a minimal standby unidirectional connection with the utility for emergencies; electric-vehicle-ready parking spots with bidirectional charging to the microgrid, buildings, or the grid; load flexibility and forecasting applications to manage effective load shedding to meet peak demand reduction; building electrification technologies such as heat pumps, heat pump water heaters, induction cooktops, heat pump dryers, light-emitting diode lights, occupancy-based sensors for lighting controls in the commercial spaces, and advanced power strips; and non-energy/nature-based solutions, including exterior cork siding insulation, exterior-grade mass timber carports, grey water re-use design from laundry to landscape, low-carbon concrete pathways, and an orchard ecosystem.

Key Results

The project design expects to achieve the following results, as determined by building energy modeling and cost analysis calculations:

- 100 percent of the units dedicated to affordable housing, with 25 percent dedicated to supporting individuals/households experiencing homelessness.
- A 100-percent reduction of the energy burden on residential tenants and approximately a 9-percent reduction in electricity bills for commercial tenants.
- Approximately a 90-percent reduction in operational carbon and a 40-percent reduction in embodied carbon.
- A 100-percent reduction in building load during peak demand hours of 4:00 p.m. to 9:00 p.m., through a combination of onsite solar, battery storage, and load management strategies.
- 100-percent electric-vehicle-charging-capable parking spaces, with approximately 36 percent that can respond to building and microgrid signals and the remaining 64 percent that can respond to grid signals.
- A standalone F-150 Lightning truck and electric vehicle charger with vehicle-to-building capabilities, to enhance building and community resilience in the event of power loss.
- An alternative standby utility connection to allow the community to use 100-percent onsite emissions-free clean energy (via the microgrid) for 95 percent of the year.

The overall calculated costs show an increased first cost of $35,992 per unit from the owner's perspective, comparing the proposed design to a standard design (Title 24 2022).[1] During the lifecycle of the building, the residents save on costs, since rent of the standard design is the same as that of the proposed design, and residents in the proposed design do not pay utility bills because of the minimal unidirectional standby power and microgrid design. The proposed-design owner is leveraging a number of federal and state tax credits, cap-and-trade programs, rebates from utilities and community choice aggregators, and green loans from banks to finance the project, and future all-electric, net-zero emissions, affordable housing developers can leverage these incentives as well. While green incentives are not consistent, it is anticipated that future green incentives will continue to persist and increase in number. The incremental costs from the operational carbon and embodied carbon reduction measures are also expected to decrease as more all-electric and net-zero emissions buildings are scaled. Viewing the project economics from an energy justice lens, the carbon emissions avoided

[1] California Energy Commission. 2022 (Aug). *2022 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*. Publication Number: CEC-400-2022-010-CMF. Available at https://www.energy.ca.gov/sites/default/files/2022-12/CEC-400-2022-010_CMF.pdf.

through the proposed building design lead to a $166,383 societal lifecycle cost savings that should be accounted taken into account when evaluating project financing.

The project benefits to California ratepayers, the public, and the environment include: a scalable design and community engagement approach to affordable multifamily housing; enhanced utility service reliability; accelerated deployment of clean energy distributed energy resources; a reduced tenant energy burden; increased building resilience against climate change disasters; reduced greenhouse gas emissions; and improved water quality, air quality, and physical and mental health for the community and greater California.

Knowledge Transfer and Next Steps

The project team has shared knowledge regarding Meridian's design with stakeholders and the public through several knowledge transfer activities. These include presentations on the overall design strategies, technology selection, and scalable opportunities with utilities, city council members, researchers, engineers, and universities. Conversations and public forums have been hosted with the city of Petaluma and community-based organizations to communicate the project design with community members. In addition to posting features on project team websites and online news articles, the project team will continue knowledge transfer of the project design through a public video; presentations at upcoming workshops, meetings, and conferences; and white papers regarding the interconnection process and non-energy solutions and benefits to utility stakeholders.

The next step is to complete construction and occupancy of Meridian based on the project design summarized in this report. The project team will conduct field measurement and verification, collect data from the occupied community, and compare the measured results with the modeled results to derive insights and lessons learned. Best practices will be shared with the community, the city of Petaluma, and the California Energy Commission through reports, community engagement surveys and educational workshops, and workforce development opportunities. The educational services for future tenants of Meridian, developers, property management, and residents of the city of Petaluma will be focused on energy savings, climate change, and opportunities to reduce impacts related to climate change. Surveys hosted for the community can help the project team verify how the project design yields positive results to the tenants and help the property management team identify opportunities for improvement. Throughout construction, the project team intends to work with local workforce development programs to increase access to green careers by introducing young apprenticeship training opportunities on the construction site. The field demonstration and knowledge transfer of best practices from this California Energy Commission Next Electric Program Investment Charge Challenge project will help the state of California in working towards lowering building emissions, increasing adoption of electric vehicles and clean energy, and reaching net-zero emissions by 2045.

CHAPTER 1: Introduction

Climate Change and Housing Challenges in California

California is grappling with two critical challenges: climate change and housing affordability. Recent devastating fires and findings from *California's Fourth Climate Change Assessment*[2] emphasize the urgent need to reduce greenhouse gas (GHG) emissions. To meet aggressive policy goals for decarbonization of the energy sector by 2045, the State of California is focusing on building decarbonization through energy efficiency, onsite renewable generation, and end-use electrification as a key strategy.[3] Simultaneously, California faces a housing affordability crisis, with an undersupply of housing exacerbated by escalating housing and living costs. Local government policies, which restrict new housing construction in established neighborhoods, are a significant driver of this housing deficit, resulting in new development in exurban and rural areas that are more prone to wildfires, floods, and other climate-related disasters.[4] Governor Newsom and the California Legislature aim to bridge the housing gap by constructing, by 2030, 2.5 million new homes that emphasize smart growth, mixed-used development, and affordability as important components.[5] Figure 1 reflects the latest Regional Housing Needs Assessment (RHNA) findings, that 1.5 million of these new homes need to be dedicated to low- and moderate-income households.

---

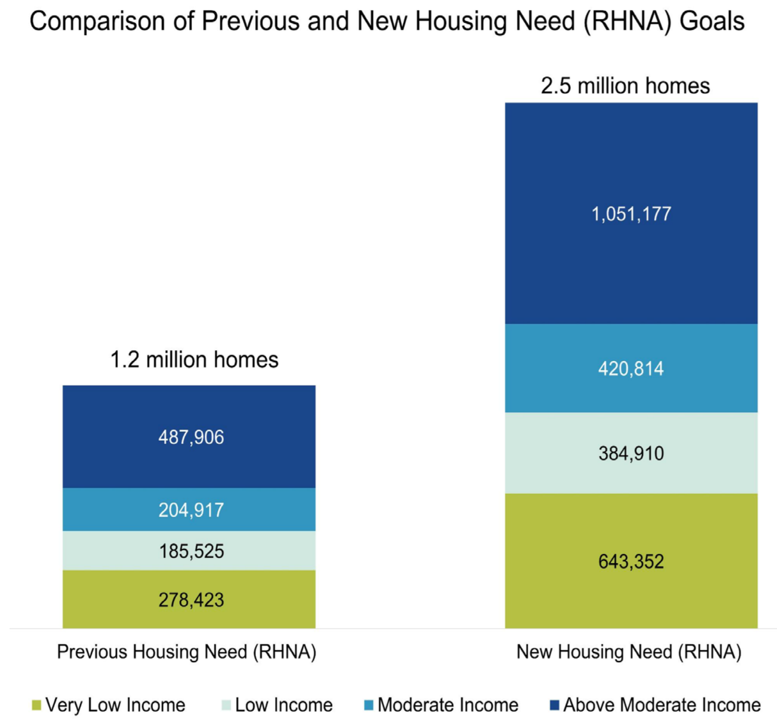
[2] California Office of Planning and Research. 2019. *California's Fourth Climate Change Assessment*. Available at http://climateassessment.ca.gov/.

[3] California Air Resources Board. 2022 (Nov 16). *2022 Scoping Plan for Achieving Carbon Neutrality*. Available at https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf.

[4] O'Donoghue, L., and Breach, M. 2023 (Mar 23). "Opinion: California Housing and the Environment are Often at Odds. They Don't Have to Be." *The Los Angeles Times*. Available at https://www.latimes.com/opinion/story/2023-03-23/california-housing-climate-environment-legislation.

[5] California Department of Housing and Community Development. 2022 (Mar). "A Home for Every Californian: 2022 Statewide Housing Plan." Available at https://storymaps.arcgis.com/stories/94729ab1648d43b1811c1698a748c136.

Figure 1: RHNA Updated Goals for 2030



Source: RHNA, 2022

Despite its potential, achieving a zero-emission, mixed-use development poses challenges due to uncertainties, technical limitations, and economic feasibility with current technologies and building practices. Current studies also indicate that smart growth may exacerbate gentrification and displacement of low-income households.[6] As such, the purpose of this California Energy Commission (CEC) Next Electric Program Investment Charge (EPIC) Challenge project is to design and demonstrate an affordable, equitable, and emissions-free mixed-use development that can address GHG emissions and meet housing needs while maintaining market appeal. The project uses innovative and integrated measures such as emerging technologies, tools, and construction practices to design a mid-rise, mixed-use development that is affordable, equitable, climate-resilient, cost-competitive, and emissions-free.

Project Objectives

The project design aims to fulfill and exceed the following metrics proposed by the CEC to ensure affordability, climate resilience, cost-effectiveness, and zero net energy (ZNE):

- Addressing affordability: Dedicate 100 percent of the total units to affordable housing, with at least 25 percent of the total units dedicated to lower income households.
    - Reduce the energy burden on tenants by approximately 50 percent.

[6] Grabinsky, J., and S.M. Butler. 2015 (Feb 10). "The Anti-Poverty Case for 'Smart' Gentrification, Part 1." *Brookings*. Available at https://www.brookings.edu/articles/the-anti-poverty-case-for-smart-gentrification-part-1/.

- Addressing smart growth: Include 131 housing units and achieve a site density of 139 residential units per acre.
    - Locate the project near public transit and create a walkable community.
    - Align project design with the goals of the host site city and the local community.
- Addressing emissions-free: Feature an all-electric building design with no gas consumption allowed.
    - Reduce embodied carbon (in foundation and construction) by approximately 40 percent and operational carbon by at least 90 percent.
    - Meet the development’s residential load during peak demand hours, 4:00 p.m. to 9:00 p.m., through a combination microgrid of onsite solar photovoltaic (PV), onsite battery energy storage systems (BESS), and load management.
    - Install electric vehicle (EV) charging stations in 100 percent of all parking spaces associated with the development, with about 36 percent capable of responding to building and microgrid signals.
- Addressing scalability: An alternative standby, unilateral interconnection with the utility speeds up the construction process and mitigates financial losses commonly associated with lengthy bidirectional interconnection processes.
- Addressing grid-interactivity:
    - Temporarily manage or curtail a minimum of 20 percent of the development’s peak load to respond to grid conditions.
    - Control all residential end uses through the home energy management system (EMS) and be capable of responding to real-time pricing signals.
    - The microgrid controller is interoperable with distributed energy resource (DER) aggregation platforms such as virtual power plants (VPPs).
- Addressing resilience: The development can island from the main grid during an outage and shed discretionary loads to provide power to Tier 1 critical loads (10 percent of the peak load) and Tier 2 priority loads (25 percent of the peak load).
    - The microgrid is sized for indefinite renewables-driven backup power of Tier 1 critical loads, using a combination of onsite PV, BESS, and load management.
    - A standalone F-150 Lightning truck and EV charger with vehicle-to-building (V2B) capabilities enhances building and community resilience in the event of power loss.
    - Nature-based/non-energy solutions are designed to increase community resilience.

Project Benefits

The low-carbon, zero-emission affordable housing project design and improvement of construction practices, coupled with demonstration of advanced energy efficiency, electrification, and renewable energy technologies, can yield substantial benefits for California ratepayers and utility customers in multiple ways:

- **More Affordable Housing:** As cities across California grapple with rising house costs and insufficient housing, this project can inform cities and building stakeholders of the best practices for designing and scaling NZE affordable housing.
- **Enhanced Reliability:** The energy management design reduces load during peak times, supporting enhanced electric service reliability for California ratepayers.
- **Low Rates and Clean Energy:** The design uses an innovative selective interconnection service agreement with the utility, to allow the community to use the onsite emissions-free microgrid to power residential loads for most of the year. This can lead to a reduced tenant energy burden as well as reduced costs associated with lengthy interconnection processes. This also contributes to California's goal of 100-percent clean electricity by 2045.
- **Increased Resilience:** The design of the Resilience Hub acts as shelter for the community and greater-city members during extreme climate events or long-duration power outages. The hub will also serve as an educational resource and a community gathering site throughout the year.
- **EV Integration and Expansion:** The project design is prepared for 100-percent EV charging in the community to accelerate and prepare for the adoption of EVs by California residents. This contributes to the state's goal of 100-percent new zero-emission vehicle sales by 2035.
- **Non-energy Benefits:** The ZNE design reduces building operating and embodied GHG emissions. GHG reduction provides benefits such as reduced occurrences of major climate events and improved water quality, air quality, and physical and mental health for occupants, the local community, and greater California.
- **Community Engagement:** The importance of engaging with community stakeholders when designing a ZNE mixed-use development is emphasized throughout this project. The alignment of the community's and the city's objectives with the project design ensures alignment with the state's overall goals.

This alternative interconnection project can serve as a proof-of-concept framework for affordable housing developers, architects, engineers, builders, contractors, and other relevant built environment stakeholders. Design and construction industry professionals can leverage the lessons learned and the results from this project to help scale and deploy more affordable and ZNE mixed-use developments and overcome barriers to achieving California's energy goals.

CHAPTER 2: Project Approach

The Project Team and Site Location

In pursuit of the project's goal to create an affordable, zero-emissions, mixed-use development addressing both GHG emissions and escalating housing costs, the project site was strategically chosen in a developed section of an expanding California town — an ideal location for implementing smart growth principles. Meridian at Corona Station in Petaluma, California, is an affordable multifamily housing campus designed with 131 affordable housing units, including 33 permanent supportive housing units for individuals experiencing or at risk of homelessness (Figure 2). Spread across multiple three-story and four-story buildings, the campus also features amenities and mixed-use services that benefit the community:

- Open green space with outdoor recreational amenities
- An onsite restaurant garden, which will allow for the hook-up of six electric food trucks
- Onsite office space and therapy rooms for third-party social services and healthcare workers
- A planned adjacent, separately funded, Sonoma-Marin Area Rail Transit (SMART) train station and electric bus terminal

Supported by the city of Petaluma, the design goals align well with Petaluma's goal to be carbon neutral by 2030, with one such strategy being the elimination of emissions from the building sector through zero-emission new construction.[7] After failing to meet its 2013 to 2015 RHNA cycle affordable housing production goals, the city of Petaluma is determined to meet its 2023 to 2031 RHNA planning period affordable housing production goals.[8] The Danco Group (Danco) was selected as the developer and property manager due to the company's commitment to build and manage all-electric and ZNE affordable housing developments. Danco is a progressive homebuilder focused on promoting new technology implementation in its affordable and market-rate communities.

---

[7] City of Petaluma. 2021 (Jan 11). *Climate Emergency Framework*. Available at https://storage.googleapis.com/proudcity/petalumaca/uploads/2021/02/Climate-Action-Framework_Final.pdf.

[8] City of Petaluma. 2023 (Aug 10). *Affordable Housing Finance Analysis*. Available at https://static1.squarespace.com/static/5ea880f6d9a2075c7b7f54af/t/64e528aacfa548043f604a68/1692739755610/Petaluma+GPU_5.10+Housing+Finance+Analysis_20230810_v2.pdf.

Figure 2: Aerial View of Meridian Housing Development in Petaluma, California

Source: Mithun, 2023

The Electric Power Research Institute (EPRI), acting as the main project manager and technical lead, worked with subcontractors Redwood Energy, Danco, Larsen & Toubro (L&T), PAE Engineers (PAE), Mithun, and The Rahus Institute to successfully design and model the project. As an all-electric design firm, Redwood Energy assisted in providing expertise on identifying emerging technologies and performing a cost-benefit analysis to create an all-electric and ZNE building design. As a firm specializing in engineering and construction, L&T provided expertise on designing the controls for the community's energy system. PAE, a sustainable engineering design company, provided the building energy modeling for the project design. Mithun is a nationally recognized architecture and urban design firm, which provided expertise on climate and community resilience non-energy/nature-based aspects of the design. The Rahus Institute is a non-profit community-based organization (CBO) that provided community engagement and outreach guidance on the project as the team worked with the host community and the city of Petaluma.

Project Tasks and Milestones

The project team performed the following tasks to successfully achieve the project milestones.

Task 1: Design a Cost-Effective Zero Net Energy Mixed-Use Development

To achieve the project goal of designing the development of an all-electric, ZNE, affordable mixed-use community, the project team collaborated to implement cost-effective and innovative technologies and strategies.

Milestone Deliverables: Conceptual drawings, design plans, and an architectural scale model of the development. A description of the emerging technologies and strategies proposed to be used in the design.

Task 2: Engage With the Community and Obtain Input to Ensure Equity

Throughout the design, the project team worked to obtain design input from community stakeholders, including the tenants, the developer and property management (Danco), and the city of Petaluma with community discussions and surveys.

Milestone Deliverable: A community engagement plan to solicit input from the community throughout the design process.

Task 3: Perform Energy Modeling and Data Analysis to Understand Impacts

To demonstrate the effectiveness of the development design, the project team used building envelope and energy modeling, including thermal comfort modeling, daylight modeling, and whole building life cycle analysis (LCA), to evaluate the performance of the design. A combination of metrics was evaluated, including costs and carbon impacts.

Milestone Deliverables: The software modeling results of the development's expected energy and emissions performance and impacts on tenants' energy bills. An analysis of the project benefits and the estimated cost difference between the zero-emission design and the standard building design, construction, and operations.

Task 4: Understand the Technology/Knowledge Transfer of Lessons Learned

The project team engaged in market research to better understand the challenges of and opportunities for scaling ZNE community development across California and the nation, such as utility interconnection and community choice aggregator (CCA) incentives. The team also collected lessons learned regarding the barriers to, challenges of, and opportunities for specifying, contracting, and designing a ZNE community with various building electrification technologies and distributed energy resources (DERs).

Milestone Deliverable: An analysis of project results and market opportunities for broader adoption of the project design.

Task 5: Prepare Site Readiness and Build Phase Selection

The project team conducted preparatory activities to submit the design to the CEC and seek a grant for the construction phase. This grant will enable the project team to showcase and evaluate the design in a real-world setting, benchmarking its actual performance against the modeled performance.

Milestone Deliverables: An approved set of construction drawings and permits, and a proposal application to the CEC for the construction phase grant.

Project Approach

The project approach emphasized using input from the community and leveraging the team's expertise in designing sustainable buildings to incorporate ZNE technology and nature-based/ non-energy strategies into the normal workflow of designing a mixed-use housing development.

Community Engagement Strategy

This project is planned to mitigate gentrification and provide affordable housing for the disadvantaged communities within Petaluma. Over the past eight years, Petaluma has trailed the Bay Area in producing units for households with low or very low incomes and has set goals to reverse the shortage in affordable housing units within the city.[9] When designing an affordable housing community, it is important to understand the community and its needs and to find opportunities for the design to best meet them in an equitable manner. For the design, the project team interviewed local community members and CBOs, surveyed a similar new-construction affordable housing community in San Francisco, and researched the city of Petaluma's Climate Emergency Framework to meet the needs of the city of Petaluma. Through this community engagement approach, the project team found that Petaluma would like to use more nature-based/non-energy related measures to mitigate hazardous events, such as extreme heat, flooding, drought, wildfires, and power outages that the city frequently faces due to climate change.[10] As such, Meridian's design considers resilience to wildfires and public safety power shutoffs, protection of urban forest ecosystems (that can reduce heat island impacts), education and workforce development of green jobs, and reduction of GHG emissions. Interviews with a new-construction, affordable multi-family housing community in San Francisco revealed that sustainable building design improved indoor air quality, increased the health and well-being of occupants with a high satisfaction with the outdoor amenities, and achieved a global warming potential (GWP) below San Francisco's 2030 target challenge goal. Though the survey primarily yielded positive results from the building occupants, some of the challenges mentioned included the following: the electric stovetop may limit what kind of meals the occupant can cook; poor sound insulation; extreme heat indoors from poor window insulation; inadequate air ventilation if people are cooking or smoking indoors; uncertainty of how to use the fans within the bathroom; desire for access to better and healthier food; preference for educational events targeted at sustainability; and the inability of maintenance staff to fix the upgraded technologies. The interviews helped the project team understand the importance and potential impact of sustainable building design to tenants. When designing Meridian, the project team used these survey results to mitigate the apparent challenges occupants faced in their community, such as improved ventilation and air filtration, Passive House building envelope design for better sound and heat insulation, education and training on the emerging technologies and sustainable measures for the tenants and property staff, and the inclusion of mixed-use cases, such as an electric food truck garden and a potential

[9] City of Petaluma. 2023 (Aug 10). *Affordable Housing Finance Analysis*. Available at https://static1.squarespace.com/static/5ea880f6d9a2075c7b7f54af/t/64e528aacfa548043f604a68/1692739755610/Petaluma+GPU_5.10+Housing+Finance+Analysis_20230810_v2.pdf.

[10] City of Petaluma. 2021 (Jan 11). *Climate Emergency Framework*. Available at https://storage.googleapis.com/proudcity/petalumaca/uploads/2021/02/Climate-Action-Framework_Final.pdf.

grocery store or deli for access to healthier foods. Figure 3 shows a rendering of Meridian's interior court design, which reflects the addition of outdoor amenities to support resident health and well-being as well as to build an environmental urban ecosystem. Lastly, the team found that the city of Petaluma launched its Climate Emergency Framework in 2021 with support from a majority residents (80 percent) who were concerned about climate change.[11] The framework provides a set of goals for future planning, policy, and action for Petaluma to be carbon neutral by 2030, with four focuses: equity and climate justice, mitigation and sequestration, adaptation and social resilience, and community engagement. The design of Meridian reflects the core concepts of this framework, with technologies for reducing GHG emissions, strategies for resilience, and community engagement approaches.

Figure 3: Rendering of Meridian's Interior Court Design, Which Includes Feedback From the Community Engagement Strategy

Source: Mithun, 2023

Emerging Technologies and Strategies

Through the development design, the project team aimed to achieve the project objectives by using the following unique and innovative measures in addressing GHG emissions, cost-effectiveness, and resilience. While Meridian's energy design is one of the most cutting edge of any mixed-use affordable housing development in the United States, the design is also a straightforward application of best practices proven in homes and apartments across the world. The design includes emerging technologies that provide ZNE and resilience to the development.

[11] Ibid.

Standby Microgrid With Minimal Unidirectional Connection

Interconnection processes for customers and utilities have typically been lengthy, complicated, and costly, which can significantly delay bringing electricity online to communities and deploying onsite renewable energy systems. The current interconnection process is a barrier not just to microgrids but also to deployments of PV and BESS alone. From prior experience with projects that underwent the interconnection process, the project team observed several main causes for interconnection delays. Notably, utilities have important operational and grid protection considerations. Utilities want to ensure confidence in the PV system, the storage system, and/or the microgrid system's ability to not backflow onto (by establishing PV hosting capacity limits/thresholds behind certain distribution feeders that already have significant solar installed) or draw from the grid without the utility's permission to operate for such behind-the-meter (BTM) systems. To build this confidence, most utilities require functionality or proof of compliant operations testing of these BTM DERs, even for non-export and non-import designs. There are a number of logistical and scheduling barriers to this functionality test, as the customer needs to create and conduct a test plan with the utility's approval, while siloed internal utility departments lacking streamlined communication, such as interconnection, distribution planning, and emerging technologies, each want to review and approve the test plan.

More often than not, a utility analysis of interconnection applications triggers a distribution feeder upgrade, which leads to further delays and additional costs. This is due to conservative analysis of potential generation and load for grid safety, which means utilities view PV and energy storage systems independently, even if the customer is planning on using energy storage to mitigate any backflow onto the grid. The project team has noticed a lack of clarity on behalf of the customers and installers on what procedures/documentation is required and what the anticipated timeline is in order to complete the interconnection process.

Meridian is located in Pacific Gas and Electric Company's (PG&E's) utility service territory, which has seen some affordable housing projects wait for over a year and a half to reach an interconnection agreement.[12] In previous projects, the project team noted approximately $230,000 per month in costs incurred while waiting for microgrid interconnections and the loss of over $10,000 per month for interconnection of a PV system alone. To reduce this challenge, the team proposed an innovative approach by leveraging standby tariffs, which exist for investor-owned utilities (IOUs), with an NZE building design coupled with a PV and a BESS to interconnect the community.

The team proposes an NZE microgrid with 1,270-kilowatt (kW) direct current of solar PV panels and a 2.0-megawatt-hour BESS that can power the loads of the community for 95 percent of the year with renewable energy. As a design criterion set by the design team, both the solar PV and the battery systems are sized to limit the need for backup power from the grid to less than 5 percent of the community's annual energy demand. Minimizing the need for

---

[12] Quackenbush, J. 2023 (Mar 10). "Bills Aim to Fix California's Long Delays in Connecting Construction Projects to the Grid." *The North Bay Business Journal*. Available at https://www.northbaybusinessjournal.com/article/article/bills-aim-to-fix-californias-long-delays-in-connecting-construction-projec/.

backup energy, either in the form of backup grid connection and/or vehicle-to-microgrid (V2M) energy transfer, requires increased capacities for the solar PV and the BESS.

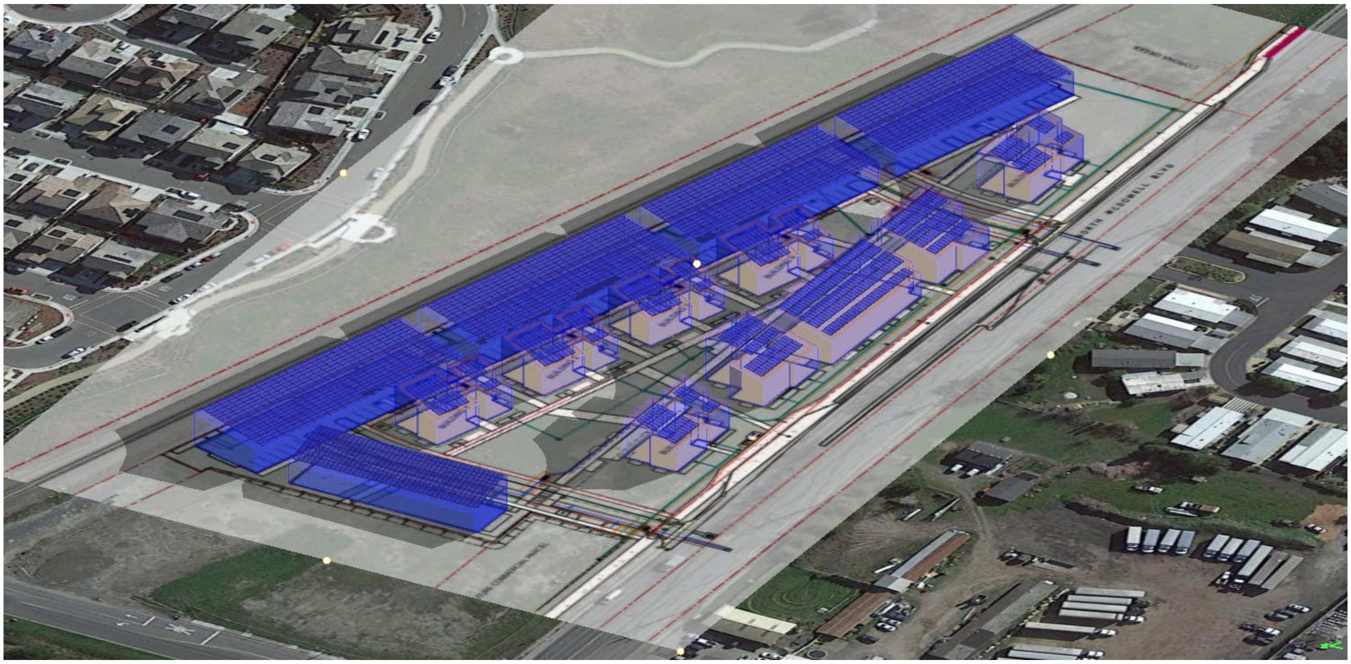
Solar panels will cover the building rooftops at 15 degrees to the maximum extent allowable for fire safety rules, and timber carport solar arrays will be built to cover most of the parking lot, as shown in Figure 4. The solar PV will deliver enough power to the BESS to maintain the community's daytime energy use, fill the BESS for overnight use, and have excess power during the day to provide EV charging to residents and the public.

The microgrid is designed with outdoor ratings to maintain resilience during extreme climate events; however, in the instance of prolonged periods of low solar irradiance (for about 350 to 400 hours, during two to three weeks of the winter in mid-December to January), Meridian has the option to use the utility grid as a standby power source – estimated to be 5 percent of the year. Under the California energy code Title 24 2022 baseline scenario,[13] a winter storm grid outage would always result in a loss of power for the tenants; with this project design, that risk overlap is much less likely to occur. With a minimal unidirectional connection without exporting energy back to the grid, this off-grid microgrid design provides the community with emissions-free energy and resilience, while simultaneously streamlining the process for PG&E to deliver the necessary service size to the community.

The solar PV arrays and the BESS are designed on a single 480-volt (V) bus, using a separate transformer from the dwelling units to provide higher efficiency for the ZNE microgrid as well as permit the microgrid to be isolated from the grid during normal conditions and connect during emergency conditions by a transfer switch. A low-power unidirectional charger will be permanently connected to the grid in a limited standby connection of 200 amperes (amps) that can optionally provide supplemental charging to the BESS and serve a number of EV chargers in periods of low irradiance. The site controller will ensure that this grid connection is not active during peak periods, such as from 4:00 p.m. to 9:00 p.m.

[13] California Energy Commission. 2022 (Aug). *2022 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*. Publication Number: CEC-400-2022-010-CMF. Available at https://www.energy.ca.gov/sites/default/files/2022-12/CEC-400-2022-010_CMF.pdf.

Figure 4: Aerial View of the Project Solar PV Array Design at Meridian



Source: Redwood Energy, 2023

Electric Vehicles and Bidirectional Charging

To help increase EV adoption and support research on emerging EV charging technologies, V2M-capable EV chargers are designed to allow vehicles to serve the building load in the microgrid. Of the 138 parking spots, 50 will be wired to the central battery with V2M bidirectional charging and grid-following capabilities, allowing the chargers to respond to the state of charge (SOC) of the BESS system and supply additional power to the microgrid based on signals from the building's EMS. Example V2M chargers include the Fermata FE-15 and the InCharge ICE-V2X, and the project team anticipates that more V2M-capable charger technologies and bidirectional charging EVs will come to market in the near future. These chargers will respond to the building EMS via an automatic load management system subpanel, in compliance with CalGreen 5.106.5.3.3, which requires the chargers to deliver at least 3.3 kW when charging multiple EVs. This subpanel will prioritize using kilowatt-hours (kWh) from the solar PV arrays first, then kWh from the battery, and, as a last resort, grid energy through the unidirectional grid connection. One EV charger for a Ford F-150 Lightning truck will be designed for vehicle-to-building (V2B) bidirectional charging capabilities to test providing backup power to a designated community building. The design intent is for the remaining 88 parking spaces to be wired for bidirectional charging to the grid. Initially, lower cost unidirectional, smart Level 2 and Level 3 chargers will be installed as placeholders, while the industry matures and future bidirectional charging to the grid can be explored. The central control server will be configured to take demand response (DR) signals and remove the EVs from the priority tree whenever DR signals indicate the grid is impacted, taking EV charging off-grid as a grid benefit.

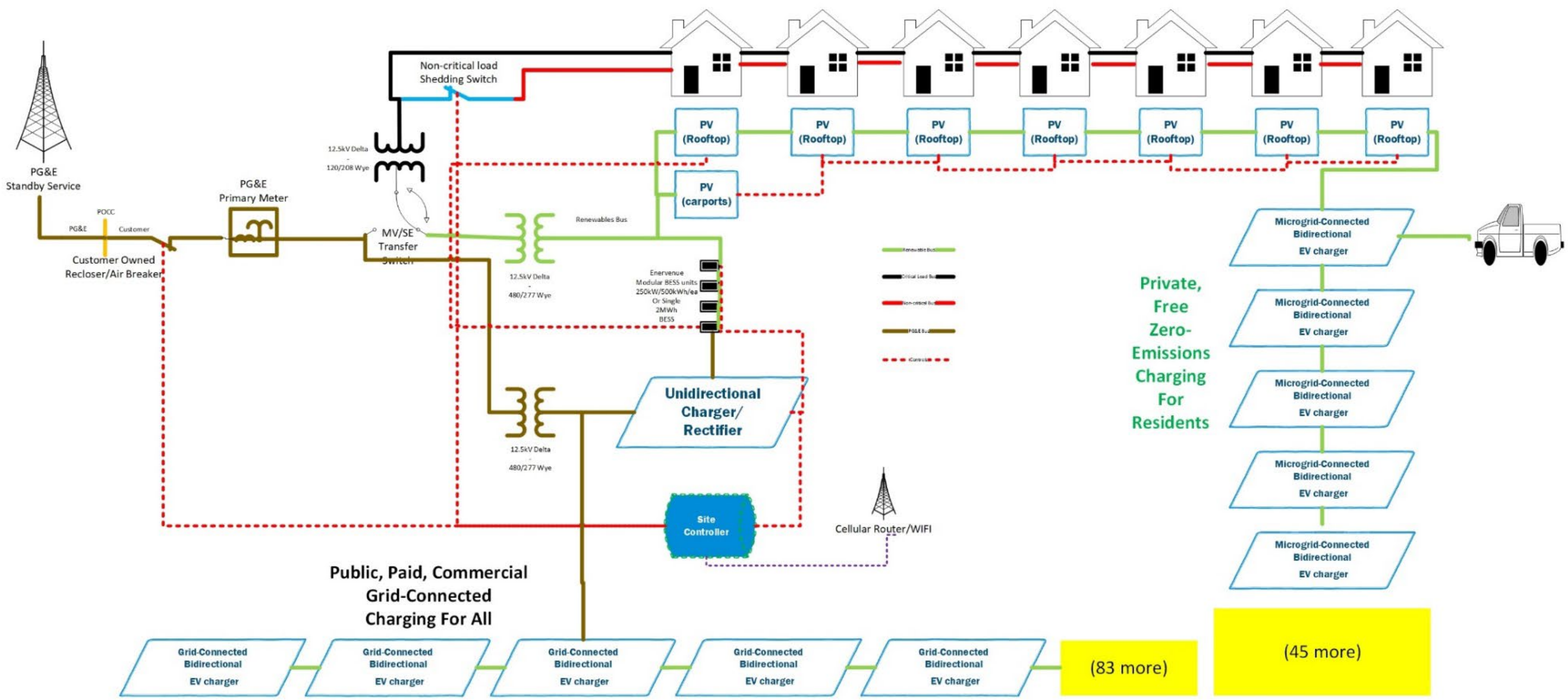
By installing the first 50 V2M chargers to the isolated microgrid, the project team can de-risk the deployment of bidirectional chargers and provide learnings about these technologies, independent of utility challenges and restrictions, while providing free charging benefits to residents and facilitating cost-effective EV adoption by residents. To offset the cost of providing this service to residents, certain chargers will be exclusively allocated for commercial customer charging at a nominal cost. Additionally, electric hook-up pedestals for the electric food truck garden will be available for a fee.

Load Flexibility and Forecasting

Meridian's unique electrical system facilitates economically effective and equitable load shedding in the event of a renewables shortfall or price-driven requirement. Figure 5 reflects the schematic of the community's energy system. The design anticipates needing a customer-owned recloser or air breaker at the point of common coupling (POCC). A 200 amp breaker will serve the unidirectional charger/rectifier, providing standby power to the community's energy system during periods of low irradiance. The circuits feeding each dwelling unit will be of the split-phase type. When load shedding becomes necessary, the site controller will open one leg of the split-phase feed to each dwelling unit — reducing the electrical load of all dwelling units by approximately 50 percent without the need for high-cost and labor-smart panels. All residents will retain the same critical circuits to ensure occupant comfort and safety. Figure 6 shows a diagram of this split-phase wiring strategy, which enables a cost-neutral pathway to load control in each unit.

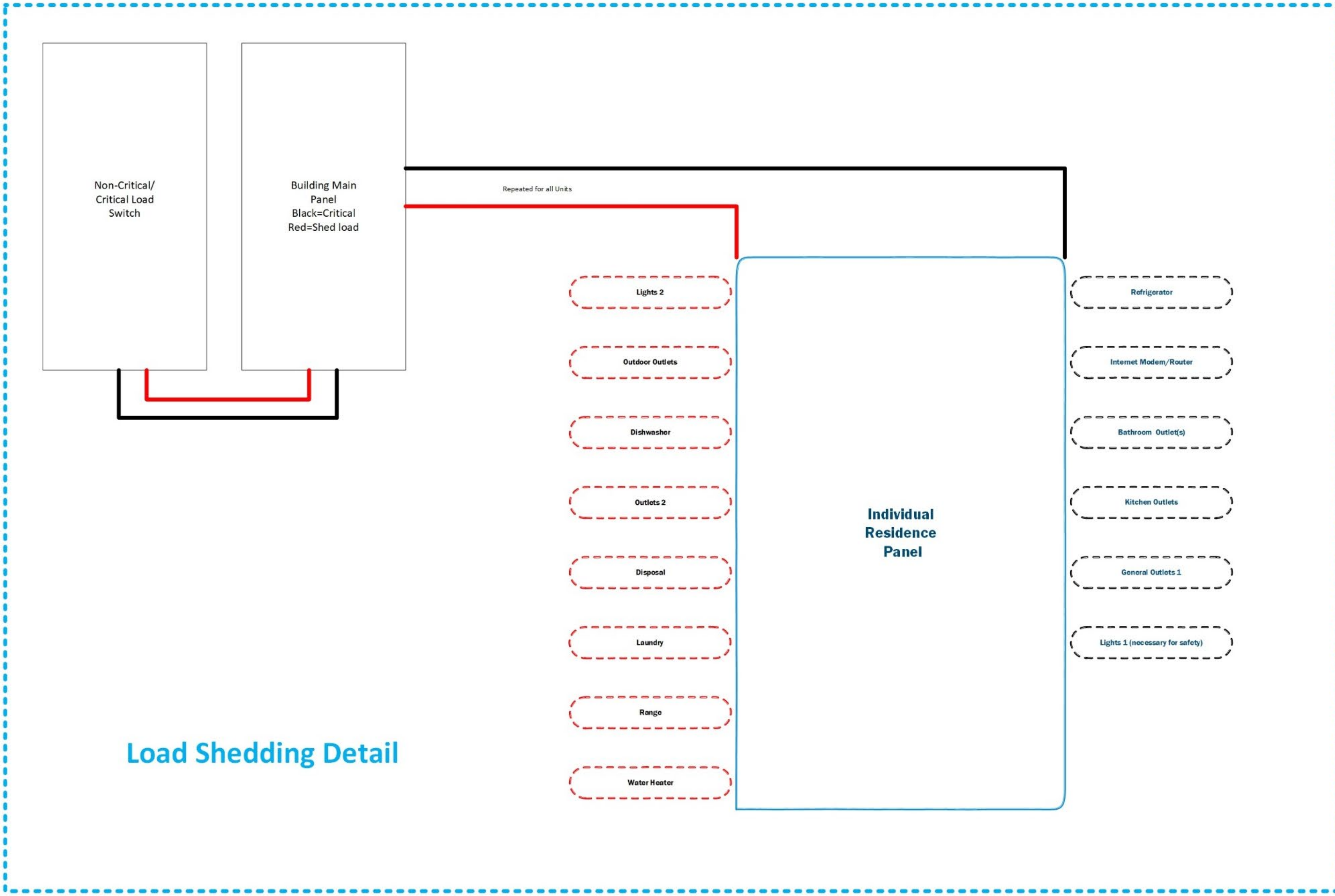
Solar PV and load forecasting applications will be employed to predict and budget energy for the site a day or more in advance, to allow the site controller to prepare for times of higher or lower irradiance. The site controller can drive the SOC of the BESS up or down in advance of events, as needed by load curtailment or by pre-heating water heaters or pre-heating/pre-cooling units with heat pump systems. Load shifting methods will be employed, including distributed heat pump water heating systems controlled with open-standards-based approaches such as CTA-2045, on a schedule and DR model. The community's energy system will not present any demand to the grid, unless desired, for example, during times of zero or negative locational marginal pricing. The microgrid, V2M charging, and forecasting applications prevent the community from needing to draw power from the grid during periods of peak demand, such as from 4:00 p.m. to 9:00 p.m. Figure 7 depicts the load management strategy. Meridian will use separate busses for critical and noncritical loads, with the two busses serving panels in each dwelling unit. During the event of low irradiance or other energy constraints, the noncritical-loads bus will be de-energized to preserve SOC in the BESS and allow the facility to ideally ride through without a need for grid power. This solution provides for equitable distribution of potentially limited energy resources among the building occupants, while prioritizing their critical load to be served, and it prevents the need to request that occupants respond, which is always met with variable and unpredictable responses.

Figure 5: Line Diagram Schematic of Meridian's Energy System



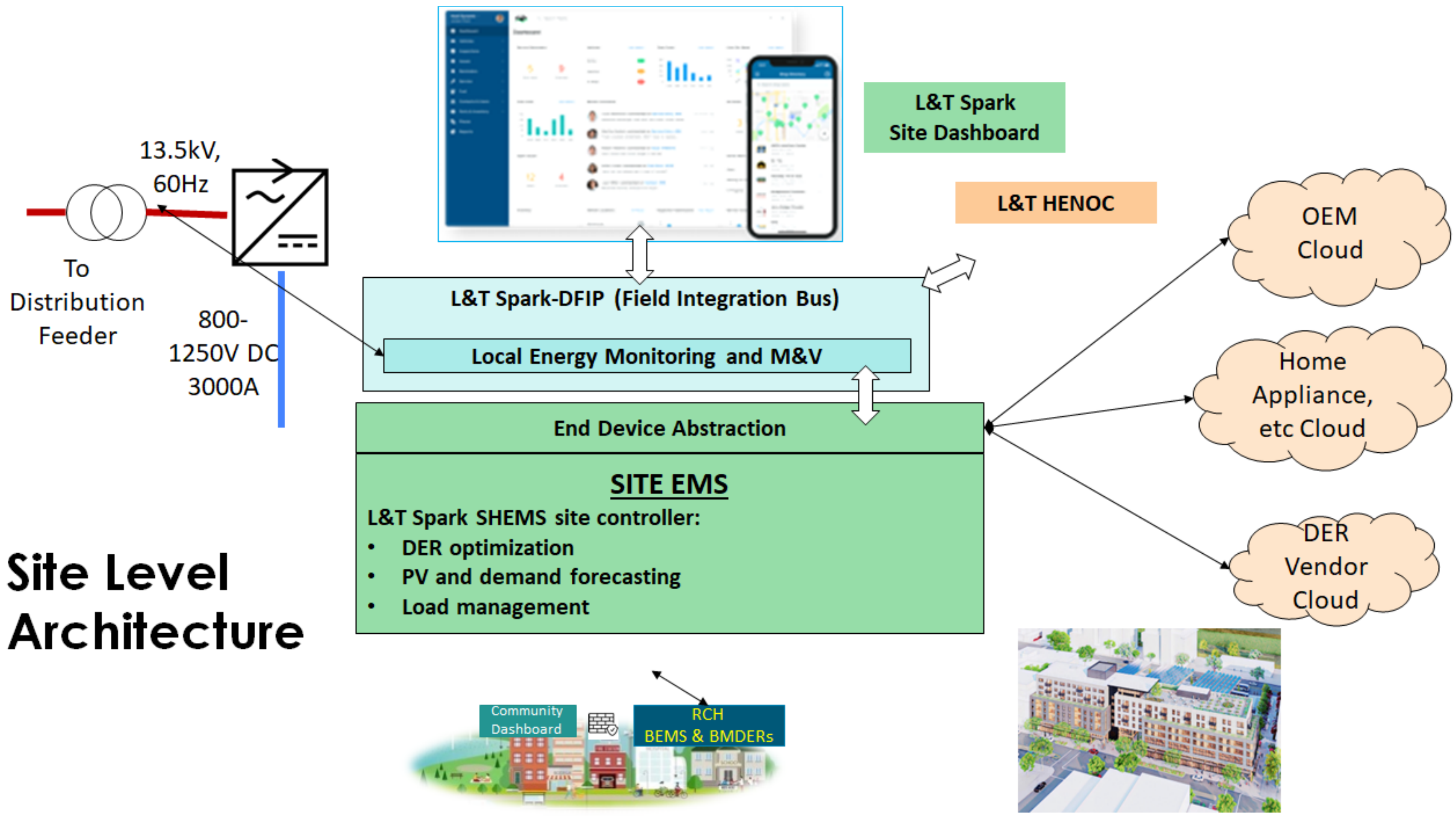
Source: EPRI, 2023

Figure 6: Load Shedding Detail of the Battery and Energy Management System



Source: EPRI, 2023

Figure 7: Diagram of Meridian's Load Management Strategy



HENOC: Hybrid Energy Network Operation Center
OEM: Original Equipment Manufacturer
SHEMS: Site Hybrid Energy Management System

Source: EPRI, 2023

Building Electrification Strategies

As an all-electric building design, Meridian will have no natural gas service incorporated into the buildings. The all-electric design features heating, ventilation, and air conditioning (HVAC) systems, water heaters, appliances, and advanced power strips that reduce the overall energy demands of the dwelling units. To optimize the roof space for solar panels, the team opted for in-unit heat pump HVAC units rather than mini-splits and rooftop units. Compared to a centralized air source heat pump, the proposed in-unit heat pumps will have a higher heating efficiency throughout the year due to indoor source air being more consistent and warmer than outdoor air. The units feature Ephoca's 120V Wall Mounted Pro heat pump with a centralized energy recovery ventilator (ERV) system, providing enhanced performance, sleek aesthetics, and several adapters for easy installation. The newer R32 refrigerant with a lower GWP will be used for these units. The windows in each unit remain operable to leverage passive cooling via natural ventilation, and the building corridors are ventilated via exhaust-driven natural ventilation — achieving significant fan energy savings. The units also feature the only 120V heat pump water heater (HPWH) on the market: Rheem's ProTerra® Plug-in HPWH with HydroBoost. The HPWH will be on a 120V shared circuit design that uses less power than a dedicated circuit model and can share a 15A breaker. The HPWH enhances energy efficiency by storing hot water at a higher temperature and delivering water with a built-in thermal mixing valve. While in-unit HPWHs result in passive cooling during the summer, they will impose additional space heating loads during the winter. This effect can be mitigated by working tangentially with space heating provided by the in-unit heat pump space conditioning units. Figure 8 shows example images of the in-unit heat pump and HPWH. Other energy-efficient features include residential induction cooking tops from ENERGY STAR® Emerging Technology Award winners (Blomberg, Frigidaire, and Samsung), commercial heat pump dryers from Miele in the community's central laundry facilities, highly efficient light-emitting diode (LED) lighting fixtures with occupancy sensor-based lighting controls in all nonresidential spaces, and advanced power strips to help avoid phantom or vampire loads that can waste energy.

Figure 8: Promotional Images of the Ephoca Pro (Top) and the Rheem 120V ProTerra® Plug-in HPWH (Bottom)

Source: Redwood Energy, 2023

Resilience and Environmental Design

To proactively plan and design for the impacts of natural disasters and address long-term vulnerabilities associated with climate change, the design team implemented the Mithun Resilience framework to 1) identify primary stressors and shocks, 2) design strategies for long-term resilience, 3) analyze for passive survivability and continuity during emergencies, and 4) foster holistic resilience thinking. Meridian's design responds accordingly to the main stressors of flooding, earthquake, and wildfire/smoke. The base elevation of the buildings is raised to lower potential damage from flooding and a predicted increase in storm surges. The United States Resiliency Council earthquake ratings are used for long-term strategic planning for reducing reconstruction costs and recovery time of structural elements following earthquakes. Passive House building envelope design with exterior cork siding provides higher-than-code minimum (Title 24 2022) insulation, improving levels of thermal comfort during the winter, keeping energy demand lower, and enabling higher levels of passive survivability for community resilience. ThermaCork insulation was selected for several unique benefits: cork is less than 10 percent the weight of cementitious fiberboard, making it easier for laborers to install; cork is fire resistant, which, in combination with the metal roof, bodes well for the fire-prone site location; and cork is a carbon negative material that sequesters seven times the amount of carbon dioxide (CO_2) in its harvesting, processing, and shipping. Figure 9 shows images of sustainable cork harvesting and the application of ThermaCork to the exterior of an apartment complex. The team aims to use continuous joint and interface taping to further seal the thermal envelope and exceed Energy Star for Homes, Leadership in Energy and Environmental Design (LEED) for Homes, and the United States Department of Energy's (U.S. DOE's) Zero Energy Ready Homes standards. The mechanical systems have also been sized and selected to allow for the replacement of standard MERV 13 filters with carbon filters during the annual wildfire smoke events.

In addition to the multiple layers of resilience built into the design, Meridian features five sources of electricity: 1) the solar PV arrays, 2) the BESS system, 3) the V2M capable EV charging stations, 4) standby utility power from the grid, and 5) a property-owned Ford F-150 Lightning truck with a 130-kWh, grid-forming battery to provide backup power to the designated community building on the premises, serving as the community's Resilience Hub during emergencies. The F-150 truck features 11 120V outlets and one 240V outlet that can enable mobile emergency services during crises, and they double as power for electric landscaping equipment during normal site operations.

Several advanced environmental design practices are employed within Meridian to further reduce GHG emissions while enhancing community comfort. Exterior-grade mass timber is selected for the columns and beams that will support the parking lot solar PV arrays. The wood volume reduces embodied carbon compared to a standard steel structure. The common area laundry machines will be connected to a grey water re-use system to cover the irrigation needs of the community's landscape. Biofiltration planters will collect runoff from impervious surfaces (such as the parking lot and concrete paving) as storm control, while the PV canopy can also collect rainfall, and permeable surfaces will be installed as much as possible. Figure 10 shows a rendering of the biofiltration planters and mass timber carports supporting the solar PV arrays. The landscape is designed around a dispersed orchard loop to provide residents with access to a walking path and encourage the community to engage with ecologically harmonious species in a thriving ecosystem. Where concrete walkways are required per city standards, low-carbon concrete mixes will be specified, which can reduce embodied carbon by up to 60 percent.

Figure 9: Sustainable Cork Harvesting and Exterior Application of Cork Siding

Source: Redwood Energy, 2023

Figure 10: Rendering of Meridian Featuring Environmental Design Measures

Source: Mithun, 2023

Table 1 summarizes the emerging energy technologies deployed in Meridian's design and compares the proposed technologies with a baseline (Title 24 2022) design.

Table 1: Emerging Technologies Deployed in Design Compared to Baseline

Measure	Baseline (Title 24 2022)	Proposed Project
Building Envelope	Roof: R-38 continuous insulation (U-0.028)	Roof: R-40 continuous insulation (U-0.025)
Building Envelope	Exterior wall: R-21 batt and R-8 continuous insulation (U-0.069)	Ext. wall: R-21 batt and R-12 cork siding (carbon sequestering) continuous insulation (U-0.036)
Building Envelope	Glazing assemblies: U-0.36	Vinyl framed glazing assemblies: U-0.30
Building Envelope	Solar heat gain coefficient (SHGC) of 0.53 to 0.83	Low-E glazing: SHGC of 0.30
HVAC	Single zone heat pump systems with inline ventilation fans and dedicated toilet exhaust fans	In-unit highly efficient Ephoca wall heat pump units with centralized energy recovery ventilator (ERV) system
HVAC	Standard controls	Smart thermostat controls
HVAC	Dedicated outdoor air system for corridors	Exhaust-driven natural ventilation for corridors

Measure	Baseline (Title 24 2022)	Proposed Project
Domestic Hot Water	Centralized air source heat pump water heating system	In-unit air source heat pump domestic water heaters
Domestic Hot Water	CalGreen-rated flow fixtures	Low-flow fixtures
Cooking	Electric stove tops	Induction stove tops
Lighting	Title 24 2022 baseline	Highly efficient LED lighting
Plug Loads and Appliances	Standard equipment	EnergyStar-rated equipment
Laundry	Standard electric resistance dryers	Heat pump dryers for half of the communal dryers
Renewable Generation	250 kW capacity of PV	Large PV (1,270 kW) and battery (2,000 kWh) system that serves the community loads for 95 percent of all hours in a year
Energy Storage	142 kWh capacity of BESS	Large PV (1,270 kW) and battery (2,000 kWh) system that serves the community loads for 95 percent of all hours in a year
Electric Transportation	N/A	51 charging stations with bidirectional V2M (vehicle-to-microgrid) capabilities; Ford Lightning F150 for Resilience Hub backup power and all-electric landscaping power equipment

Source: Redwood Energy, EPRI, and Danco, 2023

Table 2 summarizes the nature-based/non-energy solutions incorporated in Meridian's design and the corresponding benefits to the community.

Table 2: Nature-based/Non-energy Solutions Incorporated into Meridian's Design

Proposed Design Feature	Potential Benefits
Passive House level insulation — ThermaCork/cork siding	• Improved soundproofing, ultimately benefiting community members' health and well-being • Improved indoor thermal comfort • Contains less embodied carbon
Air tightness — joint and interface taping to further seal thermal envelope	• Improved indoor air quality • Improved indoor thermal comfort
Operable windows	• Community members have the option of opening windows to allow fresh air indoors and leverage nighttime cooling.

Proposed Design Feature	Potential Benefits
Greywater reuse — laundry to irrigation	• Water from the laundry room in the community can be reused for irrigation, reducing the amount of water used in the community and protecting the local water reservoir.
Trees/shrubs	• Provide a natural habitat for wildlife • Capture air pollutants • Cool the surrounding air, reducing urban heat island effects • Reduce heat stress on people and infrastructure, reducing cooling costs and emissions
Native plants/grasses/vegetation that is drought resistant	• Vegetation would need less irrigation, reducing the community's water use, which protects the local water reservoir.
Cool pavement/permeable pavement	• Absorbs less heat than traditional pavement, reducing the urban heat island effect and heat stress on people • Absorbs more water than traditional pavement, reducing water run-off onsite
Low carbon concrete	• Reduced embodied carbon onsite, protecting the climate
Biofiltration plants/raingardens	• The parking lot in the community will be at a slope, allowing any run-off from the parking lot to enter the biofiltration ponds surrounding the parking lot. Biofiltration planters contain native plant and grass species that act as a natural water filtration system to filter any polluted water run-off from the parking lot before it re-enters the ground. • Provides a natural habitat for wildlife
Marnoleum or similar linoleum	• Created from natural and renewable materials that contain no harmful toxins or pollutants • Carbon neutral flooring material that reduces embodied carbon
FSC-certified wood products	• Wood products that derive from responsibly managed forests that provide environmental benefits
Cellulose or other bio-based insulation products	• Reduced embodied carbon onsite, protecting the climate. • Natural bio-based products, which do not contain harmful chemicals or toxins that may cause health problems to sensitive populations

Proposed Design Feature	Potential Benefits
Fiberglass window frames	• Fiberglass has extremely long life cycles, reducing waste entering landfills.
Mass-timber carport frames	• A low-carbon material that reduces embodied carbon
Community amenities — gym, community garden, outdoor walking/biking paths, community orchard, Americans with Disabilities Act (ADA) accommodations, social service space, and therapy rooms	• Onsite amenities with a focus on the tenants' health, physical and mental, their well-being, and their safety • Provides access to fresh and healthy foods
Direct access to public transportation — electric bus stops and the SMART rail station	• Reduced vehicles miles traveled, reducing vehicle emissions • Tenants have a location to store bikes.

Sources: Redwood Energy, EPRI, Danco, Mithun, 2023

CHAPTER 3: Modeled Results

Energy and Emissions Performance

To understand the quantifiable potential results of the development design, the PAE and Redwood Energy project team members used building modeling and simulation software to evaluate the energy and emissions performance of the proposed design. The project team used Integrated Environmental Solutions Virtual Environment 2021 as the annual energy simulation software to model the proposed and code minimum (Title 24 2022) designs. These energy models incorporated all the building strategies except the microgrid system comprising the solar PV and the BESS.

First, the team developed a thorough analysis of several improvement measures to develop the most energy-efficient project design. By optimizing the lighting, building envelope, HVAC, and domestic hot water systems, the team could reduce the load on the solar and battery systems required to meet the microgrid design goals. Second, the annual energy models generated hourly building energy demand data, which were exported into Excel and used to perform detailed microgrid analysis, mimicking the intended microgrid system operation. The annual and hourly onsite solar energy generation was calculated using HelioScope software for solar energy modeling and was used in the microgrid analysis. Lastly, the annual energy models and microgrid calculations were compared to standard/baseline designs using inputs from the Title 24 2022 standard. Overall, the proposed design emits 5.0 metric tons of CO_2 equivalent (mt CO_2e) per year versus a standard design of 62.6 mt Co_2e per year, leading to a 92-percent savings in carbon emissions.

Several assumptions were made during the modeling process. California Climate Zone 2 was used as an input. Weather data inputted for the annual energy simulation was derived from the Petaluma Municipal Airport as the closest available weather file for the project site. All schedules, internal loads, and envelope parameters were modeled in detail to ensure that the results represent as close to real-world operation as possible. The results for one typical Meridian residential building were scaled to account for all project buildings. For the internal load utilization schedules in the energy model, the energy modeling team used default multifamily utilization schedules from the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) 90.1 Standard User Manual, which are commonly used for LEED energy modeling. Based on the recent measured energy data obtained from several energy-efficient affordable housing projects collected by Redwood Energy, further adjustments were applied to the utilization schedules to calibrate the appliance/plug loads and lighting loads. Energy use for the laundry equipment was taken from the Energy Star Multifamily Residential Energy Modeling Guidelines and Energy Star-rated appliance options.

Building Modeling Performance

Table 3 reflects the modeled site energy use intensity (EUI) and the GHG emissions intensity results by the end-use building measures, comparing the proposed building design to a baseline, code minimum design. Note that these results are from the first step of building modeling, prior to the analysis of the solar PV and the battery microgrid system. The application of the proposed emerging technologies and building design strategies (not including the microgrid) could potentially lead to an overall 28.25-percent improvement in EUI and a 31.15-percent improvement in GHG emissions intensity compared to baseline Title 24 2022 designs per the building modeling. This reflects how the proposed design can lead to higher energy efficiency, reduced building load demand, and reduced GHG emissions.

Table 3: Modeled EUI and GHG Emissions Intensity Results by End-Use for Proposed and Baseline Designs

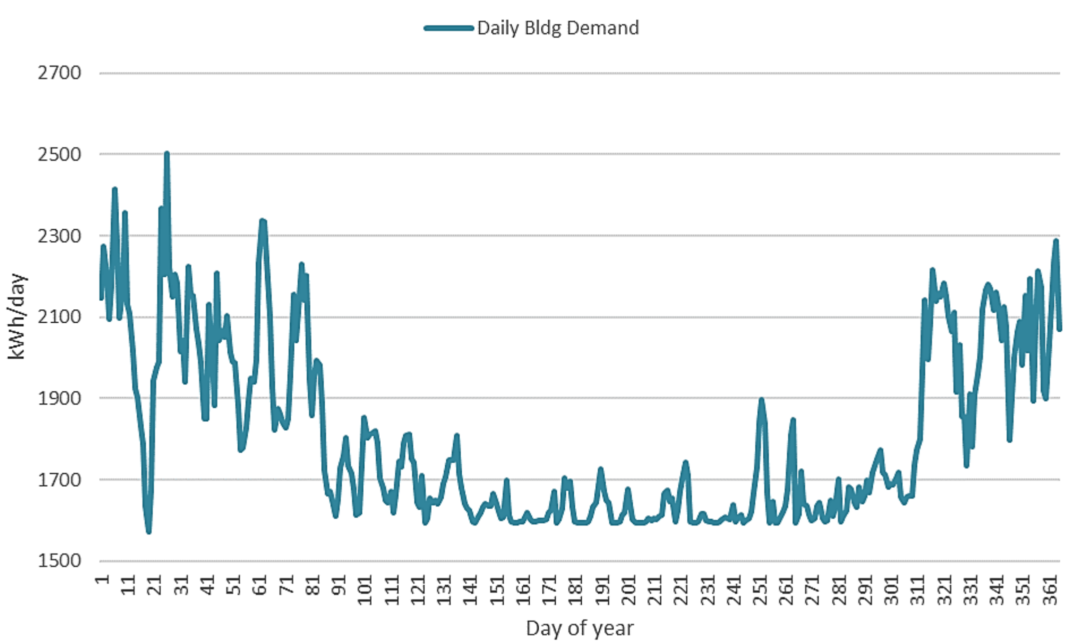
End-Use	Site EUI (kBtu/sf/yr)	Site EUI (kBtu/sf/yr)	Site EUI (kBtu/sf/yr)	GHG Emissions Intensity (kg CO_2/sf/yr)	GHG Emissions Intensity (kg CO_2/sf/yr)	GHG Emissions Intensity (kg CO_2/sf/yr)
	Baseline	*Proposed*	*% Improvement*	*Baseline*	*Proposed*	*% Improvement*
Space heating	3.3	1.9	42%	0.139	0.072	48%
Space cooling	1.5	0.1	94%	0.020	0.002	91%
Indoor fans	3.9	2.3	39%	0.101	0.064	37%
Domestic hot water (residential)	5.4	4.1	23%	0.132	0.097	27%
Domestic hot water (laundry)	0.1	0.1	54%	0.003	0.001	54%
Indoor lighting	2.8	1.7	41%	0.075	0.044	41%
Outdoor lighting	0.4	0.4	-	0.014	0.014	-
Receptacles	8.8	8.2	7%	0.159	0.148	7%
Laundry equipment	0.7	0.5	26%	0.012	0.009	26%
Total	**26.9**	**19.3**	**28.25%**	**0.655**	**0.451**	**31.15%**

kBTu/sf/yr is thousands of British thermal units used per square foot per year; kg CO_2/sf/yr is kilograms of CO_2 per square foot per year.
Source: PAE, 2023

Microgrid Performance

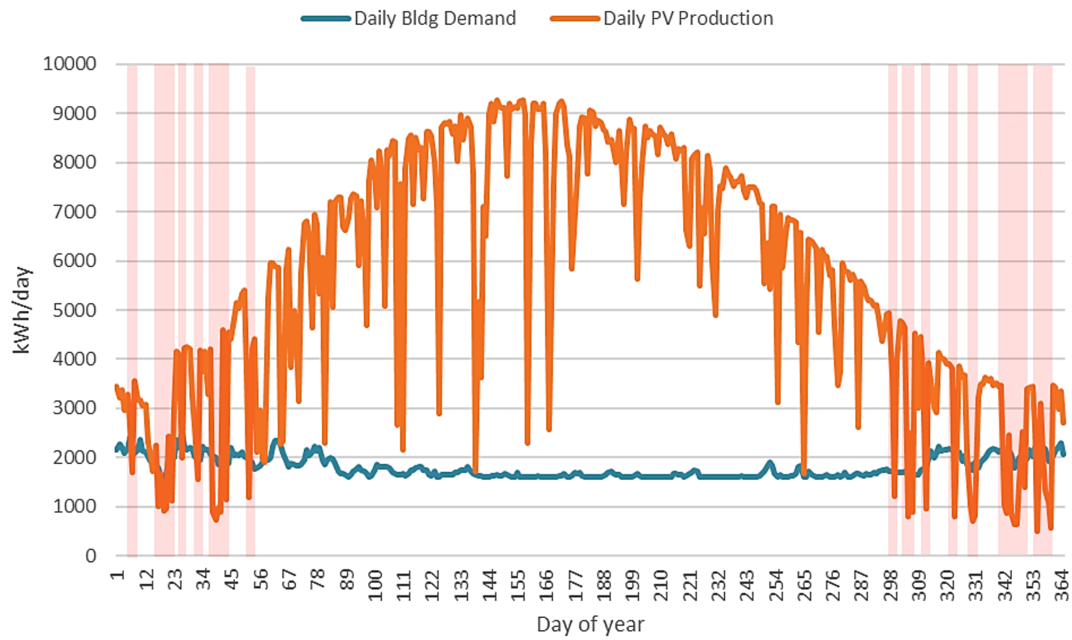
For the microgrid analysis, the project team used the annual energy demand profile for the optimized building energy model, which incorporated the proposed efficiency measures applicable to the building envelope, building systems, and load management strategies. The energy demand profile is reflected in Figure 11, which shows the typical daily energy use profile for the site after incorporating the efficiency measures, excluding EV charging demand. The average daily energy demand is in the range of 1,800 kWh to 1,900 kWh per day, with demand peaking in the winter months due to additional electric heating demand. As shown in Figure 12, with the proposed PV capacity of 1,270 kW, the daily generated solar energy generally surpasses the daily building energy demand. This surplus energy can be used to offset the majority or all of EV charging energy during spring, summer, and fall months. During cloudy days in the winter, the solar generation falls below the daily building energy demand (shown in the pink regions of Figure 12), sometimes for consecutive days. During these times of low irradiance, the microgrid will rely on energy stored in the BESS. Figure 13 depicts the few times during the year when the BESS gets depleted and a backup energy source will be required. The few times are expected to occur during February, November, and December, based on a Standard TMY3 weather file that was used for Petaluma in the analysis. To prevent any power outages or severe power curtailments to the community, the microgrid will use the unidirectional standby connection to the grid as a backup energy source. With this strategy, the batteries will be charged by the grid whenever the battery state falls below 25 percent charged capacity, as shown in Figure 14. The analysis shown in Figure 15 indicates that the proposed microgrid will use the standby grid connection for up to a total of 365 hours over the course of 36 days; this amounts to 5.5 percent of the annual building demand, with the proposed microgrid powering the community for 94.5 percent of the year. This demand can be further reduced or completely eliminated with the use of further load reduction strategies adopted by the residents or V2M bidirectional EV chargers as alternative backup energy sources. EV battery analysis calculates that using 25 to 50 bidirectional EV chargers could eliminate Meridian’s winter weather challenges for the energy system.

Figure 11: Daily Energy Demand Profile for All Buildings Onsite Meridian



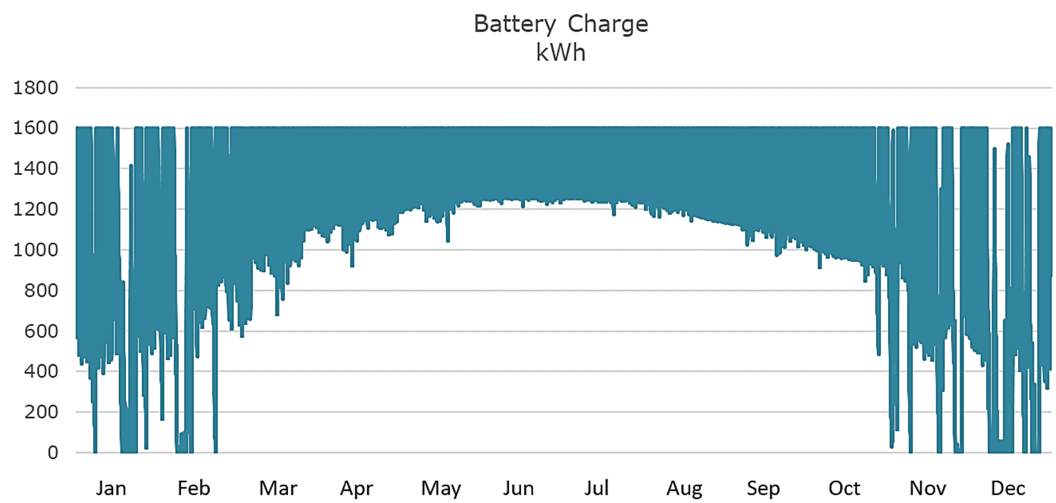
Source: PAE, 2023

Figure 12: Daily Building Energy Demand Versus Solar Energy Generation for Meridian



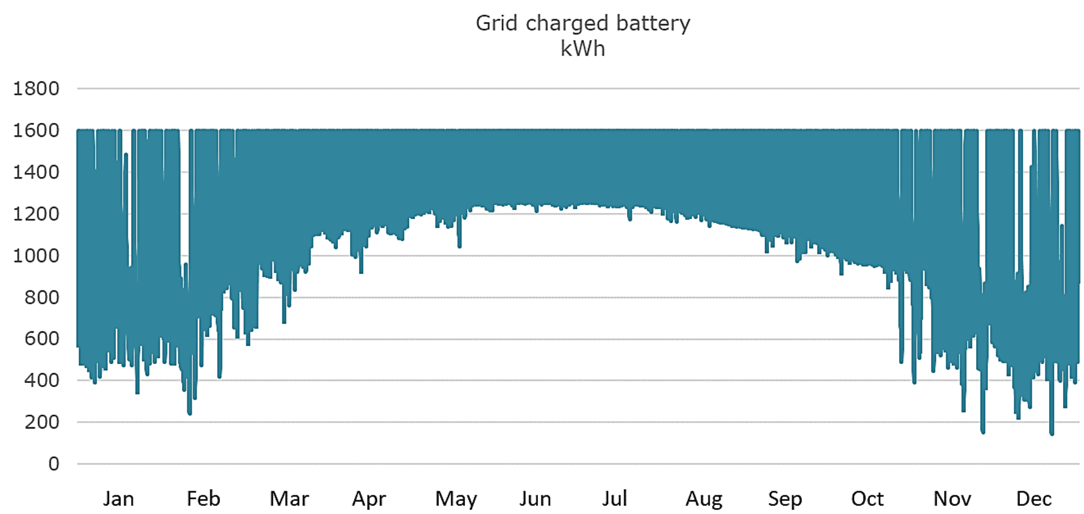
Source: PAE, 2023

Figure 13: Daily Battery Charge State Without Backup Energy Source



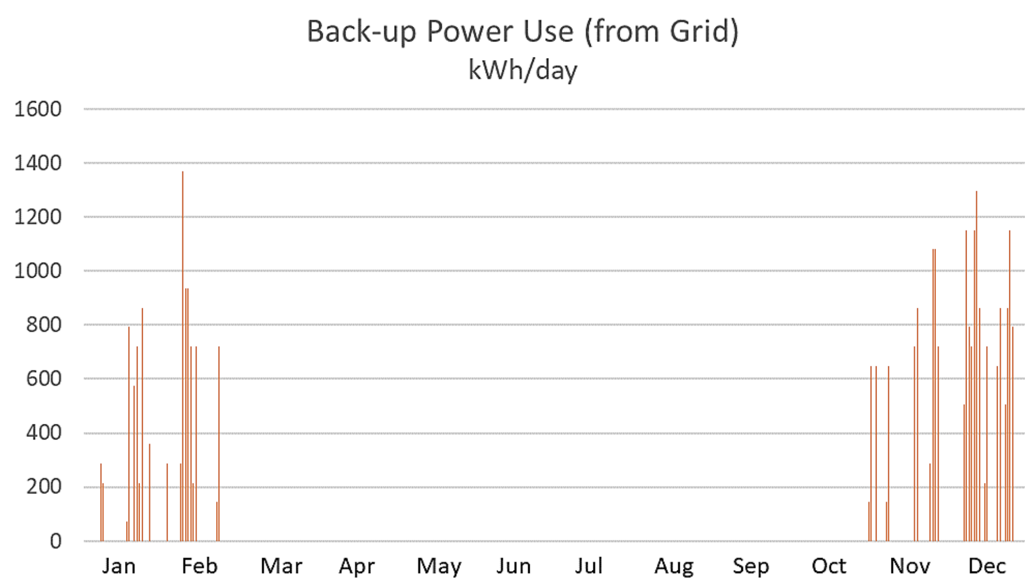
Source: PAE, 2023

Figure 14: Daily Battery Charge State With Unidirectional Standby Grid Connection



Source: PAE, 2023

Figure 15: Backup Grid Power Utilized to Charge BESS



Source: PAE, 2023

Table 4 shows the resulting avoided GHG emissions from using the off-grid renewable onsite solar PV and battery storage microgrid to solely power the community compared to the baseline (Title 24 2022, using a smaller renewable microgrid as backup and the main source of power from the grid).

Table 4: Calculated Avoided GHG Emissions Results From Renewable Microgrid

Technology Type	Avoided GHG Emission Measurement	Baseline	Proposed
Solar PV	*Rated Electricity Generation Output Capacity (kW)*	250 kW	1,270 kW
Battery System	*Rated Electricity Generation Output Capacity (kW)*	142 kW	2,000 kW
Total	*Rated Electricity Generation Output Capacity (kW)*	Proposed Microgrid	Proposed Microgrid
Solar PV	*Annual Electricity Generation (kWh)*	402,162	2,042,981*
Total	*Annual Electricity Generation (kWh)*	402,162	2,042,981*
Solar PV	Avoided GHG Emissions (metric ton CO_2)	10.88	17.41*
Battery System	Avoided GHG Emissions (metric ton CO_2)	3.32	30.54
Total	Avoided GHG Emissions (metric ton CO_2)	14.2	47.95*
Solar PV	% Improvement		60%
Battery System	% Improvement		820%
Total	% Improvement		238%

*Note: The proposed microgrid system operates in off-grid mode, with no excess solar energy exported back to the grid. The avoided GHG emissions from the proposed design account only for carbon offsets related to direct building energy demand offset; excess solar generation is not used for further carbon offsets in this calculation.
Source: PAE, 2023

Resilience and Load Flexibility Performance

Table 5 and Table 6 demonstrate the energy system's capability to meet daily peak electricity demand using onsite renewables, storage, and a load management strategy (load shedding and load shifting).

Table 5: Calculated Peak Demand of Meridian

(1)	(2)	(3)	(4) = [(2)+(3)]/(1)
Highest peak demand in a year (kW)	**Peak clipping due to onsite solar and storage on the highest peak day in the year (kW)**	**Peak clipping due to load management on the highest peak day in the year (kW)**	**% Peak reduction from onsite solar, storage, and load management**
192.62	120.62	N/A*	62.62%

Table 6: Calculated Energy Consumption of Meridian During Peak Hours (4:00 p.m. to 9:00 p.m.)

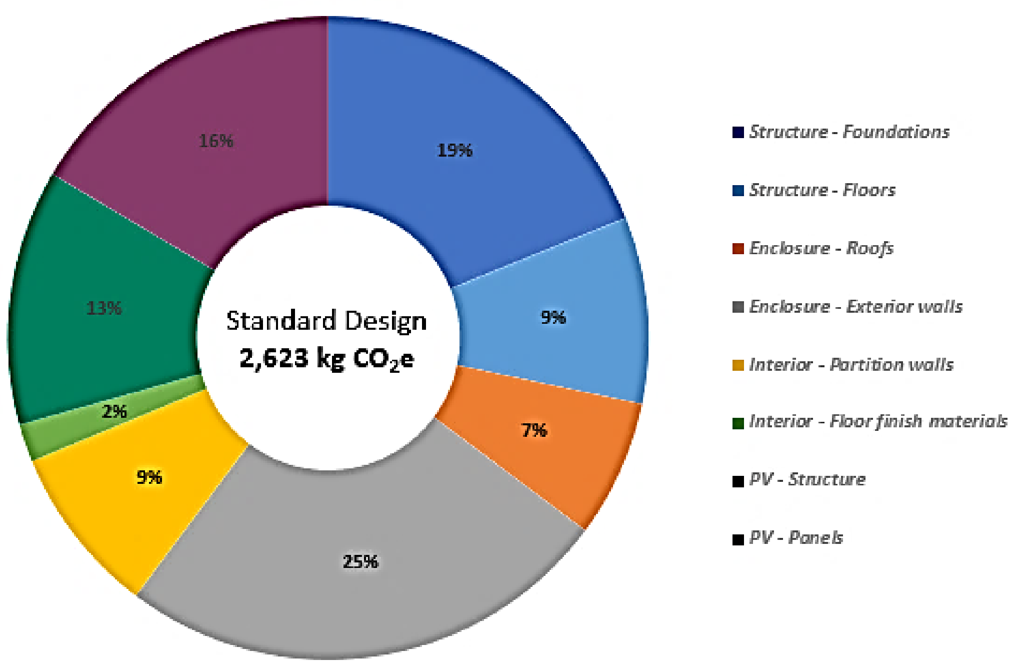
(1)	(2) = (3)+(4)+(5)	(3)	(4)	(5)	(6) = [(4)+(5)]/(2)
Annual electricity consumption (kWh)	**Annual consumption during peak hours (kWh/yr)**	**Annual grid purchase during peak hours (kWh/yr)**	**Annual load reduction from onsite solar and storage during peak hours (kWh/yr)**	**Annual load reduction from load management during peak hours (kWh/yr)**	**% Peak reduction from onsite solar, storage, and load management**
192.62	178,163	0	(178,163)	N/A*	100%

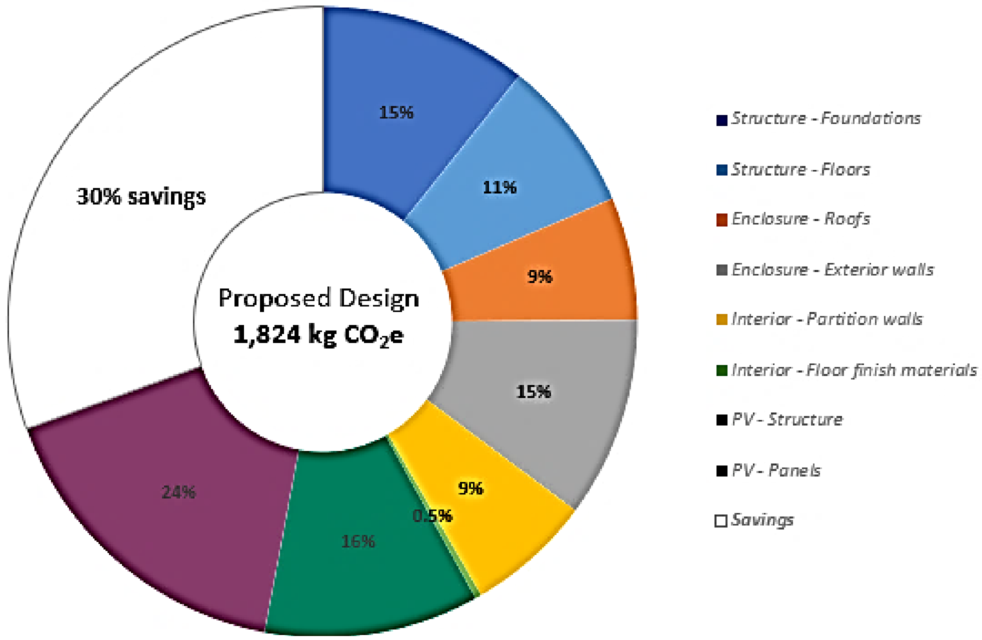
*Note: The proposed off-grid microgrid system acts as the primary load reduction strategy, since it eliminates the need for grid-supplied electricity during regular operations of the buildings.
Source: PAE, 2023

Embodied Carbon Reduction Performance

The proposed embodied carbon reduction strategies from non-energy and nature-based measures in the foundation, floors and floor finishes, roofs, exterior and interior walls, and carport structures are modeled to produce 1,824 kg CO_2e of embodied carbon compared to a standard design, which would produce 2,623 kg CO_2e (as shown in Figure 16). Figure 17 reflects how the combined usage of embodied carbon reduction measures leads to an overall 30-percent reduction in the proposed design's embodied carbon emissions.

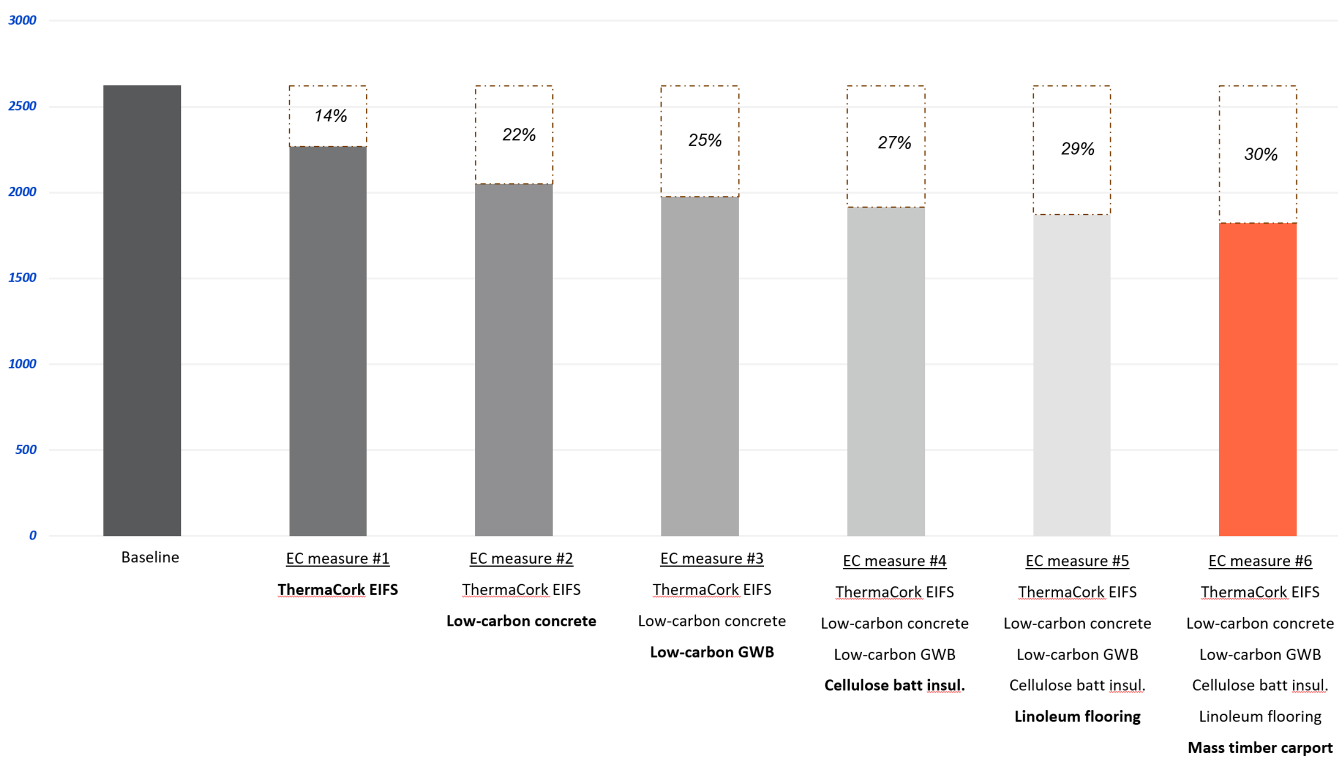
Figure 16: Embodied Carbon Reduction Measures With Total Embodied Carbon Emissions





Source: Mithun, 2023

Figure 17: Combined Embodied Carbon Reduction Measures With Percentage Reductions



EC: Embodied Carbon
EIFS: Exterior Insulation and Finish System
GWB: Gypsum Wall Board

Source: Mithun, 2023

Cost Performance

The team performed an analysis of the estimated cost difference between the proposed zero-emission build-out compared to the baseline (Title 24 2022) building design, construction, and operations.

Table 7 summarizes the overall calculated costs for a standard design versus the proposed design, and Table 8 shows the detailed cost savings that lead to a $166,383 societal lifecycle cost savings between the proposed and the baseline design from carbon emissions avoidance through the operational carbon and embodied carbon reduction measures. The first cost per unit from the owner's perspective is a total increase of $35,992. The resident's lifecycle cost savings is based on the utility bill elimination for the proposed design compared to the standard design. The project will leverage tax credit funding, cap-and-trade funding, rebates, and a discounted construction loan to finance the project and help offset the incremental first costs. Examples include cap-and-trade funding from the Affordable Housing and Sustainable Communities Program for transit-oriented affordable housing, financial support from the city of Petaluma, solar and battery tax credits from the Inflation Reduction Act, rebates for all-electric affordable housing with above code efficiency measures from California's BUILD program, rebates from the local utility (PG&E) for new all-electric multifamily buildings, and rebates on large-scale storage and EV chargers from the local CCA (Sonoma Clean Power).

Table 7: Calculated Total Costs of Proposed Design Versus Baseline Design

	Standard	Proposed	Cost Increase/Savings
Incremental First Cost Per Unit ($/unit)	661,615	697,607	+35,992
Residents' Lifecycle Cost (based on utility rates) ($)	44,590	36,136	-8,454
Societal Lifecycle Cost (based on carbon emission avoidance) ($)	278,977	112,594	-166,383

Source: Redwood Energy, 2023

Table 8: Cost Benefit Analysis of Proposed Design Versus Baseline Design

Category	Baseline Design (T-24)		Proposed Design		Societal Lifecycle Cost Difference ($)
	GWP (mt CO_2e)	Societal Lifecycle Cost Net Present Value (NPV)	GWP (mt CO_2e)	Societal Lifecycle Cost NPV	
Structure — Foundations	498.1	27,892	281.8	15,780	-12,112
Structure — Floors	246.6	13,807	206.0	11,534	-2,273
Enclosure — Roofs	182.0	10,192	164.6	9,216	-976
Enclosure — Exterior walls	649.7	36,386	270.1	15,123	-21,263
Interior — Partition walls	224.0	12,546	169.1	9,471	-3,075
Interior — Floor finish materials	50.0	2,799	8.4	469	-2,330

Category	Baseline Design (T-24)		Proposed Design		Societal Lifecycle Cost Difference ($)
	GWP (mt CO_2e)	Societal Lifecycle Cost Net Present Value (NPV)	GWP (mt CO_2e)	Societal Lifecycle Cost NPV	
Building Embodied Carbon Total	**1,711.6**	**95,849**	**961.1**	**53,820**	**-42,029**
PV — Structure	338.4	18,952	289.6	16,218	-2,734
PV — Panels (embodied carbon)	434.3	24,323	434.3	24,323	-
PV Embodied Carbon Total	**772.8**	**43,275**	**724.0**	**40,541**	**-2,734**
Embodied Carbon Total	**2,623.2**	**146,897**	**1,823.8**	**102,134**	**-44,763**
Operational emissions (annual)	76.8	4,301	52.9	2,963	-1,338
Avoided emissions — PV (annual)	(10.9)	-609	(17.4)	-975	-366
Avoided emissions — Battery (annual)	(3.3)	-186	(30.5)	-1,710	-1,524
Net operational emissions (30 years)	**62.6**	**132,080**	**5.0**	**10,459**	**-121,620**
Grand Total	**2,685.8**	**278,977**	**1,828.8**	**112,594**	**-166,383**

Source: Redwood Energy, 2023

For calculating utility cost estimates, the design team performed detailed calculations using the hourly energy demand profiles with the following tariffs. The project's NZE microgrid design aimed to eliminate the energy use cost for residential tenants of Meridian, to address affordability challenges. Therefore, in the proposed design, no tariff is applied to the residential tenant energy use, costing tenants $0 per year. For the proposed design, the selected tariff for the project's backup energy for residential and nonresidential loads is a small general service tariff for PG&E's standby connection, due to the microgrid operating off-grid for 95 percent of the year. The standby (S) tariff charges varying rates for summer versus winter months and has peak and off-pricing rates that depend on the day of the week. The standby tariff includes a reservation charge of $11.03/kW per month multiplied by 85 percent of the connection charge (200 amps or 72 kW total connection capacity).[14]

To estimate the utility cost before the solar PV and the battery microgrid load reduction for the proposed case and for all cases in the baseline model, the E-TOU-C time-of-use tariff from PG&E was used for the residential energy loads. This tariff charges varying rates for summer versus winter months and has peak pricing rates from 4:00 p.m. to 9:00 p.m. daily. The rates are reduced for any period where the daily energy consumption is below that of the baseline energy demand for the given territory. Under PG&E's service territory "T" and as an all-electric design, the baseline daily energy use values are set at 7.1 kWh per day for the summer and

[14] Pacific Gas and Electric Company. 2023 (Jan 20). "Electric Schedule S: Standby Service." Available at https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_S%20(Sch).pdf.

12.9 kWh per day for the winter. The tariff does not include any additional peak demand charges. The small general service electric schedule B-1 tariff from PG&E was selected to calculate the utility cost for nonresidential loads, due to the peak demand being less than 75 kW.[15] The B-1 tariff charges varying rates for summer months versus winter months and has peak and off-peak pricing energy rates that depend on the day of the week. This tariff also does not include any additional peak demand charges.

Table 9 and Table 10 reflect the total estimated utility electricity bill cost for the residential and the nonresidential spaces of Meridian. The proposed design leads to an overall savings of 92.5 percent of annual site utility costs.

Table 9: Total Estimated Residential Space Electricity Bill

Baseline	Proposed Design		
First-Year Bill ($)	First-Year Bill ($)	First-Year Savings ($)	Percentage Reduction (%)
202,750	$0	(202,750)	100%

Source: Redwood Energy, 2023

Table 10: Total Estimated Nonresidential Space Electricity Bill

Baseline	Proposed Design		
First-Year Bill ($)	First-Year Bill ($)	First-Year Savings ($)	Percentage Reduction (%)
16,832	15,380	1,452	8.6%
Lifetime Bill ($)	Lifetime Bill ($)	Lifetime Savings ($)	Percentage Reduction (%)
504,960	461,400	43,560	8.6%

Source: Redwood Energy, 2023

The team also used cost analysis to determine the adequate battery size to optimize the microgrid system cost. In Table 11, the baseline scenario represents a solar PV array and battery system that provides the minimum code required PV capacity as prescribed by the California Title 24 2022 energy code. While this scenario cost is only slightly more expensive than the proposed microgrid cost due to tax incentives, it draws heavily on grid energy, leading to increased emissions. The no-grid backup scenario, meaning a completely isolated microgrid with no interconnection with the utility grid, would require a very large, expensive central battery. Therefore, the proposed microgrid with a standby utility connection was ultimately chosen as the most cost-effective energy system design scenario. Figure 18 shows the breakdown of energy system costs in bar graph form.

The following assumptions were used in the energy system cost analysis:

- Battery cost: $1,000 per kWh
- PV cost: $3.2 per W for rooftop and $5.0 per W for carport canopies

[15] Pacific Gas and Electric Company. 2021 (Jul 8). "Electric Schedule B-1: Small General Service." Available at https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_B-1.pdf.

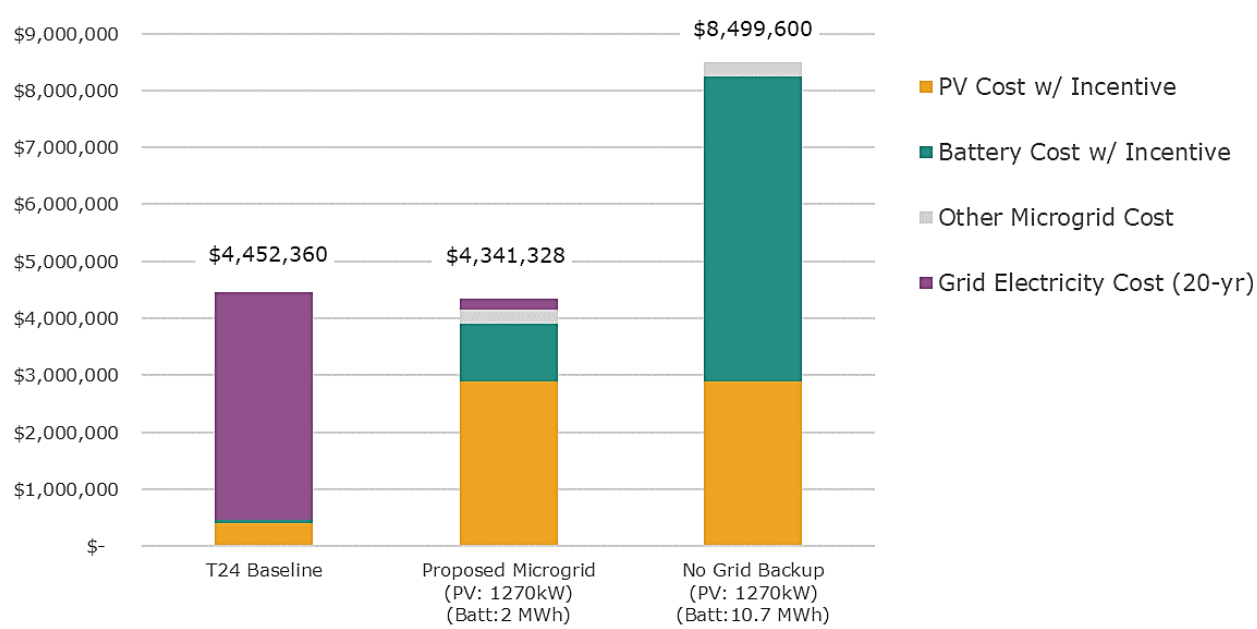
- Tax incentive: 50-percent rebate on total installed cost
- Electricity cost: The proposed microgrid uses PG&E Standby Connection Tariff S. The baseline design uses PG&E B-1 Tariff for Back of House and PG&E E-TOU-C Tariff for Residential.
- The standby utility connection assumes a 200 amp/208V one-way connection to the grid with around 72 kW charging capacity.
- The battery sizing factor for the proposed microgrid design is 1.2 (expecting 20 percent derating on the batteries over time).
- Annual maintenance costs are excluded for all options.

Table 11: Proposed Microgrid Versus Baseline Energy System Cost Summary

	PV Capacity (kW)	Battery Capacity (kWh)	% Grid Energy Use	Grid Electricity Cost (20 years)	PV Cost With Incentives	Other Microgrid Cost	Battery Cost With Incentive	Total 20-year Cost With Incentive
Baseline	250	142	61.7%	$3.98M	$400K	-	$71K	$4.45M
Proposed Microgrid	1,270	2,000	5.5%	$192K	$2.9M	$250K	$1M	$4.34M
No Grid Backup	1,270	10,700	0%	-	$2.9M	$250K	$5.4M	$8.49M

Source: PAE, 2023

Figure 18: Proposed Microgrid Versus Baseline Energy System Cost Breakdown



Source: PAE, 2023

Project Barriers and Challenges

Technical, Market, and Policy Barriers and Challenges

Investor-owned utilities (IOUs), such as PG&E, have a Standby Tariff (S) for customers who supply power regularly and completely through their own facilities not owned by PG&E, and who may require PG&E to provide reserve capacity and stand ready at all times to supply electricity on an irregular or noncontinuous basis.[16] This tariff is typically used by industrial customers such as manufacturing and mining operations that may have their own generating facilities; the tariff has yet to be applied in the scenario that Meridian is designed for: a mixed-use community with an isolated microgrid system that can provide power to the community for 95 percent of the year. Working with an IOU to facilitate this alternative interconnection process will require a comprehensive and innovative submission and application process. It will be essential to present a compelling case and effectively articulate the benefits and feasibility of the proposed energy system to the community and to the IOU. To mitigate this challenge, the project team is ensuring that PG&E is adequately informed of the proposed energy system and alternative interconnection approach. The project team will ensure that the community's energy system is compliant with PG&E's typical electrical infrastructure standards (for example, approved manufacturers and materials for the transfer switch, wires, transformers, and so on) This provides future proofing and flexibility to Danco (the builder and property owner) in the event that Danco wants to transition to the utility grid for normal power. It is also anticipated that PG&E may still request a functionality or proof of compliance operation test even though the design is not for export. To mitigate this, the project team is proposing a recloser at the POCC to ensure non-exportability of the community's energy system. The project team will also have a test plan prepared beforehand, based on test plans from previous projects. The project team has dedicated personnel assigned to collaborate closely with PG&E throughout the interconnection application process.

The incorporation of vehicle-to-X (V2X, or vehicle-to-everything) technologies, such as vehicle-to-building (V2B), vehicle-to-grid (V2G), and vehicle-to-microgrid (V2M) systems, is still in the beginning stages of adoption. While V2X technologies hold promise for enabling bidirectional energy flow, technical and market barriers exist; thus, there is only a limited number of bidirectional chargers and EVs available in the current market. There is also a concern whether acquiring V2X-capable EVs would be financially feasible for affordable housing residents. Based on market research, it is anticipated that there will be more V2X technologies available on the market in the next five years, as well as upcoming EV subsidies targeted for lower income buyers that make it more economically feasible to purchase EVs. Notably, California is expanding a statewide Clean Cars 4 All Program that will provide low- to middle-income residents up to $12,000 for cleaner alternative vehicles. In this context, Meridian's design thinks ahead, while also serving as a pilot project with research aspects to investigate the opportunities for and challenges of integrating V2X technologies with buildings, microgrids, and the grid.

---

[16] California Energy Commission. 2022 (Aug). *2022 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*. Publication Number: CEC-400-2022-010-CMF. Available at https://www.energy.ca.gov/sites/default/files/2022-12/CEC-400-2022-010_CMF.pdf.

The constantly evolving landscape of EV plug standards and EV charging protocols pose policy challenges for the design. With the lack of a standardized EV charging protocol, there is an industry shift to adopt a standardized EV plug, which could make any EV chargers selected during this design potentially obsolete during the construction phase. The dynamic environment of EVs makes it challenging to select a specific type of EV charger during the design phase. To address this challenge, the project team has dedicated personnel responsible for monitoring emerging research and standards in EV charging technology, facilitating knowledge transfer to Danco and enabling it to make the best decisions for the community.

Despite the hurdles in EV adoption and EV charging protocols, California's policies are poised to drive increased incentives and standardization for EVs, with a mandate that all new cars and passenger trucks sold in California must be zero-emission vehicles by 2035.[17]

Community Outreach and Knowledge Transfer

To ensure that the project approach and results are effectively introduced to the local community (including Meridian residents, the city of Petaluma, and the rest of the city residents), the team has collaborated with several partners to engage in community outreach. CBOs and The Rahus Institute, along with LifeSTEPS and Daily Acts, will work to enroll all Meridian households in the education, training, and personalized services of the project features and benefits. LifeSTEPS is a non-profit provider of social and supportive services to individuals and families experiencing poverty and/or homelessness. Daily Acts is a holistic education nonprofit that focuses on climate resilience, leadership training, and personal ecology. The project team in collaboration with the CBO partners will engage Meridian and the greater Petaluma community through the following outreach methods:

- **Pre-opening training videos** to staff and management of Meridian to provide education and services to future tenants moving in year-round. They will also provide training to property management on using a community app to communicate to residents when energy storage is running low and how to manage critical and noncritical loads.
- **Semi-annual open house in-person presentations** at the nonresidential space within the community, to solicit tenant participation in education on the Meridian design, such as education on renewable energy, building electrification, energy efficiency, and environmental design training. Learnings from the educational events can be used to understand how the tenants are responding to Meridian's features, and the educational materials can be shared with other community members interested in implementing similar all-electric and nature-based solutions in their communities and homes.

[17] Office of Governor Gavin Newsom. 2020. "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change." Available at https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/.

The project will use several mechanisms for eliciting, addressing, and tracking feedback of the project's design from residents to improve the community's performance and enhance tenant well-being, health, and satisfaction:

- **Occupant needs and expectations study:** Customer-centric surveys and interviews to understand tenant needs, the acceptance of the community's design features, and the expectation of improvement brought by the new features.
- **Occupant experience study:** Tracking surveys or focus group sessions to understand interactions between tenants and the community design features as well as tenant feedback on the features.
- **Pre- and post-occupancy evaluation (P/POE):** Collection of data during the pre-occupancy and post-occupancy phases of a project to measure its performance and success. POE surveys would be conducted at six months and at one year, allowing property management time to work out the new building concerns. Surveys will include health and well-being, thermal comfort, indoor air quality, quality of indoor and outdoor spaces, resilience, occupant behavior, and financial impact. At the one-year mark, there will also be an energy and water analysis to further observe quantitatively building performance results.

Results from the above surveys can be used to quantify the satisfaction, comfort, safety, and health outcomes of tenants and can be shared with community stakeholders to serve as potential points for improving policy, updating building codes and standards, and suggesting future funding opportunities for similar building designs. These results can also help inform Danco and its property management staff on potential enhancements and upgrades to the facilities for the community's benefit.

The project team will be partnering with the Rising Sun Center for Opportunity, a nonprofit organization that creates workforce development programs for youth, women, people of color, and individuals in the greater Bay Area, to recruit Bay Area young adults from disadvantaged backgrounds and offer onsite work and training in the trades through this project. Three such young adults have assisted in the design of Meridian. Workforce development within Meridian could ultimately foster more "green" job creation and training for the greater community.

Following the design phase of this project, the project team has engaged in several knowledge transfer activities to share the design of Meridian to relevant stakeholders. During Redwood Energy's 15th Annual Zero Carbon Retreat in September 2023, the project team presented on the project's overall design strategies, technology selection, and potential opportunities to various stakeholders statewide, including utility employees, council members, researchers, and university staff.[18] The team also presented on the design during EPRI's Electrification and Sustainable Energy Strategy Advisory meeting in February 2024, providing insight into the design process, future project goals, and the potential scalable opportunities associated with the project design to utility companies from across the United States.

[18] Higbee, E., Dylan Anderson, Cobe Phillips, and Jessie Lee. 2023. "The Next EPIC Challenge: Meridian at Corona Station." Redwood Energy 15th Zero Carbon Retreat. Available at https://www.redwoodenergy.net/presentations/the-next-epic-challenge-meridian-at-corona-station.

The innovative design of the project invoked several conversations with external organizations, such as the project team meeting with the city of Petaluma council members to discuss the project design and the potential benefits it could bring to the local community. The city of Petaluma held public meetings and hearings in 2020[19] to help inform the design of Meridian and recently presented on the final design during a groundbreaking event of the adjacent transit station.[20] Furthermore, the Meridian project plans were featured on the websites of the project team and stakeholders, including Danco[21] and the city of Petaluma.[22] The project was discussed during a public forum with a local Petaluma CBO, Urban Chat, to provide a platform for public discourse, feedback, and community advocacy on development projects.[23] The project has also been featured in several online news articles, including the city of Petaluma press release,[24] the Petaluma Argus-Courier,[25] and Connect CRE.[26] These conversations, meetings, forums, websites, and news articles help spread generalized knowledge to the public on Meridian's community design.

As the project continues to gain traction, the project team intends to continue spreading knowledge of the design in the form of a publicly available video that can be shared on project team websites and social media to further engage stakeholders and the public. The project team intends to undertake additional knowledge transfer activities, including presenting at EPRI's Equity and Environmental Justice Workshops and Energy Storage and Delivery Advisory Meeting, developing additional white papers regarding the interconnection process of this design and a case study on non-energy benefits and solutions that will be available to utilities and energy organizations, and submitting papers to and speaking at various public-facing conferences.

[19] City of Petaluma. No date. "Meridian at Petaluma North Station." Available at https://cityofpetaluma.org/meridian-at-petaluma-north-station/.

[20] Sonoma-Marin Area Rail Transit. 2023 (Dec). "The Community Celebrated the Groundbreaking for the Petaluma North Station." *On Track Newsletter*. Available at https://mailchi.mp/sonomamarintrain/on-track-newsletter-overnight-parking-ridership-highlights-message-from-gm?e=1b49656f71.

[21] Danco Group. No date. "Meridian at Petaluma North Station: Multi-Family Affordable Housing in Development." Available at https://www.danco-group.com/projects/meridian-corona-station.

[22] City of Petaluma. No date. "Meridian at Petaluma North Station." Available at https://cityofpetaluma.org/meridian-at-petaluma-north-station/.

[23] Petaluma Urban Chat. No date. "Voice on Development Projects." Available at https://www.urbanchat.org/committees-overview.

[24] City of Petaluma. 2023 (Sep 11). Press Release, "Meridian at Petaluma North Station, Sept. 11, 2023." Available at https://cityofpetaluma.org/press-release-meridian-at-petaluma-north-station-sept-11-2023/.

[25] Palmer, K. 2020 (Nov 19). "New Petaluma Corona Station Plans Unveiled." *Petaluma Argus-Courier*. Available at https://www.petaluma360.com/article/north-bay/new-petaluma-corona-station-plans-unveiled/.

[26] Bubny, P. 2023 (Sep 8). "California Invests $757M in Affordable Housing Projects." *Connect CRE*. Available at https://www.connectcre.com/stories/california-invests-757m-in-affordable-housing-projects/.

CHAPTER 4: Conclusion

The aim of this CEC Next EPIC Challenge project was to design and demonstrate an economically viable, inclusive, and carbon-neutral mixed-use development capable of mitigating GHG emissions while fulfilling affordable housing demands and remaining appealing in the market. The project team endeavored to design a mid-rise, mixed-use development that is affordable, equitable, climate-resilient, cost-competitive, and emissions-free. Aligned with the local community and city government goals, Meridian at Corona Station in Petaluma, California is an affordable housing and supportive housing development with the following ZNE design:

- solar + battery microgrid with enough capacity to power the community for 95 percent of the year with a minimal standby unidirectional connection with the utility for emergencies.
- 100 percent EV-ready parking spots with bidirectional charging to the microgrid, buildings, or the grid.
- Load flexibility and forecasting applications to manage effective load shedding to meet peak demand reduction.
- Building electrification technologies such as heat pumps, heat pump water heaters, induction cooktops, heat pump dryers, LED lights, occupancy-based sensors for lighting controls in the commercial spaces, and advanced power strips.
- Non-energy/nature-based solutions, including exterior cork siding insulation, exterior-grade mass timber carports, grey water re-use design from laundry to landscape, low-carbon concrete pathways, and an orchard ecosystem.

Building and energy modeling helped inform expected results of the project design, including:

- Improved energy efficiency, with reduced EUI and GHG emissions intensity.
- Avoided GHG emissions from utilizing an onsite renewable microgrid to power the community during normal hours and an alternative interconnection with the grid for emergencies.
- Enhanced peak load reduction from onsite solar, storage, and load management.
- Reduced embodied carbon emissions.

A cost analysis performed revealed a design that enables a complete reduction in the tenant energy burden, with affordable housing tenants paying zero electricity bills.

This project helped formulate a ZNE multifamily design that would contribute to California's 100-percent clean energy, net-zero emissions, and EV adoption goals by improving access to renewable energy, storage technologies, EV charging, and demand flexibility and response. A wide range of emerging technologies were examined and priced throughout the design process. Some solutions that require no subsidies to implement became new design standards for the property developer, Danco, such as heat pump HVAC units and heat pump water heaters. As a leading affordable housing developer, Danco expects these new design standards to have a significant impact on future new construction and renovated affordable housing projects that the company will work on. By interviewing CBOs, local business owners, and the local city government, the project team was able to use their feedback to implement the best strategies for the energy and community aspects and to ensure that gentrification or displacement of low-income groups is minimized. The project presents positive impacts on the tenants residing in Meridian, as well as the city of Petaluma. This ZNE multifamily design supports Petaluma's Climate Ready by 2030 goal while improving health outcomes, providing workforce development opportunities to the community, reducing the energy burden for disadvantaged populations, and providing resilience to the community. The project's community engagement strategy can influence building industry stakeholders to ensure that community feedback is received when planning and designing multifamily and affordable housing developments.

This project adopts multiple strategies that help promote broader adoption of the project design. The cost and lengthy timelines of DERs and grid interconnection delay the speed that onsite clean energy sources can be adopted throughout California and the rest of the country. Meridian's alternative standby connection method with the utility will serve as a proof-of-concept for future multifamily projects, both statewide and nationwide, that aim to improve deployment access and speed of clean energy resources. The ability of BTM DERs to serve the building demand and draw power only from the grid approximately 5 percent of hours in the year, with zero need for power from the grid during 4:00 p.m. to 9:00 p.m. peak load periods, lowers the utility's risk of the constrained grid. The demonstration of this alternative connection will help address scalability by discovering a path to scale flexible interconnection service agreement options with utilities. Several funding sources were investigated to evaluate scalable implementation of the project design. The project has committed to multiple levels of transit-oriented development via a grant from the cap-and-trade Affordable Housing Sustainable Communities program, with a subdivision of the community being used to develop a train station and rapid electric bus charging spaces. This strategy, called "funding stacking," is already a practice of affordable housing developers, and through this project it was expanded to mixed-use development. This transit-oriented funding can be scalable to other projects that may be well-suited for transit development.

The project team also investigated CCAs for additional funding. CCA programs across California differ greatly, with some offering rebates on technologies such as EV chargers, batteries, and/or solar, while others offer more holistic energy management programs specific to multifamily housing. Certain CCA programs, such as Sonoma Clean Power, offer grants to non-profits that are pursuing community projects that advance clean energy, green jobs, environmental education and stewardship. Depending on geographic location, future projects can leverage CCA rebates and programs for funding of emerging technologies or grants to pursue community projects. Federal Inflation Reduction Act funding also helps the scalability of future clean energy projects.

In this first phase, the project team has successfully designed and modeled a ZNE affordable housing community. The next phase is to demonstrate the design in a real-world setting with field data to confirm the actual energy improvements and cost savings. The project team has submitted an application to the CEC to build Meridian in Petaluma, California, and to implement measurement and verification strategies to collect data and verify the true potential of the design. The project team won the Build Phase award of the EPIC Challenge and is slated to begin construction of Meridian in 2024. The team will be considering the alternative connection challenges and bidirectional EV charging barriers during construction, while demonstrating and sharing field results and best practices through community outreach engagement and activities.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
ADA	Americans with Disabilities Act
affordable housing	the United States Department of Housing and Urban Development considers housing to be affordable when a household spends 30 percent or less of its income on housing costs.
amp	ampere
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BESS	battery energy storage system
bidirectional	the flow of electricity/communication in two directions — in this paper, bidirectional is used to describe electric vehicle charging that can communicate with the vehicle and the building, grid, and/or microgrid
building envelope	building components that separate the indoors from the outdoors
BTM	behind-the-meter — energy production and storage systems located on the customer's side of the utility meter
CalGreen	California's first Green Building Standards Code
carport	a shelter for a car consisting of a roof supposed on posts
CBO	community-based organization
CCA	community choice aggregator — programs that allow local governments to procure power on behalf of their residents, businesses, and municipal accounts from an alternative supplier while still receiving transmission and distribution service from their existing utility provider
CEC	California Energy Commission
CO_2	carbon dioxide
CO_2/sf/yr	carbon dioxide per square foot per year
CO_2e	carbon dioxide equivalent
Danco	The Danco Group
decarbonization	the process of reducing or eliminating carbon dioxide emissions
DER	distributed energy resources — onsite, small-scale generation or storage technologies
DR	demand response
EC	embodied carbon
EIFS	exterior insulation and finish system

Term	Definition
electrification	the process of replacing technologies that use fossil fuels with technologies that use electricity as a source of energy
embodied carbon	the carbon emissions released during the lifecycle of building materials, including extraction, manufacturing, transport, construction, and disposal
EMS	energy management system
energy burden	percentage of gross household income spent on energy costs
Energy Star	a joint program of the Environmental Protection Agency and the United States Department of Energy to help consumers and businesses save money and protect the environment through the adoption of energy-efficient products and practices
EPIC	Electric Program Investment Charge
EPRI	Electric Power Research Institute
ERV	energy recovery ventilator
EUI	energy use intensity — the amount of energy used per square foot annually
EV	electric vehicle
FSC	Forest Stewardship Council
GHG	greenhouse gas
grey water	domestic waste generated in households or office buildings, excluding toilet water
GWB	gypsum wall board
GWP	global warming potential
heat pump	air-source, energy-efficient technology that transfers heat between indoor air and outdoor air for building heating and cooling
HENOC	Hybrid Energy Network Operating Center
HPWH	heat pump water heater
HVAC	heating, ventilation, and air conditioning
impervious	does not allow water to pass through
induction	the use of magnets to excite metallic equipment and create heat
Inflation Reduction Act	passed in 2022, the act includes programs such as clean energy, climate change mitigation and resilience, agriculture, and conservation-related investment programs
interconnection	the process of connecting a distributed generation system to the electric grid — prior to connection, the distributed generation system

Term	Definition
	owner must obtain written approval from the local utility in the form of an Interconnection Service Agreement.
IOU	investor-owned utility
irradiance	the power per unit area received from the sun
kBTu/sf/yr	thousand British thermal units per square foot per year
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour(s)
L&T	Larsen & Toubro
LCA	life cycle analysis — a methodology for assessing environmental and cost impacts associated with all the stages of a product, process, or service
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
load flexibility	the practice of adjusting load (or energy usage) to match the supply of electricity
load shedding	the practice of reducing load to avoid excessive load on the grid
load shifting	the practice of moving electricity consumption from one time period to another
Meridian	Meridian at Corona Station
MERV	Minimum Efficiency Reporting Value — a rating that describes the size of the holes in the filter that allow air to pass through
microgrid	a group of interconnected loads and distributed energy resources that acts as a single controllable entity with respect to the grid — it can connect and disconnect from the grid to operate in grid-connected or island mode
mitigation	the action of reducing the severity or seriousness of something
mt	metric tons
nature-based solutions	solutions to challenges that involve working with nature to deliver benefits for people and biodiversity
non-energy related benefits	many and diverse benefits produced by energy efficiency in addition to energy and demand savings
NPV	net present value
NZE	net-zero emissions — a state where the quantity of greenhouse gas emissions produced by human activities is equal to the quantity of greenhouse gas emissions removed

Term	Definition
OEM	original equipment manufacturer
operational carbon	amount of carbon emitted during the operational or in-use phase of a building
PAE	PAE Engineers
passive house	a voluntary set of building standards that aim to create houses and other structures that are comfortable and healthy yet consume very little energy
peak demand	the highest electrical power demand on the electrical grid that occurs over a specified period of time
permeable	porous urban surface that catches precipitation and surface run-off
pervious	material that allows water to pass through
POCC	point of common coupling
P/POE	pre-/post-occupancy evaluation
PG&E	Pacific Gas and Electric Company
PV	photovoltaic
resilience	the capacity to withstand or to recover quickly from difficulties
RHNA	Regional Housing Needs Assessment
sequestration	the process of capturing carbon and storing carbon
SHEMS	Site Hybrid Energy Management System
SHGC	solar heat gain coefficient — the fraction of solar radiation admitted through a window, door, or skylight
SMART	Sonoma-Marin Area Rail Transit
SOC	state of charge — the level of charge of a battery relative to its capacity
standby tariff (S)	a utility customer rate charged to customers who have their own generating facilities and require reserved capacity from the utility grid in case their generating facilities fail
supportive housing	permanent housing that is paired with comprehensive services and case management for individuals experiencing homelessness
Title 24	California’s energy code that requires all new construction to meet certain energy efficiency requirements
transfer switch	a device designed to transfer electrical loads between power sources, such as utility power and generator power
unidirectional	electricity flow in a single direction — in this report, unidirectional is used to reference the flow of electricity from the utility to the building.

Term	Definition
urban forest	networks or systems of trees located in an urban setting
U.S. DOE	United States Department of Energy
V	volt
V2B	vehicle-to-building
V2G	vehicle-to-grid
V2M	vehicle-to-microgrid
V2X	vehicle-to-everything
VPP	virtual power plant — a network of distributed energy resources that can provide grid resources
ZNE	zero net energy — a state where, on a source energy basis, the actual annual consumed energy is less than or equal to the onsite renewable generated energy

References

Bubny, P. 2023 (Sep 8). "California Invests $757M in Affordable Housing Projects." *Connect CRE*. Available at https://www.connectcre.com/stories/california-invests-757m-in-affordable-housing-projects/.

California Air Resources Board. 2022 (Nov 16). *2022 Scoping Plan for Achieving Carbon Neutrality*. Available at https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf.

California Department of Housing and Community Development. 2022 (Mar). "A Home for Every Californian: 2022 Statewide Housing Plan." Available at https://storymaps.arcgis.com/stories/94729ab1648d43b1811c1698a748c136.

California Energy Commission. 2022 (Aug). *2022 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*. Publication Number: CEC-400-2022-010-CMF. Available at https://www.energy.ca.gov/sites/default/files/2022-12/CEC-400-2022-010_CMF.pdf.

California Office of Planning and Research. 2019. *California's Fourth Climate Change Assessment*. Available at http://climateassessment.ca.gov/.

City of Petaluma. 2021 (Jan 11). *Climate Emergency Framework*. Available at https://storage.googleapis.com/proudcity/petalumaca/uploads/2021/02/Climate-Action-Framework_Final.pdf.

City of Petaluma. 2023 (Aug 10). *Affordable Housing Finance Analysis*. Available at https://static1.square.space.com/static/5ea880f6d9a2075c7b7f54af/t/64e528aacfa548043f604a68/1692739755610/Petaluma+GPU_5.10+Housing+Finance+Analysis_20230810_v2.pdf.

City of Petaluma. 2023 (Sep 11). "Press Release, "Meridian at Petaluma North Station, Sept. 11, 2023." Available at https://cityofpetaluma.org/press-release-meridian-at-petaluma-north-station-sept-11-2023/.

City of Petaluma. No date. "Meridian at Petaluma North Station." Available at https://cityofpetaluma.org/meridian-at-petaluma-north-station/.

Danco Group. No date. "Meridian at Petaluma North Station: Multi-Family Affordable Housing in Development." Available at https://www.danco-group.com/projects/meridian-corona-station.

Grabinsky, J., and S.M. Butler. 2015 (Feb 10). "The Anti-Poverty Case for 'Smart' Gentrification, Part 1." *Brookings*. Available at https://www.brookings.edu/articles/the-anti-poverty-case-for-smart-gentrification-part-1/.

Higbee, E., Dylan Anderson, Cobe Phillips, and Jessie Lee. 2023. "The Next EPIC Challenge: Meridian at Corona Station." Redwood Energy 15th Zero Carbon Retreat. Available at https://www.redwoodenergy.net/presentations/the-next-epic-challenge-meridian-at-corona-station.

O'Donoghue, L., and M. Breach. 2023 (Mar 23). "Opinion: California Housing and the Environment Are Often at Odds. They Don't Have to Be." *The Los Angeles Times*. Available at https://www.latimes.com/opinion/story/2023-03-23/california-housing-climate-environment-legislation.

Office of Governor Gavin Newsom. 2020. "Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change." Available at https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-drastically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/.

Pacific Gas and Electric Company. 2021 (Jul 8). "Electric Schedule B-1: Small General Service." Available at https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_B-1.pdf.

Pacific Gas and Electric Company. 2023 (Jan 20). "Electric Schedule S: Standby Service." Available at https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_S%20(Sch).pdf.

Palmer, K. 2020 (Nov 19). "New Petaluma Corona Station Plans Unveiled." *Petaluma Argus-Courier*. Available at https://www.petaluma360.com/article/north-bay/new-petaluma-corona-station-plans-unveiled/.

Petaluma Urban Chat. No date. "Voice on Development Projects." Available at https://www.urbanchat.org/committees-overview.

Quackenbush, J. 2023 (Mar 10). "Bills Aim to Fix California's Long Delays in Connecting Construction Projects to the Grid." *The North Bay Business Journal*. Available at https://www.northbaybusinessjournal.com/article/article/bills-aim-to-fix-californias-long.

Sonoma-Marin Area Rail Transit. 2023 (Dec). "The Community Celebrated the Groundbreaking for the Petaluma North Station." *On Track Newsletter*. Available at https://mailchi.mp/sonomamarintrain/on-track-newsletter-overnight-parking-ridership-highlights-message-from-gm?e=1b49656f71.

Project Deliverables

The Project Deliverables include a bulleted list of the products produced — primarily the deliverables noted in the key technical tasks — as identified in the Agreement and Scope of Work. The project deliverables are available upon request by submitting an email to pubs@energy.ca.gov.

- Architectural and Mechanical Design Documents
- Load Management Report
- Energy Modeling Reports
- Equipment and Material List
- Survey Report
- Design Report
- Building Permit Application
- Permit Drawing Package
- Sustainability Plan and LEED Scorecard
- Project Benefits Questionnaire
- Project Case Study
- Build Phase Application Package
    - Conceptual Design and Engineering Report
    - Energy and Emissions Performance Model Report
    - Emerging Technologies and Strategies Report
    - Zero-Emission Cost-Benefit Analysis Report
    - Community Engagement Plan
    - Concept Video
    - Presentation Material