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Planning for a Sustainable and Resilient Energy System – Islesboro, Maine

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Executive Summary

Islesboro formed the Islesboro Energy Committee (IEC) to identify and seek solutions to existing energy challenges on the island. The IEC applied and was selected as one of the communities in the U.S. Department of Energy's (DOE) Energy Transitions Initiative Partnership Project (ETIPP). The focus of ETIPP is to provide strategic energy planning for remote and island communities to address local energy and infrastructure challenges and enhance the long-term resilience of their energy systems. Through ETIPP, the community received technical assistance from Pacific Northwest National Laboratory (PNNL), Sandia National Laboratories (SNL), and the National Renewable Energy Laboratory (NREL). The Island Institute was also engaged as a regional partner throughout this project to provide additional support.

Islesboro's application to ETIPP highlighted the island's vision of an island community that is "100% fossil-fuel free, in which all inhabitants benefit equitably from low-cost, emergency-resilient electricity produced in large measure locally." By engaging key island leadership and stakeholders the IEC, Island Institute, and DOE labs collaborated to develop a set of energy goals for Islesboro centered around increasing the uptake of fossil fuel-free energy systems on the island, enhancing the resilience of the island's power system, ensuring equitable access to resilient energy on Islesboro, and identifying key steps for implementing Islesboro's energy vision.

To understand Islesboro's existing conditions the team collected data on existing energy systems serving the island and how energy is being used in island buildings. Using this information, the labs team created energy models for Islesboro that were used to develop load forecasts and more accurately assess energy opportunities on the island. This part of the analysis resulted in the following key findings:

- Fossil fuel use (fuel oil, kerosene and propane) in buildings on Islesboro is estimated to represent around 75% of the annual energy consumption in Islesboro, but only around 50% of the building energy-related emissions. Electricity and wood consumption account respectively for 34% and 13% of these emissions. Reducing fossil fuel use or using alternate energy sources to meet those energy needs is the most significant and impactful opportunity to reduce emissions from Islesboro's buildings.

- Islesboro has over 800 buildings that are estimated to occupy approximately 2 million square feet. It's estimated that 90% of the buildings are residences. Seasonal residences represent more than double the footprint of year-round residences, while using approximately the same amount of energy as year-round residences. This highlights the importance of encouraging both year-round and seasonal residents to implement changes that contribute to the island's energy vision.

- Implementing energy efficiency projects in Islesboro buildings represents a significant opportunity for reducing not only energy use and emissions, but also energy costs for Islesboro residents. Measures like lighting retrofits to LEDs, envelope upgrades like adding insulation and weatherizing buildings, and upgrading heating equipment were found to be cost-effective for a typical residence in Islesboro.

- An alternative approach to reducing the dependence of Islesboro's buildings on fossil fuels is to use other energy sources such as electricity for space and water heating. When combined with certain measures, such as home weatherization and envelope improvements, electrification of building systems can help reduce heating energy costs and emissions while improving comfort and indoor environmental quality.

- Approximately 6% of Islesboro's annual electricity need is supplied by local solar photovoltaic

(PV) systems. To offset all of its current local electricity demand, Islesboro needs to generate nearly 6,200 MWh of additional electricity through on-site resources, which translates to approximately 4.7 megawatts direct current (MW-DC) of solar PV capacity. The analysis of available rooftop and open ground area on the island showed that there is sufficient space for this additional PV capacity on Islesboro.

The baseline conditions and energy opportunities were used to develop three load cases that were analyzed to understand the implications of choosing different combinations of technologies (PV, for power generation; lithium-ion batteries for storage; and conventional diesel generators for backup power). The load cases included a baseline scenario, an all-electric scenario, and an all-electric with energy efficiency measures scenario. The baseline scenario reflects the island's total electric load as assessed in the baseline conditions analysis. The all-electric scenario reflects electrification of space and water heating, with widespread adoption of heat pump technology, electric cooking, and electric transportation in the form of electric vehicles (EVs). The all-electric with energy efficiency measures scenario reflects the all-electric scenario plus the impact from installed energy efficiency measures.

An NREL tool was utilized to model various configurations of systems to find the least cost combination of components that met specified loads. This part of the analysis revealed the following:

- For all load cases, the least-cost system was one where PV generation satisfied the entire island-wide electric load on an annual basis (95% energy availability). The net present cost of the PV array over the expected lifetime of the system is lower than the net present cost of energy purchased from the grid. A larger system would be less advantageous because any excess energy would be provided to the utility grid at no cost. This system has no battery storage because the net metering arrangement allows the use of the grid as a zero-cost battery. The loss of service over the year, for all least-cost systems, hovered around 1%. The cost of energy for the least-cost system was lower than the utility cost by over 30%. Another option involved a zero emissions microgrid comprised of battery storage and a PV array. The size of the battery storage system was dictated by the need to serve the load for the five consecutive days during a period with low solar irradiance. The levelized cost of energy for the system was between 50% and 100% greater than the low-cost system.

- The difference in cost between the resilient, all-renewable fully electrified case with and without energy efficiency measures is on the order of a savings of $60M. In this case, implementing electrification and efficiency measures and installing a smaller renewable system is a better economic choice than installing a larger renewable system. The benefit of the reduced electric load from the energy efficiency measures translates into a smaller renewable system which is less expensive.

Pursuing an island-wide renewable energy project will require seeking clarity from the Maine public utility commission on the 2 MW limit for net metered systems. Finally, net-zero emissions for the grid-tied case depend heavily on what Central Maine Power does with electricity exported to its system, namely whether it offsets fossil generation, or whether and how it is sold on the carbon offset market.

Understanding the current conditions, opportunities and resilient energy systems options for Islesboro is only the first step in progressing towards the island's energy vision. With this information, island residents can begin taking proactive steps that lead them closer to their goals, such as increasing local outreach on energy efficiency and renewable energy, engaging with contractors and nearby communities to establish community-based programs for implementing energy opportunities, and beginning the process for collectively deciding on large-scale energy projects that may enhance the island's resilience and reduce cost. The roadmap and implementation plan presented in this report outlines a few steps that Islesboro can take to become more energy resilient and achieve its energy goals.

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1. Background

The U.S. Department of Energy's Energy Transitions Initiative Partnership Project (ETIPP) provides strategic energy planning for remote and island communities to address local energy and infrastructure challenges and enhance the long-term resilience of their energy systems.[1] Pacific Northwest National Laboratory (PNNL), Sandia National Laboratories (SNL), and the National Renewable Energy Laboratory (NREL) partnered with the island community of Islesboro, Maine (Islesboro), to provide technical assistance as part of the ETIPP's first cohort of communities (Figure 1.1).

Islesboro is an island located three miles off Lincolnville, Maine, that is home to approximately 600 year-round residents and an additional 1,400 summer residents. Islesboro primarily depends on the mainland for their electricity needs, supplied via an underwater transmission cable. Due to extreme weather that is common in Maine, the island regularly experiences outages, even if the storm does not affect them directly. Islesboro formed the Islesboro Energy Committee (IEC) to identify and seek solutions to existing energy challenges on the island, and the IEC applied to ETIPP in 2021. This report summarizes the outcomes of the Islesboro ETIPP project, including the island's existing energy use and conditions, and the opportunities and pathways for the island to achieve its energy goals.

Figure 1-1: Locations of ETIPP Cohort 1 communities.

1.1 Lab and Community Partners

As part of ETIPP, Islesboro was paired with PNNL and SNL as well as with regional partner The Island Institute to support the study of the island's energy transition needs. NREL provided programmatic support across all participating communities in the first ETIPP cohort. A brief introduction to the participating national labs is provided below.

[1] ETIPP Site

Pacific Northwest National Laboratory: PNNL is a Department of Energy (DOE), Office of Science national laboratory located in Richland, Washington. As a partner on ETIPP, PNNL offered its expertise in buildings and connected energy systems applications, which includes a number of topics from building energy and water evaluations to energy security and climate resilience planning for communities and utilities. PNNL was also the lead lab providing technical support to Islesboro.

Sandia National Laboratories: SNL is one of three National Nuclear Security Administration research and development laboratories in the United States. Through ETIPP, SNL offered experts from their Renewable Energy and Distributed Systems Integration program. This part of the effort was designed to support rapid decarbonization of energy systems while addressing reliability, resilience, and cybersecurity needs. SNL was the support lab for Islesboro.

National Renewable Energy Laboratory: NREL is a DOE, Office of Energy Efficiency and Renewable Energy lab that focuses on advancing the science and engineering of energy efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems. NREL's role was to coordinate the communication efforts of the ETIPP partners and selected communities throughout the entire project time frame.

The Island Institute[2]: The Island Institute is a nonprofit organization based in Rockland, Maine, that collaborates with coastal communities to build economic, climate and social resilience for the Maine coast. The Island Institute is the ETIPP Regional Partner for the northeast region. ETIPP Regional Partners serve as conduits between communities and the national laboratories. The Island Institute provided regional context, connected the national laboratories to local and regional parties, and helped the laboratories communicate with the communities. They also helped Islesboro find and collect data and navigate the technical assistance process.

1.2 Stakeholder Engagement

To ensure that the appropriate stakeholders were engaged and that the project efforts met the needs of the community, the national labs team hosted monthly discussions with the IEC and The Island Institute to discuss the work and results generated throughout the process. The PNNL team also attended the island's Energy Jamboree event held in May 2022, which brought together community members to learn about various energy-related topics such as solar energy, electric transportation, and others. The PNNL team presented a short talk at this event describing the work being conducted as part of ETIPP and surveyed community members on the biggest barriers to implementation of energy projects on the island. Figure 1.2 and Figure 1.3 show pictures of Islesboro's 2022 Energy Jamboree.

[2] The Island Institute

Figure 1-2: 2022 Islesboro Energy Jamboree. Source: NREL.

Figure 1-3: Electric bicycles at the 2022 Islesboro Energy Jamboree. Source: NREL.

2. Islesboro Energy Vision

The first phase of the ETIPP effort for Islesboro focused on establishing a scope of work that outlined the technical assistance to be provided by the labs. Islesboro's application to ETIPP highlighted the island's vision of an island community that is "100% fossil-fuel free, in which all inhabitants benefit equitably from low-cost, emergency-resilient electricity produced in large measure locally." By engaging key island leadership and stakeholders, the partners developed a list of goals for the island that guided the analysis conducted by the labs. Table 2-1 describes Islesboro's energy goals.

Table 2-1: Islesboro Energy Goals

Goal	Description
Achieve as close to 100% fossil-fuel-free energy systems on Islesboro as possible	Transform Islesboro's energy systems and eliminate as much fossil-fuel use on the island as possible.
Enhance the resilience of the island's power system	Enhance the resilience of the island's power system by lowering vulnerability to external hazards and increasing backup power capabilities on the island.
Ensure equitable access to low-cost, resilient energy on Islesboro	Implement energy projects that provide equitable, low-cost access to resilient electricity for island residents.

3. Existing Conditions: Buildings, Energy Infrastructure, and Energy Use

Developing a plan for Islesboro to achieve its energy vision began with acquiring a detailed understanding of the energy systems serving the island as well as how energy is being used in island buildings. This understanding of baseline conditions allowed the labs team to create energy use models for Islesboro that were used to develop load forecasts and more accurately assess energy opportunities on the island.

3.1 Existing Buildings

Islesboro has over 800 buildings on the island that are estimated to occupy approximately 2 million square feet. According to a survey of housing units on Islesboro as well as real estate records, over 90% of buildings on Islesboro are residences and approximately 65% of those are used only as seasonal summer residences. Seasonal residences are estimated to have more than double the total floor area of year-round residences.

The island has a few municipal buildings, a school, a community center, and other commercial and recreational buildings. The energy sources used at these buildings include electricity, fuel oil, kerosene, propane, and wood. The IEC identified 18 critical buildings on the island that are equipped to serve as shelters, food supply centers, and provide aid to residents during an emergency. These critical facilities include the ferry support facilities, the school, buildings around the town center (town office and health center, community center, island market grocery store, and others), buildings in northern Islesboro (Sporting Club, Durkee's general store, and others), and buildings in Dark Harbor (Tarratine club, Christ Church Dark Harbor, and others).

3.2 Existing Energy Infrastructure Overview

3.2.1 Electric Utility Power Transmission and Distribution

Power to Islesboro is provided by Central Maine Power (CMP). All power distribution systems on Islesboro, both high and low voltage, are owned, operated, and maintained by CMP. Islesboro's electricity is currently supplied from a single underwater transmission feed connecting the Lincolnville substation on the mainland to the center of the island near the ferry terminal. The island operates on a single three-phase circuit spine that spans the length of the island from north to south and distributes electricity in a radial layout. There are no substations on the island. Figure 3-1 shows the location of CMP-owned three-phase circuits on the island. The power that CMP supplies to Islesboro is generated on the mainland.

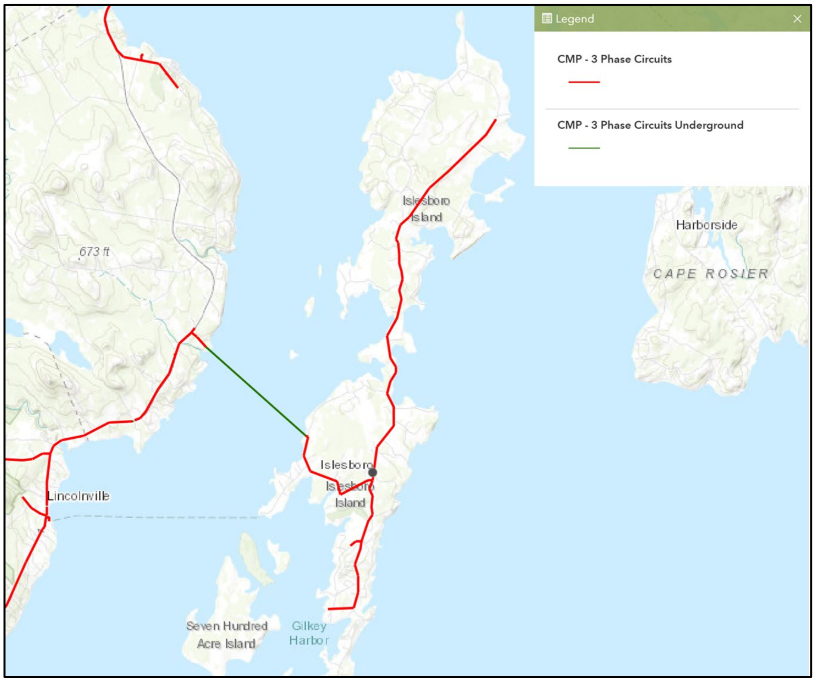

Figure 3-1: Three-phase circuits by CMP on Islesboro. Source: CMP[3]

3.2.2 *Existing Renewable Energy*

The first documented solar photovoltaic (PV) system on an Islesboro residence was installed in 1994. Since then, the island added almost 350 kW of installed PV capacity mostly through residential installations. Currently, solar PV is installed in less than 5% of all buildings on Islesboro and supplies approximately 6% of the island's power needs. The documented PV systems on the island and their estimated annual generation are summarized in Table 3-1.

Table 3-1: Installed Solar PV Systems

Location	Array Size (kW)	Annual Generation (kWh/Year)
Town Office / Health Center	46	58,000
School	68	85,000
North Transfer Station Salt Shed	32	41,000
Pendleton Yacht Yard	41	51,000
Residences (24 Total)	165 Total	207,000 Total
Total	352	442,000

[3] Central Maine Power 3 Phase Circuits

3.2.3 Backup Power Generation

Backup power to critical buildings and residences on Islesboro is primarily supplied by diesel and propane backup power generators—there are very few battery energy storage systems on the island. Only six of the 18 critical buildings identified on the island currently have backup power generation in place. These include the town school, the Islesboro Community Center, the town office/health center, the Boardman Cottage Assisted Living facility, the Sporting Club, and the Ferry Building. It is estimated that Islesboro has generators installed in approximately 20% of all the buildings on the island, including those installed in critical buildings. Figure 3.2 shows the backup power generator serving Islesboro's Town Office building.

Figure 3-2: Islesboro town office backup power generator.

3.2.4 Heating and Other Fuels

Heating on Islesboro is supplied primarily by fuel oil and is supplemented with kerosene, propane, wood, and electricity. Some residences may use a single fuel or a combination of these to meet their heating and hot water needs. Fuel oil, kerosene, and propane are delivered to the island via the ferry. Wood is either directly procured by residents or purchased from suppliers on the island and on the mainland.

3.2.5 Other Building Energy Technologies

Figure 3-3 shows the percentage of year-round buildings and all buildings on the island with a specific building energy technology installed according to data collected by the IEC and the Island Institute. These results highlight the potential to implement energy efficiency measures on Islesboro.

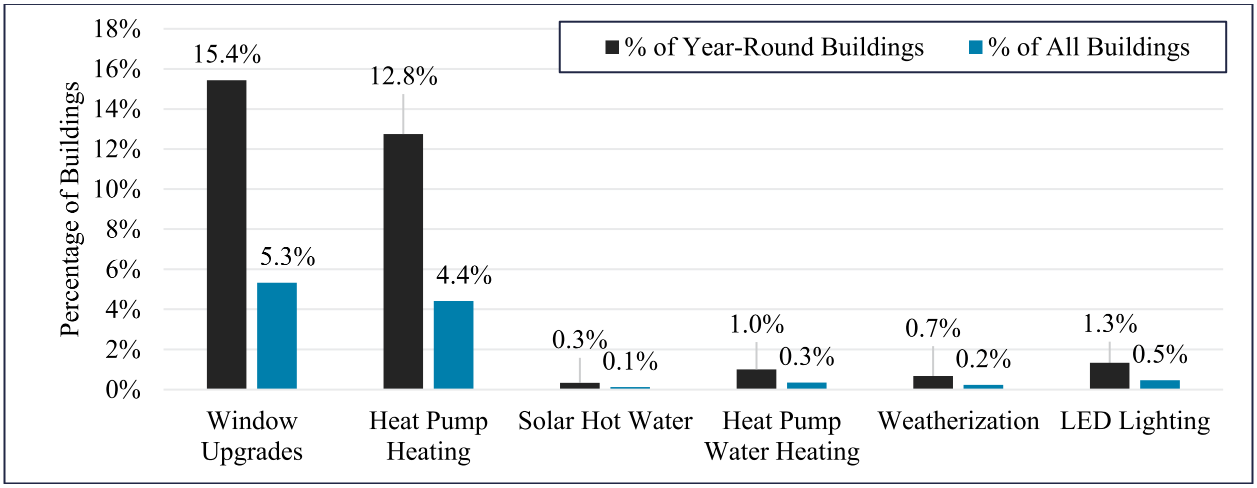

Figure 3-3: Survey of installed energy-conserving technologies on Islesboro.

3.3 Energy Use

Energy use on Islesboro was estimated through a combination of energy bills at the island level supplied by IEC and CMP, as well as an energy model developed by the labs team. The energy model was calibrated to represent the average annual energy use on the island based on data from 2017 to 2021 and was used to better understand how energy use is split between different building types and energy end uses at the building level. On average, buildings on Islesboro consume approximately 35,500 million British thermal units (MMBtu) per year. Figure 3-4 and Figure 3-5 show the split of energy consumption by end use, energy source, and building type.

Of the total annual energy consumption on Islesboro, it is estimated that 56% is from fuel oil use, 23% from electricity use, and the remainder is from kerosene, propane, and wood use. Approximately 64% of all energy is used for heating, followed by hot water and miscellaneous uses. The majority of the energy is estimated to be used in seasonal housing buildings; however, these buildings have a lower energy use intensity than year-round homes.

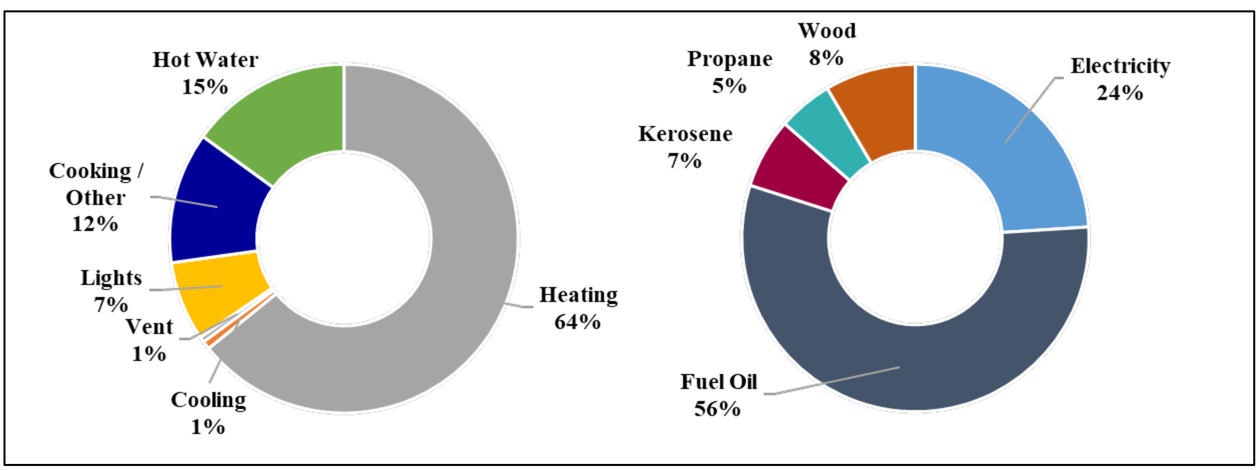

Figure 3-4: Islesboro energy consumption by end use and energy source.

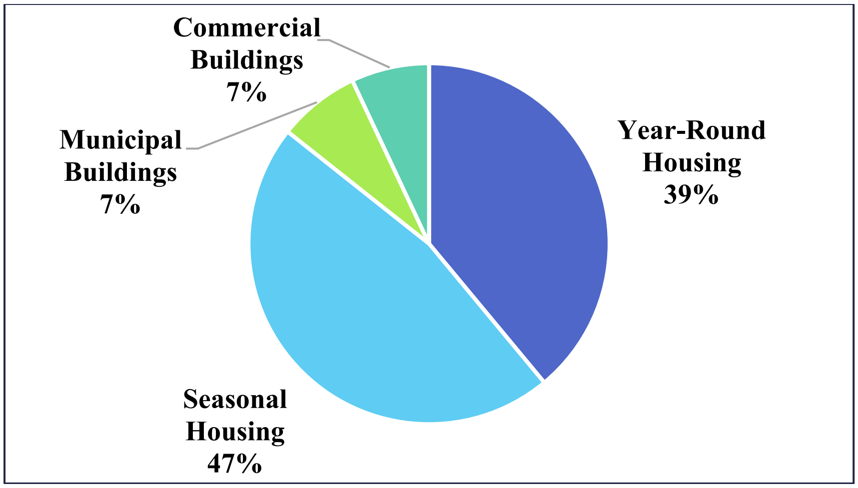

Figure 3-5: Islesboro energy consumption by building type.

3.4 Energy Costs

Islesboro's annual energy costs are approximately $3 million based on energy costs of $0.21/kWh of electricity, $3.4/gallon of fuel oil, $3.5/gallon of propane, $3.8/gallon of kerosene, and $268/ton of wood. Of these costs, approximately 43% is for the purchase of electricity, 51% for the purchase of fossil fuels, and 6% for the purchase of wood. According to IEC and Islesboro residents, energy costs have been increasing over time, both for electricity and heating fossil fuels such as fuel oil, kerosene, and propane.

3.5 Energy Greenhouse Gas Emissions

Building energy-related greenhouse gas (GHG) emissions on Islesboro have been steadily increasing over time along with the island's energy use, as shown in Figure 3-6. On average, GHG emissions by fuel type are 34% electricity, 53% fossil fuels (fuel oil, kerosene, and propane), and 13% wood.

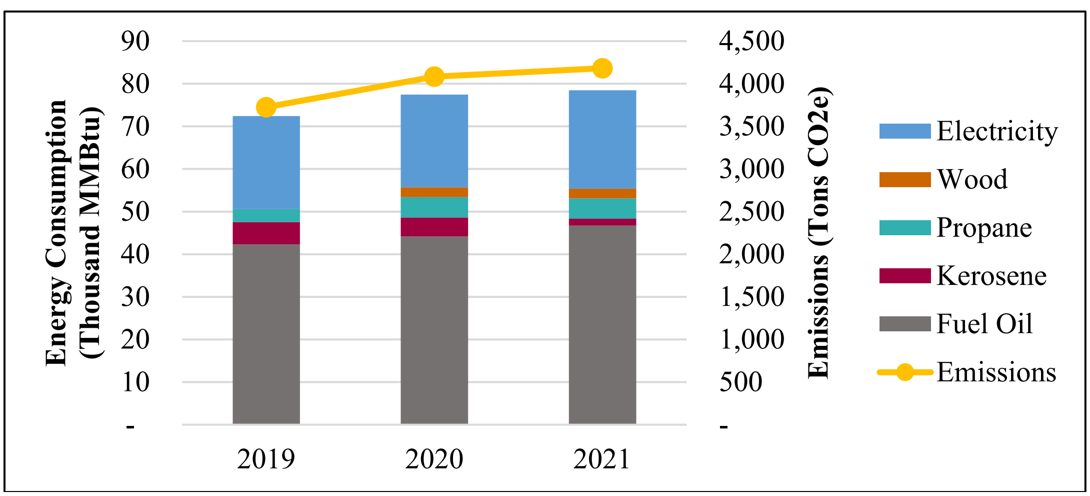

Figure 3-6: Islesboro historical energy consumption and emissions.

Figure 3-7 shows the estimated split of building energy-related emissions on Islesboro based on the energy model developed for island buildings. Building heating is responsible for the majority of the emissions, followed by cooking and other plug loads, hot water, and lighting. Ventilation and cooling do not contribute significantly to emissions.

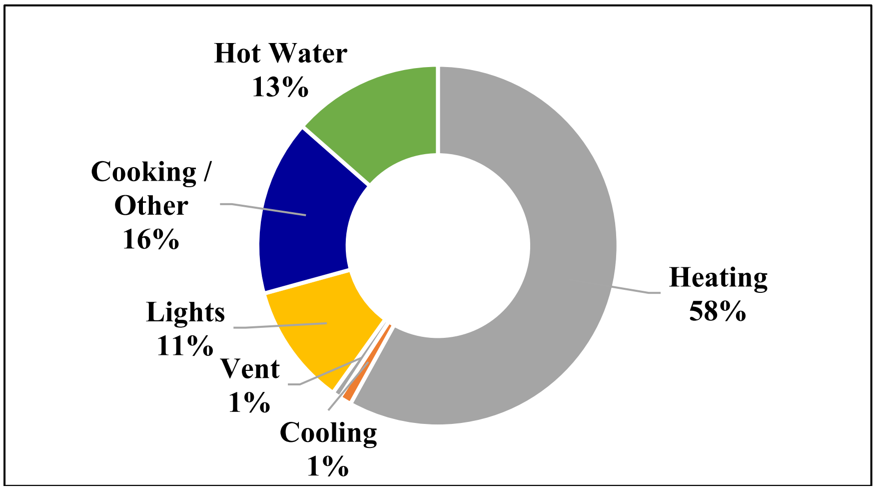

Figure 3-7: Islesboro building energy emissions split by end use.

4. Hazard and Resilience Risk Assessment

This risk assessment includes a review of natural hazards, technical hazards (historical power outages), and climate-change-related risks the island might experience in the coming years.

4.1 Natural Hazards

There are several natural hazards that could potentially affect Islesboro. Understanding the direct and indirect impacts of natural hazards is important when reviewing resilience at a location. Natural hazards can either directly affect infrastructure (such as high winds) or indirectly inhibit infrastructure function by preventing utility maintenance personnel from performing repairs (such as floods or winter weather). Utility infrastructure and critical facilities on the island should be designed to withstand natural hazards prevalent to the area.

This hazard assessment uses the National Risk Index (NRI) as the main data source for evaluating current risk. The NRI is a dataset and tool created by the Federal Emergency Management Agency in 2020 that includes 18 natural hazards, leveraging data sources such as the National Weather Service, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, the U.S. Army Corps of Engineers, Smithsonian databases, the Arizona State University Spatial Hazard Events and Losses Database of the U.S. (SHELDUS), and the U.S. Department of Agriculture. The risk index is granular down to the county level.

According to the NRI report (FEMA 2023), winter weather is the most prevalent threat to Waldo County, Maine. Lightning, drought, coastal flooding, and ice storms are significant threats as well.[4] Four of these five hazards (as shown in Table 4-1) can cause significant damage to electricity infrastructure. It is important to consider not only the frequency with which the hazards impact the county, but also the financial impact they have in terms of destruction potential.

Table 4-1. Summary Table of the Most Prevalent Hazards for Waldo County, Maine (Source: NRI)

Hazard	Annualized Frequency (Events/Year)	Expected Annual Loss Score	Electric Infrastructure Susceptance to Damage
Winter Weather	7.7	$36,527	Moderate
Lightning	6.7	$100,216	Moderate
Drought	5.8	$914,446	Low
Coastal Flooding	4.4	$40,665	Moderate
Ice Storm	1.2	$340,600	High
Hail	0.8	$27,701	Moderate
Riverine Flooding	0.8	$166,989	Moderate
Strong Wind	0.7	$53,708	High

[4] NRI defines winter weather as storm events where the main types of precipitation are snow, sleet, or freezing rain. NRI distinguishes ice storms separately from winter weather. Ice storms are defined as a freezing rain event with significant ice accumulations of .25 inches or greater and are not subsets of the winter weather hazard.

4.2 Power Outages

Between March 2016 and March 2021, Islesboro experienced 42 power outages. The majority of these outages were caused by downed power lines and poles that were likely the result of heavy winds from winter storms and windstorms. Although most outages that affected Islesboro occurred on the island itself, nearly 40% of them were caused by an issue on the mainland. Most outages last less than 24 hours, although there have been infrequent outages that have lasted multiple days.

4.3 Climate Change Impacts on Energy Systems

According to the *Scientific Assessment of Climate Change and Its Effects in Maine* report by the Maine Climate Council, climate change is expected to affect not only Maine's climate, but also its hydrology, ocean temperature, sea level rise and storm surges, forests, agriculture, and its human and animal health (MCC STS 2020). The changes that might impact Islesboro's energy systems are described in this section.

4.3.1 Climate

Climate change studies conducted on Maine have shown that the state's annual temperature might increase by an additional 2 to 4°F and up to 10°F by 2050 beyond the 3.2°F it has increased since 1895. The *Maine Won't Wait Climate Action Plan* indicates that the Gulf of Maine is one of the fastest-warming water bodies on Earth (MCC 2020). These temperature increases have been associated with longer summers and shorter and warmer winters across the state. The *Fourth National Climate Assessment for the U.S.* by the U.S. Global Change Research Program (USGCRP) found that heat waves and cold waves are becoming more common across the northeastern United States and elsewhere in the world (USGCRP 2018). These temperature changes, as well as changes in season duration, are likely to affect the way Islesboro uses energy for building heating and cooling.

4.3.2 Storms

The Maine Climate Council report found an increase in cold season storm frequency and intensity in the Northern Hemisphere beginning in the 1950s. Although it is unclear how storms affecting the northeastern United States will continue to change in the future, it is likely that extreme precipitation events, coastal storms, and nor'easters will increase in frequency and intensity in the region. Ice storms and severe windstorms are also expected to become more frequent and intense under warming climate conditions and could increase the incidence of prolonged power outages in places like Islesboro. The impact and significance of power outages for Islesboro residents will likely increase as the island seeks to reduce its reliance on fossil fuels.

4.3.3 Sea Level Rise

Sea level rise is an escalating consequence of climate change on Islesboro. As an islanded community, Islesboro is particularly susceptible to the impact of sea level rise. The Town of Islesboro engaged a consultant in 2017 to conduct a study on the potential effects of sea level rise on road infrastructure at two critical locations on the island: Grindle Point and the Narrows. Grindle Point is where the ferry to the mainland docks, so all travel to the island passes through there. The Narrows is the region that connects southern Islesboro to its northern counterpart. If either of these areas were to become submerged, it would be necessary to create a new ferry site, roads, bridges, and power infrastructure. The study states that it is possible that Grindle Point will become its own island and that the Narrows will be fully submerged, separating northern and southern Islesboro into two islands. This would result in the north island being cut off from the emergency services offered in the town center and is an important consideration when evaluating energy resilience options and access on Islesboro.

5. Opportunity Assessment

Opportunities to implement the following broad strategies were evaluated to achieve Islesboro's goals outlined in Section 2 and mitigate the risks described in Section 1.

1. Reduce Energy Load through Energy Efficiency – Actions that increase the efficiency with which energy resources are used.
2. Electrify Buildings – Actions that reduce or eliminate the use of fossil fuels for providing space heating, hot water, and cooking energy.
3. Increase On-Site Energy Generation – Actions that increase the amount of electricity that is generated locally on Islesboro, enabling longer-term sustainment of facilities and reducing the risk of disruption.
4. Improve Infrastructure Conditions to Enhance Resilience – Actions that improve Islesboro's resilience through improvements to energy infrastructure.

This section describes the opportunities evaluated, their potential costs and benefits, and general information on next steps for implementation. The steps are divided into short-, medium-, and long-term actions that the Islesboro community can take to implement these strategies.

5.1 Reduce Energy Load through Energy Efficiency

The potential for implementing energy efficiency measures (EEMs) in Islesboro's buildings was evaluated as a key opportunity to reduce not only the island's energy consumption, but also emissions and energy costs. The measures selected for evaluation included lighting system and control upgrades (e.g., upgrading incandescent and fluorescent lighting to LED), envelope upgrades (e.g., weatherization, adding insulation, and upgrading windows), and heating and hot water system efficiency upgrades (e.g., replacing existing boilers and furnaces with newer, more efficient equipment), among others. The energy savings and costs for each measure were determined using energy simulation and standard industry calculations. For a full description of each measure and the process of evaluating them, see Section E.1 in Appendix E.

5.1.1 Additional Benefits of Energy Efficiency

One of the main benefits of energy efficiency projects is that reducing energy use translates to energy cost savings that allow residents and businesses to have reduced electric and fuel bills as well as lower energy emissions. However, the projects have other non-energy benefits that are essential to achieving Islesboro's vision of a fossil-fuel free and resilient energy system on the island. For example, energy efficiency projects that improve the performance of a home's envelope can help reduce the heating load in the winter by reducing the amount of heat that is lost to the environment. This can make the home more comfortable for residents and require a smaller heating source, enabling an easier and less-costly conversion to electric heating systems. Converting systems that currently use fuel oil or propane to electricity simplifies the energy systems on the island and enables carbon reduction and resilience solutions.

In addition, a lower overall energy load resulting from the implementation of energy efficiency projects better position the island for implementing certain resilience solutions. Resilience projects, such as local grid-tied energy generation and storage, can often be costly. However, reducing energy use before implementation will allow the solution to be sized smaller and therefore cost less. Energy efficiency projects can also enhance resilience by offsetting some of the added load from the electrification of heating systems and transportation, easing the pressure on grid infrastructure.

5.1.2 Estimated Costs and Savings for Energy Efficiency

The measures were evaluated separately for the three different building types—year-round housing, seasonal housing, and commercial and municipal buildings—because each of these buildings has different operating characteristics that can make certain measures more or less attractive. For example, seasonal housing is used minimally in the winter, so measures related to heating savings are not as cost-effective for those types of buildings. A cost-benefit analysis using simple payback years as a metric was conducted to assess the cost-effectiveness of each measure.

Figure 5-1 shows the distribution of the rough order of magnitude energy cost savings and implementation costs for all measures if they were to be implemented on all buildings on Islesboro, where the size of the bubble represents the amount of energy savings for each measure. Measures like window upgrades and higher-efficiency heating system upgrades have higher energy and cost savings, but also higher implementation costs. Other measures like weatherization or high-efficiency plumbing have smaller savings but require a lower investment.

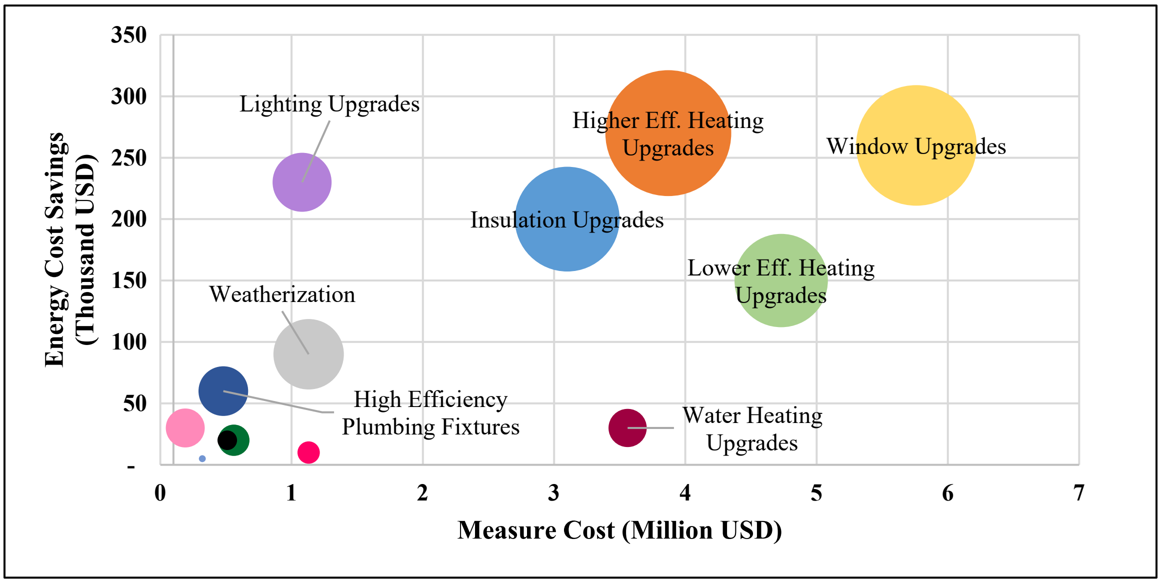

Figure 5-1: Distribution of energy efficiency measure cost savings and implementation costs.

Table 5-1 shows the range of estimated annual energy cost savings, full investment, incentives, and simple payback in years for each of the EEMs if implemented for all buildings on Islesboro. If these EEMs are implemented as part of expected or required equipment replacements, the total investment required is estimated to be 40 to 45% lower. Measures are identified as cost-effective if they take fewer years to pay back than the typical lifetime of that measure. Some measures are close to being cost-effective without utility or state incentives (or rebates) but are most cost-effective when implemented as part of planned upgrades. For measures that have available incentives, a simple payback both with and without the incentive was calculated. The annual energy cost savings that can result from these measures are estimated to be $1.1-$1.2 million USD (the annual energy expenditure on Islesboro is estimated at $3 million USD).

Table 5-1: Energy Cost Savings and Capital Investment for EEMs – All Buildings

Measure	Annual Energy Cost Savings ($)	Full Capital Investment ($)	Estimated Incentives ($)	Simple Payback without Incentives (Years)	Simple Payback with Incentives (Years)	Cost-effective?
Lighting Fixture Upgrades	230K	1M	220K	4	3	Yes
Lighting Control Upgrades	5K	220K	-	44	-	No
Insulation Upgrades	200K	3M	1.2M	15	9	Yes
Window Upgrades	260K	5.7M	-	22	-	Yes, when part of planned upgrades
Weatherization	90K	1M	210K	11	9	Yes, with incentives
Programmable Thermostats	20K	460K	-	23	-	Yes for some buildings (a)
Temperature Setbacks	30K	90K	-	3	-	Yes
Heating Equipment Upgrades (Lower and Higher Efficiency) (b)	150–270K	3.8–4.6M	-	14–31	-	Yes in most cases
Water Heating Equipment Upgrades	30K	3.5M	-	115	-	No
Pipe Insulation	10K	1M	-	103	-	No
High-Efficiency Plumbing Fixtures	60K	380K	-	6	-	Yes
Upgrade Cooling Equipment	20K	410K	-	21	-	No
Total	1.1–1.2M	20.5–21.5M	1.6M	17–19	14–17	-

(a) Year-round homes are especially likely to benefit from the use of programmable thermostats
(b) Higher-efficiency heating equipment upgrades result in higher energy savings and pay back faster than low efficiency heating equipment.

The cost-effectiveness and benefits of implementation vary depending on the specific building type. For example, the measures shown as cost-effective in Table 5-1 will all typically be cost-effective for year-round homes. In the case of seasonal homes, only lighting and insulation upgrades were found to be cost-effective. Table 5-2 shows the average cost savings, investment, and available incentives for each home type when implementing cost-effective measures.

Table 5-2: Estimated Savings and Costs for Cost-Effective EEMs by Home Type

Building Type	Annual Energy Cost Savings ($)	Full Capital Investment ($)	Estimated Incentives ($)	Simple Payback without Incentives (Years)	Simple Payback with Incentives (Years)
Year-round Homes	1.4K	14K	1.5K	10	9
Seasonal Homes	300	5K	1.7K	16	10

5.1.3 Recommended Actions for Load Reduction Implementation

Table 5-3 shows recommended next steps for implementing EEMs in the short (within a year) and medium (within 3–5 years) terms. Potential funding avenues for energy efficiency projects on Islesboro can include private capital supplemented by incentives from Efficiency Maine and other state programs, or grants from local institutions such as the Island Institute. Measures like weatherization are completely covered by incentives for low-income Mainers.

Table 5-3: Next Steps for Implementing Load Reduction Opportunities

Step	Responsible Party	Description	Time Horizon
Promote Energy Efficiency Locally	IEC	Begin promoting and socializing the benefits of adopting EEMs to island residents.	Short
Connect with Neighboring Communities	IEC	Research and connect with neighboring island communities in Maine making efforts toward energy transformation and decarbonization. For example, the organization *A Climate To Thrive on Mount Desert Island* has implemented programs around building retrofits and solar energy that may be a useful model for Islesboro.[5]	Short
Identify Applicable Incentives and Application Processes	IEC with Island Institute Support	Investigate in more detail available incentives and the application process for each. A conversation with Efficiency Maine as an incentive provider may also be useful to learn whether the incentive process can be streamlined for a larger number of applications.	Short
Identify Contractor(s) for EEM Implementation	IEC with Island Institute Support	Hold discussions with local contractors that may be able to implement EEM projects on Islesboro to better understand costs and available programs. Consider discussing options for deploying an EEM at scale on the island (e.g., lighting retrofits in both year-round and seasonal homes).	Short
Implement EEMs	Residents	Begin implementing selected EEMs where possible.	Medium
Track Progress	IEC	Track the implementation of EEMs through periodic surveys and review of utility bills.	Medium

[5] A Climate to Thrive

5.2 Electrify Buildings

As shown in Figure 3-7, building heating, hot water production, and cooking are responsible for the majority of building energy-related emissions on Islesboro. This is largely due to the widespread use of fossil fuels in providing these end uses; in fact, electricity only accounts for an estimated 8% and 20% of heating and hot water emissions, respectively. As the electric grid continues to decarbonize, the proportional contribution of fossil-fuel-based heating to Islesboro's emissions will continue to increase, reaching nearly 75% if electricity is completely decarbonized. Some buildings on Islesboro use wood for heating, but this only accounts for 23% of all heating. For purposes of this analysis, the IEC requested that wood not be considered as an emissions source.

Building heating, hot water, and cooking electrification was considered an opportunity to advance Islesboro's vision of 100% fossil-fuel-free energy systems on the island. Note that there are other ways to reduce emissions from these types of systems, such as switching to alternative fuels like biogas, but these were not considered in this analysis.

When combined with certain EEMs, such as home weatherization and envelope improvements (insulation and window upgrades, for example), electrification of building systems can help reduce heating energy costs and emissions while improving comfort and indoor environmental quality. The conversion to an electric cookstove can also help improve the indoor air quality of a space by minimizing the by-products of combusting propane.

5.2.1 Estimated Costs and Savings for Building Electrification

There are two primary types of electric heating and hot water systems: resistance-based systems, which are 100% efficient and work by converting electricity to heat (i.e. baseboard electric heater),[6] and heat pump systems, which use electricity and the refrigeration cycle to move heat from one space to another with more than 100% efficiency.[7] Heat pumps are categorized in terms of their heat source: air, water, or ground (also referred to as geothermal). Both resistance-based and heat pump heating systems can be obtained in a variety of forms such as wall units, furnaces, etc. Similarly, electric water heaters can also be resistance- or heat-pump-based and can include systems with or without tanks. The best system type and configuration will vary by building.

Table 5-4 shows the range of estimated annual energy and cost savings, full investment, incentives, and simple payback in years for each of the system conversion options if implemented at all buildings on Islesboro. Note that for resistance-based options, costs increase due to lower system efficiencies and the cost of electricity.

[6] Electric Resistance Heating

[7] Heat Pump Systems

Table 5-4: Energy Cost Savings and Capital Investment for Heating, Hot Water, and Cooking Conversions

Electrification Option	Annual Energy Cost Savings ($)	Total Energy Savings (%)	Full Capital Investment ($)	Estimated Incentives ($)	Simple Payback without Incentives (Years)	Simple Payback with Incentives (Years)
Convert Heating to Heat Pump Systems	360K	35%	6.2M	1M	17	15
Convert Heating to Resistance-based Systems	980K Increase	11%	4.8M	-	No payback	-
Convert Water Heating to Resistance-based Systems	300K Increase	3%	5.1M	2.5M	No payback	-
Convert Cooking Systems to Electricity	60K Increase	-	1.6M	-	No payback	-

These measures are not mutually exclusive; it is possible that some buildings can use resistance-based heating while others can use heat pump heating systems. Heat pump domestic water heaters are also an alternative to resistance-based water heaters but were not included in this analysis.

5.2.2 Recommended Next Steps for Building Electrification

Table 5-5 shows recommended next steps for implementing electrification strategies in the short (within a year) and medium (within 3–5 years) terms. Potential funding avenues for conversion of heating, hot water, and cooking systems on Islesboro can include private capital supplemented by incentives from Efficiency Maine and other state programs, or grants from local institutions such as the Island Institute.

Table 5-5: Next Steps for Implementing Building Electrification Opportunities

Step	Responsible Party	Description	Time Horizon
Engage a Contractor to Evaluate Electrification Requirements	IEC	Engage a contractor to evaluate typical homes on Islesboro to obtain a better estimate of costs and actions that would be required to electrify heating and hot water systems. Islesboro could also request the contractor to provide recommendations for enabling homes to be ready for electrification, such as upgrading the electrical wiring, service, etc. Islesboro residents can use this information to evaluate electrification in their own homes and prepare for potentially installing an electric system during an emergency replacement or a planned upgrade.	Short

Step	Responsible Party	Description	Time Horizon
Identify Contractors for Building Electrification	IEC	As for EEMs, hold discussions with local contractors that may be able to assist in building electrification. Examples of contractors that may be needed include electricians and heating, ventilation, and air conditioning (HVAC) and plumbing specialists. Create a list of potential contractors and make it available to island residents to support their preparation for electrification.	Short
Review Local Ordinances	IEC / Town	Review local ordinances or applicable building codes to identify and address barriers (if any) to the installation of electric systems on Islesboro.	Medium
Make a Plan	Residents	Encourage Islesboro residents to make a plan for existing equipment replacement. If interested in electrifying, what preparations does each home need to make?	Medium
Track Progress	IEC	Track the progress through periodic surveys and review of utility bills.	Medium

5.3 Increase On-Site Renewable Energy Generation

Approximately 6% of Islesboro's total electricity need is supplied by local solar PV systems, which leaves significant remaining potential to install additional renewable energy systems on the island. The renewable energy options for Islesboro were investigated as part of this analysis to assess the total potential, space needs, and cost where applicable for each type of technology.

5.3.1 Challenges Addressed

Installing additional renewable energy capacity on Islesboro can have two key benefits: first, it can offset part or potentially all of the electricity consumption for a given building, reducing energy costs and carbon emissions in the process. It can also enhance resilience for buildings on Islesboro by providing a local source of power that, when paired with energy storage, can serve as an alternative when the grid is not available.

5.3.2 Renewable Energy Potential Capacity

To offset all of its current local electricity demand, Islesboro needs to generate nearly 6,200 MWh of additional electricity through on-site resources. Three types of renewable energy technologies were assessed to determine whether they can fill this gap: solar PV, wind energy, and tidal energy. Of these three technologies, solar PV was deemed to be the most applicable given the potential availability, cost, and acceptance by the community. For more information on the assumptions, inputs, and results of the analysis for all technologies, see Section E.2 in Appendix E.

To generate as much electricity as it currently consumes annually, Islesboro would need to install an additional 4.7 megawatts direct current (MW-DC) of solar PV capacity. Two types of PV options were evaluated for this purpose –rooftop and ground-mounted PV. Satellite imagery and information collected during the site visit in May 2022 were used to estimate the available rooftop and open ground area that could be used to install PV. Table 5-6 shows the estimated available area, total potential capacity for each type of PV, and estimated cost.

Table 5-6: Estimated Potential Capacity for Solar PV on Islesboro

PV Type	Total Available Area	Total Potential Capacity (MW-DC)
Rooftop PV	Approximately 250,000 square feet of available rooftop area for solar PV across all buildings on Islesboro.	3.6
Ground PV	Approximately 300,000 square feet (7 acres) of available open ground area that can be used for PV. Note that this is a conservative estimate based on a few selected sites, and there is more than this amount of open space on Islesboro.	4.6

Islesboro has more than enough available area to install sufficient PV to offset its annual electricity consumption. The Maine legislature passed legislation in 2019 that creates new opportunities for solar and other small renewable energy projects across the state. These programs are available for both residential and non-residential customers. Residential utility customers may choose to install their own project or share in a project with others.

In a community or shared solar project, a renewable solar project is built, operated, and maintained by either a solar developer, utility, nonprofit entity, or multiple community members. Electricity is produced by the solar system and delivered to the grid. The community solar project owner/operator seeks customers of the local utility (CMP in the case of Islesboro) to buy or lease a portion of the community solar project. Those enrolled in the project receive kilowatt-hour (kWh) credits for their portion of the project, and these credits are subtracted from their total electric consumption on their utility bill, reducing the total payment to the utility. Because of this metering arrangement and credit system, the PV array can either be installed in the physical vicinity of where its customers are, or elsewhere in the utility's territory. This type of approach is a viable option for residents that cannot install solar projects on their own property. When considering signing up for a community solar project, residents should check the Maine Public Utilities Commission website to ensure the solar developer is legitimate and registered before considering investment in the project.[8]

Residents can also have their own solar energy project by installing solar PV systems at their residence or on their property. Homeowners should seek to lower their energy consumption as much as possible before assessing the solar potential of their site to reduce the size of the system that would be needed. Once the solar potential is assessed, there are multiple options to consider when purchasing and installing a solar project at a residential site.

- The first option involves residents purchasing a solar system to be installed at their site. In this option, a third party typically installs the system, and the resident owns, operates, and maintains their own solar energy system. A loan may be utilized for this option.
- Residents can also lease a solar energy system to be installed at their site. In this option, a third party installs, owns, operates, and maintains a solar system installed at a resident's site. There are numerous leasing arrangements and metering options to consider when leasing a solar system.

[8] Maine Public Utilities Commission

- A third option is a power purchase agreement. Under this agreement, a third party installs, owns, operates, and maintains a solar system installed at a resident's site. The resident purchases the electricity generated by the on-site solar system directly from the system owner at a set rate per kWh, typically competitive with the utility electric rate.
- For all options described above, if the system is to be tied to the grid, the resident and installer must work with the utility on permits, interconnections, and a metering arrangement.

5.3.3 Next Steps

Table 5-3 shows recommended next steps for implementing EEMs in the short (within a year) and medium (within 3–5 years) terms. Solar energy systems can be a large financial investment. Residents and businesses on Islesboro should explore financing options and incentive offers in collaboration with the appropriate contractors. The Database of State Incentives for Renewables and Efficiency is also a good resource for investigating renewable energy incentives.[9]

Table 5-7: Next Steps for Implementing Renewable Energy Opportunities

Step	Responsible Party	Description	Time Horizon
Engage and Educate Community Stakeholders on Renewable Energy	IEC / Town	Continue engaging with and educating local stakeholders on the benefits and pathways for installing renewable energy projects on Islesboro.	Short
Connect with Neighboring Communities to Learn Best Practices	IEC	Research and connect with neighboring island communities in Maine making efforts toward energy transformation and decarbonization. For example, the organization A Climate To Thrive on Mount Desert Island has implemented programs around building retrofits and solar energy that may be a useful model for Islesboro.[10]	Short
Investigate the Possibility of Community Solar Projects	IEC / Town	Islesboro residents can further investigate the possibility of community solar on the island. This process can involve activities such as identifying viable locations for a large-scale solar project, conducting outreach, and obtaining consensus from residents on project options, investigating, and engaging with potential vendors, and others.	Medium

5.4 Improve Infrastructure Conditions to Enhance Resilience

5.4.1 Challenges Addressed

Table 5-8 provides an overview of the challenges and infrastructure vulnerabilities affecting Islesboro's resilience.

[9] DSIRE Database
[10] A Climate to Thrive

Table 5-8: Electricity System Vulnerabilities

Vulnerability	Islesboro
Critical facilities lack adequate backup power	12 of 18
Existing generators lack sufficient on-site fuel supply	All
Single point of failure from transmission system (single transmission line or distribution substation)	Yes
Lack of automation in switching capabilities results in reliance on third party to transfer loads during an outage	Yes
Electrical panel layout inhibits capability to strategically shed noncritical loads	Yes
Generator maintenance protocols omit key requirements (fuel sampling, flushing of cooling system, battery replacement)	Unknown
Lack of emergency refueling plan for generators	Unknown

5.4.2 Measures to Improve Power Supply Resilience

There are several potential measures that could improve the resilience of Islesboro's power supply. Not all options are feasible for every location on the island but priority should be focused on systems and infrastructure that directly supports critical facilities to reduce the likelihood of utility disruption to those facilities. Some potential measures include the following.

<u>Supply Side – Ensuring a dependable supply of energy to meet critical needs</u>

- Install permanent backup generation at critical facilities.
  - Critical buildings should be considered for a permanent backup generator. Currently, only 6 of 18 critical buildings identified in Section 3.1 have dedicated backup generators installed.
  - Utilize mobile backup generators to augment permanently installed backup generators at critical facilities. As an alternative to permanently installed backup generation, trained volunteers can connect mobile generators to critical facilities during a utility disruption. This option provides flexibility in where backup generation is placed. This solution entails procuring mobile generators and associated fuel storage, installing generator quick-connect panels on critical facilities for easy connection of mobile generators, and training volunteers on mobile generator deployment and connection.
- Access Option – Increasing access to energy through alternative routes or fuels
- Engage with the utility to identify opportunities to enhance the existing layout by adding loops in the distribution network to create a more resilient and robust electric infrastructure.
  - Current Situation: Islesboro is currently fed from a single submarine feed connecting the Lincolnville substation on the mainland to the center of the island near the ferry terminal. The island operates on a single three-phase circuit spine that spans the length of the island from north to south and distributes electricity in a radial layout. There are no substations on the island. The current scenario has a single point of failure from the single transmission feed to the radial distribution system. If a piece of equipment fails on the distribution system (e.g., a tree falls on a distribution line), usually all loads connected to that radial distribution line will lose electricity service because there are no alternate paths for electricity to flow.
  - Proposed Solution: The distribution system's resilience could be enhanced by adding loops to the current radial layout where feasible to provide an extra layer of reliability. The loop itself does not

reduce the chances of mishaps or faults occurring; instead, it could minimize the number of affected customers. Under normal conditions, the loop is fed from both of its ends in opposing directions. At some point along the loop, a "normal open" switch isolates one leg of the loop from the other. Should a fault occur, the faulted section can be isolated from the rest of the loop by opening the nearest upstream and downstream switches, thus isolating the fault and reducing the extent of the outage. Consider including automation in switching capabilities to alleviate reliance on a third party to transfer loads during an outage.

- Explore the option of placing a generating asset at the end of the radial circuit similar to the Eastport scenario.
- Explore dual-fueled equipment when replacing equipment at the end of its life to allow fuel switching between diesel and other fuels readily stored on the island (e.g., propane). This capability diversifies and expands potential fuel choices for this equipment.

<u>Proactive Utility Engagement</u>

- Develop robust emergency operating and outage recovery plans with the utility and emergency response teams. Update the recovery plans at least once annually with all parties involved to ensure all information is up to date. Recovery plans should include sustained generator refueling plans for the duration of the outage.
- Exercise recovery plans and procedures with variable outage scenarios at least once annually to ensure utilities and emergency response teams are prepared for potential utility outages.
- Hold periodic meetings with utilities to develop clear lines of communication and explore resilience options.
- Engage with utility on electrical distribution and transmission maintenance.
  - Vegetation management – Engage with CMP to build a robust vegetation management schedule for trimming all circuits on the island. It is recommended to trim the circuit a minimum of every 48 months.
  - Circuit inspection – Verify that CMP periodically inspects distribution circuits to identify potential weaknesses and has pole maintenance programs and underground/submarine cable remediation programs to address aging infrastructure as needed.
  - System review and planned system improvements – Verify that CMP (1) assesses all circuits to identify circuits missing reliability thresholds, (2) reviews all whole-circuit outages to determine the cause and look for repetitive outages, and (3) maintains a root cause analysis program for further investigating circuit outages.

<u>Measures Evaluated but Not Recommended</u>

- Underground Distribution System – While a majority of the outages were caused by downed power lines and poles, it is not recommended to convert the overhead distribution system to an underground system in an effort to add resilience to the system. This is an expensive conversion project that the utility would need to approve and fund. Additionally, operations, maintenance, and repairs of underground systems can be time consuming and inconvenient compared to overhead facilities, especially if mishaps occur during a contingency situation. For example, an underground line that has faulted must be located underground, which can require special equipment and crews from the mainland. After the fault has been located, it must be repaired by either pulling in a new conductor or by removing the damaged section of the conductor and splicing in a new conductor section, a process that can take hours to days to complete.

5.4.3 Next Steps

Islesboro should take a look at the various measures and actions identified in this section to determine which ones they should explore and implement. Funding, time, stakeholder interest, and feasibility will determine the viability of which measures and actions can take place on the island. No funds are needed to proactively engage and plan with the utility if employees of Islesboro and the Energy Committee are utilized. However, funds from Islesboro's operating budget or other sources would be needed to procure backup generators for critical buildings.

6. Techno Economic Analysis of Alternative Power Systems

The Islesboro community stakeholders requested a techno economic analysis of power systems that could serve as alternatives to the utility in different load scenarios. The tool used to perform the techno economic analysis is HOMER (Hybrid Optimization Model for Electric Renewables), developed by NREL and currently commercialized by UL. HOMER was originally developed to optimize the design of renewables-based distributed energy systems. It has since been updated to also consider hybrid systems, for example consisting of solar, battery and diesel systems that can work both in grid-tied and islanded modes. HOMER finds the least cost combination of components that meet electrical and thermal loads specified by the user. HOMER simulates a large number of system configurations, optimizes for lifecycle cost, and produces a list of possible system options ranked by cost. The analysis intends to provide an assessment of feasible alternatives that can advance Islesboro's goals and are provided at a conceptual design level of detail that can then be utilized by the community to move forward with RFIs and /or RFPs.

6.1 Load Cases

Three load cases were developed for use in the HOMER alternatives analysis: (1) baseline, (2) all-electric, and (3) all-electric with EEMs. The baseline scenario reflects the island's total electric load today as estimated using the energy model described in Appendix D, which was calibrated to historical electricity demand and consumption data. The all-electric scenario reflects fuel switching of space and water heating (widespread adoption of heat pump technology), cooking, and transportation (EVs). The all-electric with EEMs scenario reflects a combination of investment in energy efficiency as well as electrification of space and water heating and cooking. See Appendix F for more information on the island-wide load cases. The electric loads for the three scenarios are shown graphically in Figure 6-1, Figure 6-2, and Figure 6-3 in terms of average daily profile, seasonal profile, and yearly heat map of hourly load vs. day of year. The heat map plots reflect the seasonal profile resulting from part-time residents in the summer. Also evident in the heat maps is the effect of the electrification of heating loads, visible in the cold season in the early part of the year. It should also be noted that efficiency measures cut peak loads in the all-electric scenario by a factor of approximately two, compared to the scenario with electrification but no EEMs. The all-electric scenario with efficiency measures is only slightly higher than the baseline.

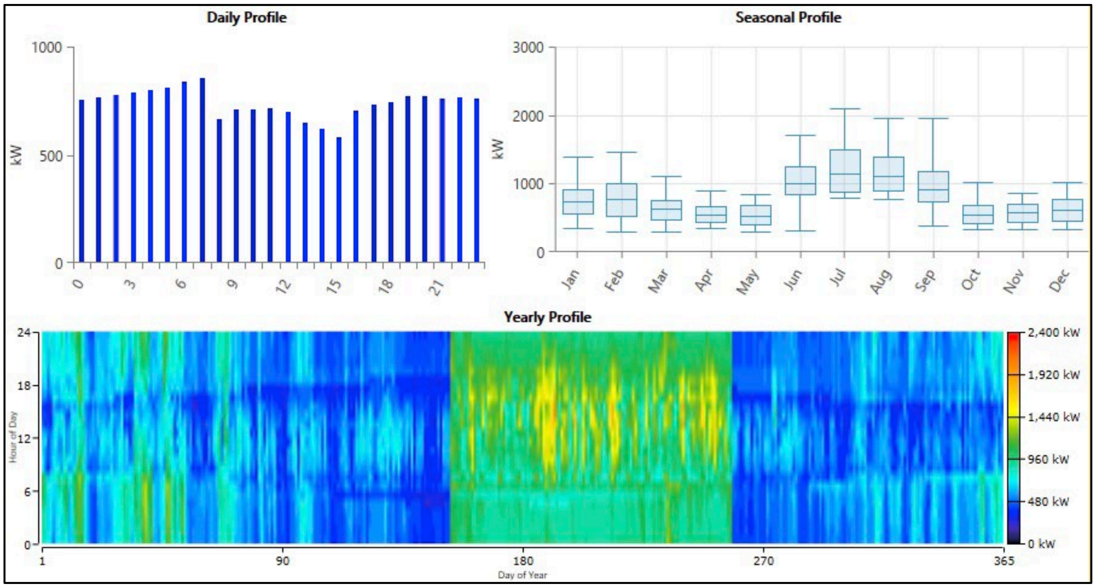

Figure 6-1: Island-wide Load Scenario 1: Baseline.

The electric loads shown graphically in Figure 6-1 include a yearly heat map of hourly load vs. day of year. The vertical axis of the graph shows the 24 hours in the day with noon in the middle, the horizontal axis shows all the days in one full year starting on January 1. The legend describes in color the load level in kW. As can be seen in this heat map the peak load values are in yellow and red that occur during the summer and peak in the late afternoon.

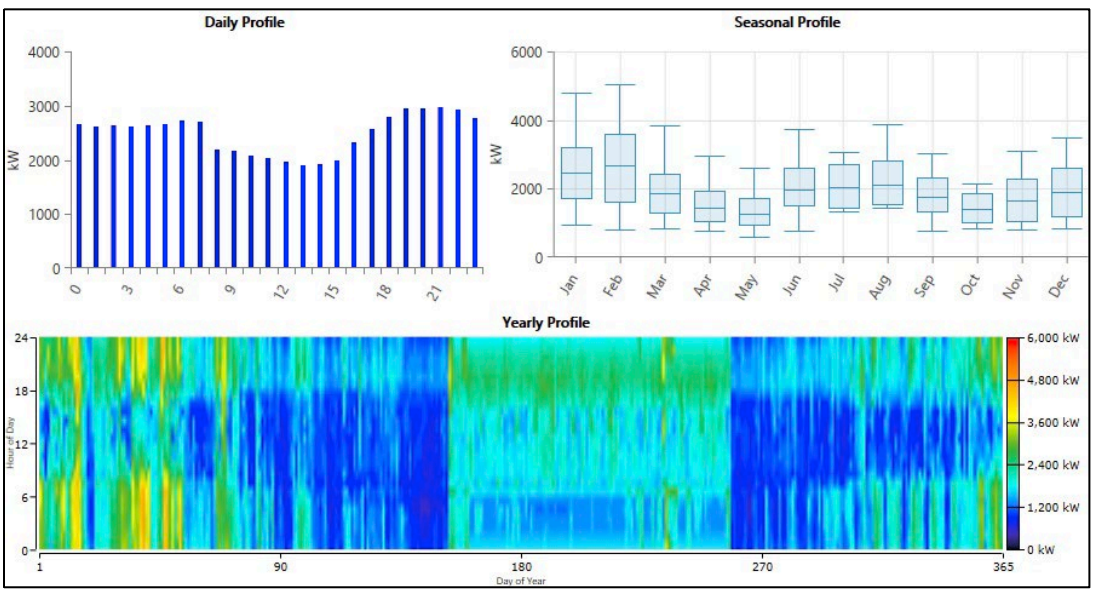

Figure 6-2: Island-wide Load Scenario 2: All-electric.

The electric loads shown graphically in Figure 6-2 include a yearly heat map of hourly load vs. day of year. The vertical axis of the graph shows the 24 hours in the day with noon in the middle, the horizontal axis shows all the hours in one full year starting on January 1. The legend describes in color the load level in kW. As can be seen in this heat map the peak load values are in yellow and red and they have shifted from the summer months to the winter months and peak during the evening hours.

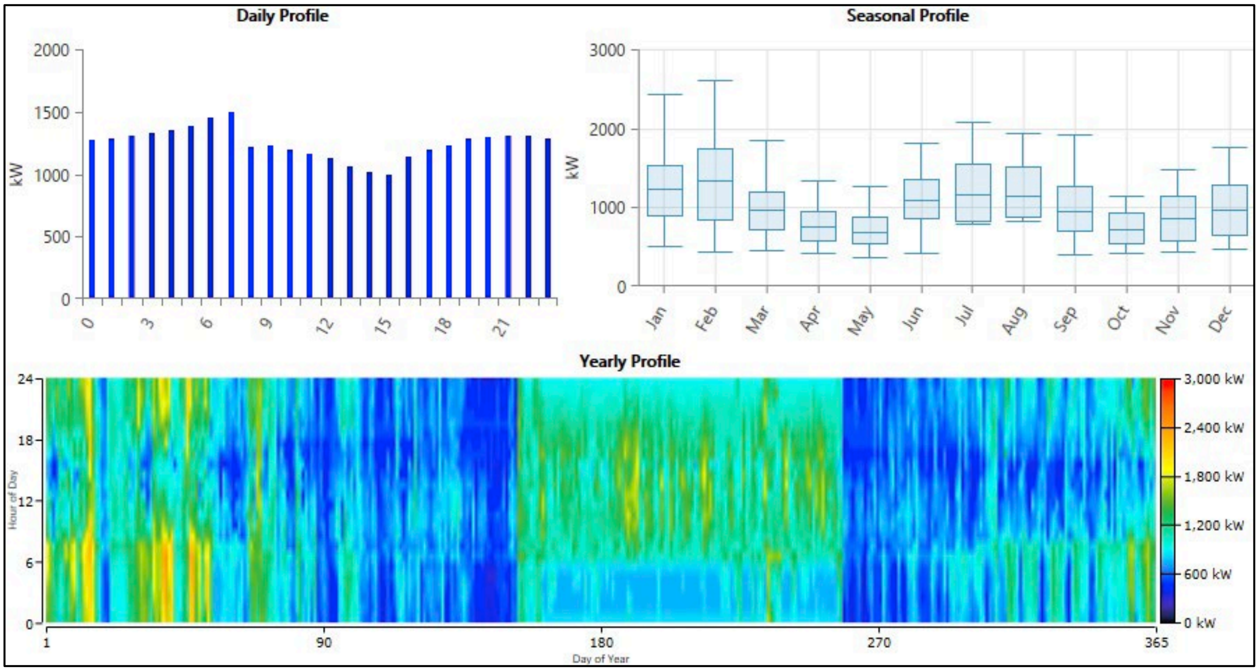

Figure 6-3: Island-wide Load Scenario 2: Electrification and EEMs.

The electric loads shown graphically in Figure 6-3 include a yearly heat map of hourly load vs. day of year. The vertical axis of the graph shows the 24 hours in the day with non in the middle, the horizontal axis shows all the hours in one full year starting on January 1. The legend describes in color the load level in kW. As can be seen in this heat map the peak load values are in yellow and red and they occur now both in the summer and peak in the late afternoon and during the winter months and peak during the evening hours.

6.2 Method

The method developed for this project starts with the three load cases described earlier and develops both scenarios for island-wide power system solutions and detailed solutions focused on three discrete island locations. The total number of scenarios explored includes nine cases for island-wide solutions and six cases focused on the discrete locations of the town center, school, and northern shelter.

The method we utilized was based on the following assumptions for running the HOMER analysis, as detailed in Table 6-1 below. Grid-connected systems were modeled with the goal to make them 100% self-sufficient with a small annual grid export and to achieve maximum emissions reduction. The resilient microgrid systems provided year-round power like the grid-connected systems, but also provided power during the five-consecutive-day outage each year; they were modeled using PV and either batteries or a diesel genset.

Table 6-1: Assumptions for HOMER Analysis

Scenario Assumptions
6% discount rate, 3% inflation
25-year analysis period
CMP flat rate, $0.215/kWh purchase, $0.00 sell back
Net metering assumed with each discrete system capped at 2 MW: annual true-up of net energy consumption
Cost of PV $2,569/kW (NREL ATB for residential)
One outage event each year: 5 consecutive days/year loss of grid power
86% derating of PV system based on the NREL PVWatts® Calculator estimate for shade, electric losses, dirt, etc.
Inverter sized at 100% of peak PV size
Emissions are assumed zero if there is an annual net export of energy to the grid

Although the discount and inflation rates can change dramatically depending on the financial status of the end user, we assumed 6% and 3%, respectively, as typical long-term values. These values are primarily intended to show how the time-dependent value of money influences decisions on which solution is chosen. We used a 25-year period to calculate net present cost as representative of the typical investment time horizon, and also because it is the typical lifespan of a PV panel. For the electricity costs, we used the flat rate provided to us by the IEC with no demand charges, typical of a local residential service tariff. Net metering is allowed by CMP, which allows a customer 1 year to recover an energy credit accrued at the end of a billing period. To approximate this billing arrangement, we assumed HOMER's net metering option with yearly true-up. This analysis used NREL's Annual Technology Baseline to estimate the cost to install a PV system at a residential scale of $2,569/kW. Although the cost for MW-sized island-wide systems is lower than for residential-scale systems, we used the residential value to account for the fact that multiple smaller systems would likely be deployed on the island due to the maximum interconnection size of 2 MW. Moreover, the installation of a system on an island is likely more expensive than on the mainland, so our assumption is probably not overly conservative. The system was de-rated to 86% of full capacity to account for losses due to soiling, shading, material degradation, etc., following the guidance of NREL PVWatts Calculator documentation.

Based on information from the IEC, we assumed a yearly grid outage of five consecutive days per year, with random likelihood of occurrence uniformly distributed during the year. The inverter sizing was constrained to reflect 100% of the PV DC output. We based the emissions calculation on the balance between energy used by the load and energy produced by the PV/inverter combination. If net exports to the grid are indicated over the year, we assumed that the installed renewable generation offsets the entirety of the grid emissions associated with providing service to the load when PV power is not available. We note that this is an approximation that does not account for the variability of emissions from CMP, and that this is only valid while renewable generation remains a small portion of systemwide electricity generation. The emissions values we used as inputs are based on the projected emissions goal targets for the state of Maine. Finally, we accounted for existing PV generation by adjusting the load accordingly and by inserting a fixed-size PV generator on the system.

The final key element of the analysis methodology was to consider the net metering constraints in Maine and to model realistic solutions that comply with today's rules.

6.3 Results

The techno-economic analysis resulted in 15 key scenarios and 15 different designs that describe the resulting distributed energy resource system sizing and technology specification for each scenario. Each solution includes the system's net present cost, the levelized cost of energy, and the metric kWh not served that measuring the amount of load left unserved by the solution.

Table 6-2 is a summary of the optimization results for an island-wide power system that meets different criteria. These criteria are the ability of the local PV system to (1) offset all grid electricity consumption (i.e., with a net yearly export to the grid > 0) at the *least cost*, with a maximum tolerance of 5% shortfall in service, (2) provide a system with zero net emissions and with zero tolerance for loss of service (*resilient microgrid*), and (3) provide a system that offsets all grid electricity with PV and a backup diesel generator at least cost (*resilient microgrid with diesel*). The baseline load utilized a load modeled using the 2021 total electric load for the island and other historical data and augmented by the 322 kW (peak) of existing PV generation. The "load 1" option reflects fuel switching from fossil to electric, including transportation and heating. The "load 2" option reflects fuel switching, with efficiency measures included and a lower penetration of electric transportation, resulting in a load closer to the baseline than to the "load 1" option.

Table 6-2a: Summary of Key Scenario Results from HOMER System Optimization[11,12,13,14]

Scenario	Load Description	System size and technology	Year 1 Capital Cost	Load Unserved	NPC ($)	LCOE (cents/kWh)
Island-wide Baseline	Based on 2021 load data (Ref Figure 6-1)	CMP provides all power	N/A	1.05%	23.3 M	20.1
Island-wide Baseline: Least Cost RE Design		4.75 MW PV	14.4 M	0.77%	15.3 M	13.1
Island-wide Baseline: Resilient microgrid design		5.71MW PV, 20.1 MWh Li-ion	27.4 M	0.00%	38.2 M	32.6
Island-wide projected load 1: utility only	Load 1 based on electrification of	CMP provides all power	0.0 M	1.28%	61.3 M	20.9

[11] Period of analysis: 25 years
[12] Existing PV on island included in models
[13] For loads with existing PV, load increased to model pre-PV original load
[14] Detailed HOMER results for key cases in Appendix H

Scenario	Load Description	System size and technology	Year 1 Capital Cost	Load Unserved	NPC ($)	LCOE (cents/kWh)
Island-wide projected load 1: Least cost RE design	heating, transportation, and other energy services (Ref Figure 6-2)	12.2 MW PV	35 M	0.97%	39.0 M	13.6
Island-wide projected load 1: Resilient microgrid design		18.97MW PV, 57.9 MWh Li-ion	86.3 M	0.00%	118.1 M	40.1
Island-wide projected load 2: utility only	Load based on Load 1 but including energy efficiency measures (Ref Figure 6-3)	CMP provides all power	0.0 M	1.23%	30.7 M	20
Island-wide projected load 2: Least cost RE design		6.3 MW PV	18.0 M	0.90%	20.1 M	13.3
Island-wide projected load 2:Resilient microgrid design		8.8MW PV, 29.5 MWH Li-ion battery	41.5 M	0.00%	57.5 M	37.8
Island-wide projected load 2: Resilient microgrid design with Diesel		6.3 MW PV, 3.3 MW Diesel Gen.	19.7 M	0.00%	21.9 M	14.3

Table 6-2b: Summary of Localized Results

Scenario	Load Description	System size and technology	Year 1 Capital Cost	Load Unserved	NPC ($)	LCOE (cents/kWh)
Town Center Cluster: lowest cost	Centrally located, multiple interconnected buildings including assisted living, retail, food bank, post office, bank	340 kW PV	0.95M	5.00%	1.26 M	14.2
Town Center Custer: RE-only microgrid		738 kW PV / 1647 kWh Li-ion	2.76 M	0.00%	4.74 M	53.1
Town Center Cluster: microgrid with Diesel backup		333 kW PV / 160 kW diesel	1.01 M	0.00%	1.34 M	15
School: lowest cost	284 MWh annual electricity consumption. Hourly profile for full year from REopt tool using secondary school profile	143 KW PV	0.41 M	1.04%	0.47 M	9.5
School: RE-only microgrid		347 KW PV, 880 kWh Li-ion	1.42 M	0.00%	1.91 M	38.2
School: microgrid with Diesel backup		143 kW PV / 160 kW diesel	0.49 M	0.00%	0.71 M	11.3
Sporting Club, lowest cost	Building to support social and outdoor activities on North Islesboro Island	21.8 kW PV	63 K	5.00%	70 K	14
Sporting Club, RE-only microgrid		42.1 kW PV / 90 kWh Li-ion	170 K	0.00%	224 K	44.7
Sporting Club, microgrid with Diesel backup		21.8 kW PV / 9.7 kW diesel	67 K	0.00%	106 K	15.3

The comparison of Island-wide scenarios across the metrics described in Table 6.2 are shown graphically in Figure 6-4 and Figure 6-5. The comparison of localized results across the metrics described in Table 6.2 are shown graphically in Figure 6-6 and Figure 6-7.

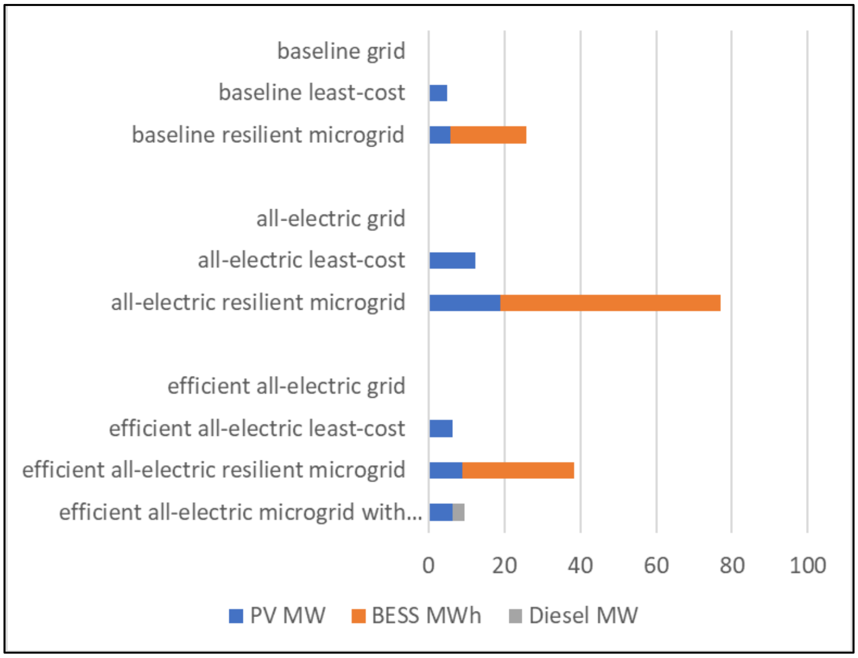

Figure 6-4: All island microgrid system by scenario.

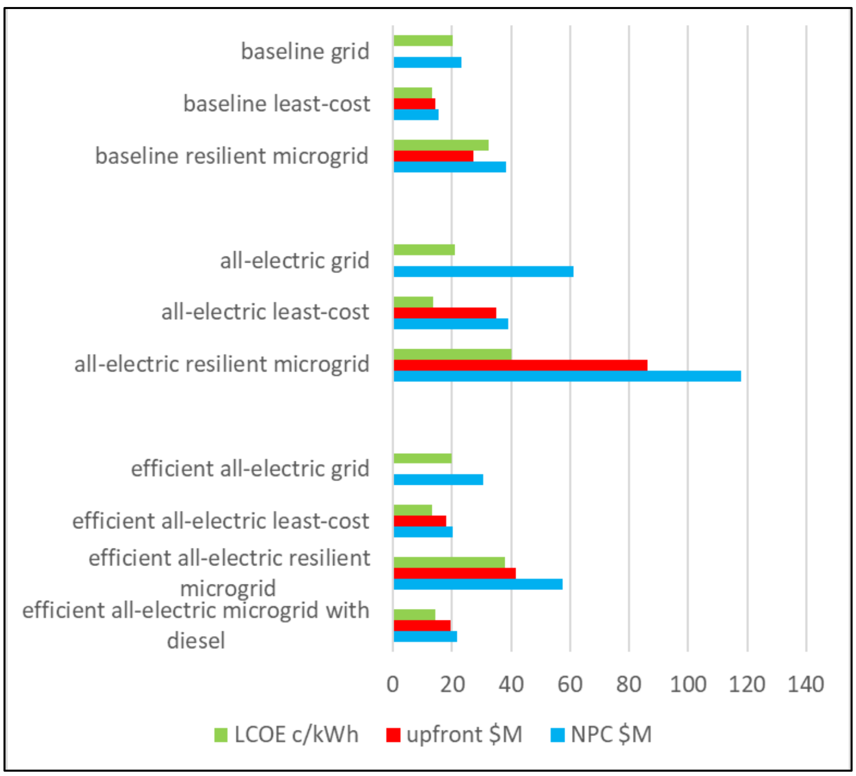

Figure 6-5: All island microgrid cost comparison by scenario.

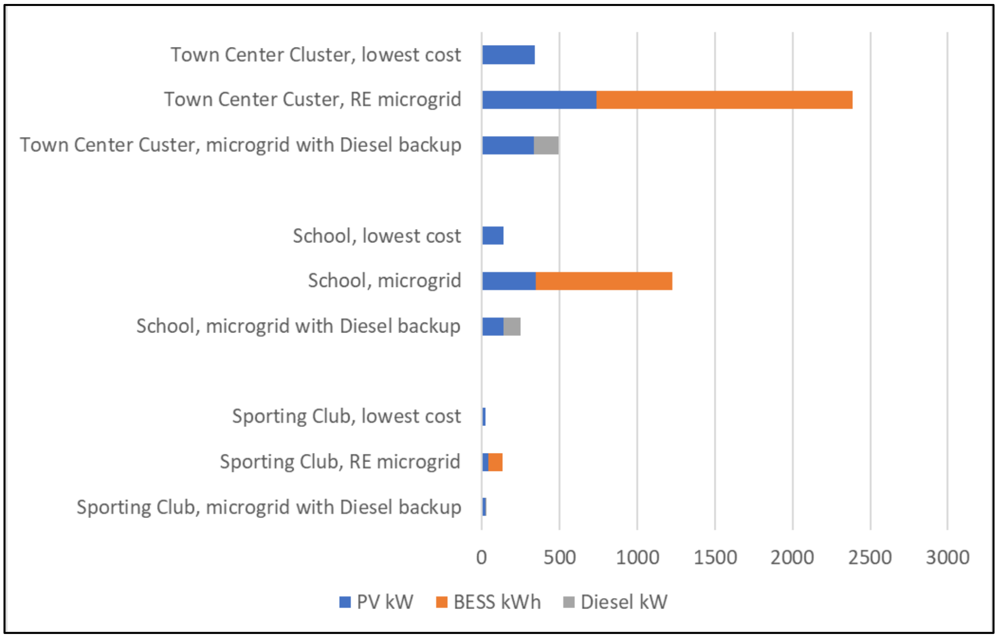

Figure 6-6: Microgrid system by location.

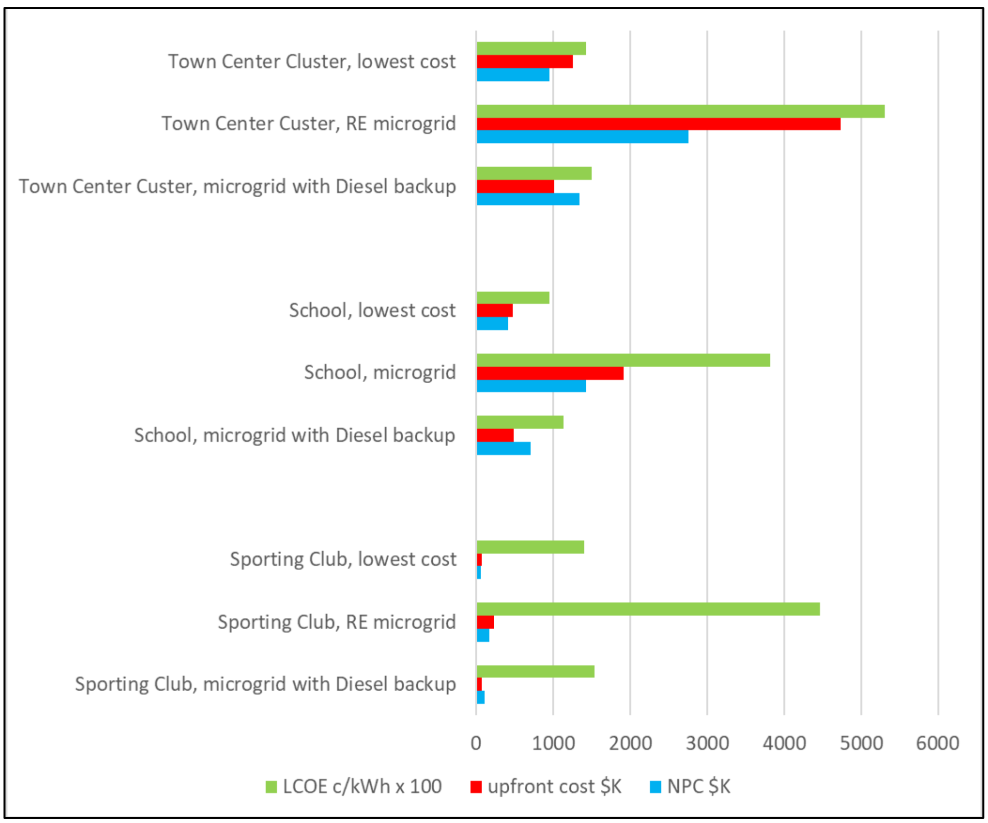

Figure 6-7: Microgrid cost comparison by location.

The key results of the simulations are as follows.

1. For all load cases, the *least-cost* system was one where PV generation satisfied the entire electric load over the course of the year. This is because the levelized cost of renewable energy, annualized over the expected lifetime of the system, is lower than the cost of energy purchased from the grid. The lowest cost resulted from a PV/inverter system large enough to generate enough energy to produce a non-zero net export to the grid. A larger system would be less advantageous because any excess energy would be provided to the grid at no cost. The least-cost system also comes with no battery storage, because the net metering allows the use of the grid as a battery and assumes no need for storage for resilience. The loss of service over the year, for all least-cost systems, was considerably less than the 5% allowed, hovering around 1%. The cost of energy for the least-cost system was lower than the CMP cost by over 30%.
2. For all load cases, the resilient, all-renewable microgrid involved the specification of a large Li-ion battery storage system combined with a PV array that was much larger than for the least-cost case. The size of the battery storage system was dictated by the need to serve the load for the five consecutive days of grid outage (with a daily recharge from the PV system, as available depending on solar irradiance). The levelized cost of energy for the resilient all-renewable system was between 50% and 100% greater than for the baseline grid-only system. In other words, going from 99% energy availability to 100% energy availability, at zero emissions, makes the cost of energy between 1.5 and 2 times larger. We also note that the battery was dispatched throughout the year, not only during the five-consecutive-day grid outage. This is because it is cheaper to store energy (thereby degrading the battery) than to buy energy from the grid given that the PV and battery are available. Also, the assumption is that the battery would have to be replaced after 15 years in any case, so degradation due to usage did not impact the mid-term battery replacement.
3. For all load cases, adding a diesel generator as an option to the optimization resulted in a system with no battery and a diesel generator large enough to carry the load when combined with the PV system, where the diesel generator only runs during the five-consecutive-day grid outage. The cost of energy with this resilient system is only about 10% higher than with the resilient zero-emissions system. Of course, due to the use of the diesel generator, the emissions are non-zero. Typically, CO_2 emissions from using the diesel backup generator amount to about 4% of the grid-only emissions for the same case (meaning that, per unit energy provided, the systemwide CMP emissions are much lower than those of a small generator). We also note that, to eliminate net emissions with the diesel system, the PV array could be sized to export more electricity to CMP.
4. The difference in net present cost between the lowest-cost system for the “load 1” scenario and the “load 2” lowest-cost scenario is about $5M, or approximately 25%. The question that arises is whether implementing efficiency measures island-wide would be cheaper than simply installing a system that can serve a larger electric load. In contrast, the difference in cost between the resilient, all-renewable “load 1” and “load 2” cases is on the order of $60M. In this case, implementing efficiency measures would almost certainly be a better economic choice than upsizing the system to serve a larger load.

Finding sustainable energy solutions that do not pollute the environment was a key goal of the community. The reductions in emissions from the base case scenario assumptions for each of the alternate cases are shown in Table 6-3.

Table 6-3: HOMER Analysis Results

Scenario Assumptions	Baseline Emissions	Alternative System	Total Emissions Avoided
Island-wide baseline	CO_2: 1,344,546 kg/y SO_2: 750 kg/y NO_x: 1,206 kg/y	Island-wide baseline least-cost RE design, zero emissions, net RE energy exporter	CO_2: 33,613,650 kg SO_2: 18,750 kg NO_x: 30,150 kg
Island-wide projected load 1 utility only	CO_2: 3,447,069 kg/y SO_2: 1,924 kg/y NO_x: 3,091 kg/y	Island-wide projected load 1 least-cost RE design, net RE energy exporter	CO_2: 86,176,725 kg SO_2: 48,100 kg NO_x: 77,275 kg
Island-wide projected load 2 utility only	CO_2: 1,774,728 kg/y SO_2: 990 kg/y NO_x: 1,591 kg/y	Island-wide projected load 2 least-cost RE design, net RE energy exporter	CO_2: 44,368,200 kg SO_2: 24,750 kg NO_x: 39,775 kg
Island-wide projected load 2 utility only	CO_2: 1,774,728 kg/y SO_2: 990 kg/y NO_x: 1,591 kg/y	Island-wide projected load 2, resilient microgrid design. Net RE energy exporter	CO_2: 44,368,200 kg SO_2: 24,750 kg NO_x: 39,775 kg
Island-wide projected load 2 utility only	CO_2: 1,774,728 kg/y SO_2: 990 kg/y NO_x: 1,591 kg/y	Island-wide projected load 2, resilient microgrid design with diesel	CO_2: 42,808,425 kg SO_2 and NO_x for diesel genset TBD

6.4 Highlights

The following are six key highlights of this analysis:

- Spatial needs look reasonable. See Appendix H for PV system acres sizing relative to airport size.
- Economics look reasonable, but many other factors will need to be costed before final cost viability can be assured. The following issues were not covered in the conceptual design: site land costs and procurement, financing, PV installed cost adder for being on an island, and interconnection risks.
- Smaller system solutions look reasonable as initial starter systems and could also be designed in the future to function as stand-alone microgrids.
- Regulatory risks exist and need to be clarified as the projects move forward toward RFPs.
- The 15 solutions described above represent existing technology solutions for Blue Sky designs and single-building microgrid designs. Technology for area microgrid creation and resynchronization is not as well established and needs to be investigated as future systems using it are considered by the community.
- The ability of the transmission link between the island and the mainland to feed excess PV into the grid needs to be assessed (with the cooperation of CMP), especially for larger PV systems. Batteries may be

required to mitigate problems (although the same batteries may also provide added resilience).

6.5 Next Steps

The key next steps resulting from the alternatives analysis are as follows:

- Pursuing an island-wide renewable energy project will require seeking clarity from the Maine public utility on harnessing the 2 MW limit for net metered systems. Determine if the community wants to seek a variance from this rule or can make multiple 2 MW solar systems to meet island-wide generation needs.
- Pursuing a smaller renewable energy project at the scale of the town cluster described above may be a good place to start because the scale and cost are more reasonable, there are multiple buildings included, and it could be a very good choice for the first resilient microgrid on the island.
- If pursuing either an island-wide renewable energy project or a smaller, focused renewable energy project like the town center, we suggest starting with a request for information (RFI) to the RE developers working in Maine and then following up with a request for proposal (RFP) once the RFI information has been evaluated and funding sources are identified.

7. Implementation Roadmap

Islesboro can begin improving its resilience posture immediately through operational planning. Taking initial steps to socialize and promote the adoption of energy efficiency and electrification measures in residences (including seasonal residences) can begin to advance the island towards its energy vision. Other more capital-intensive solutions like microgrids take years to explore in depth and may take a lower priority in implementation.

Table 7-1: Implementation Plan

Reduce Energy Load through Energy Efficiency	**Short-Term Priority (2023)**	**Medium-Term Priority (2024–2028)**	**Long-Term Priority (2028+)**
Promote Energy Efficiency Locally	Yes	-	-
Connect with Neighboring Communities	Yes	-	-
Identify Applicable Incentives and Application Process	Yes	-	-
Identify Contractor(s) for EEM Implementation	Yes	-	-
Implement EEMs	-	Yes	-
Track Progress	-	Yes	-
Electrify Buildings	**Short-Term Priority (2023)**	**Medium-Term Priority (2024–2028)**	**Long-Term Priority (2028+)**
Engage a Contractor to Evaluate Electrification Requirements	Yes	-	-
Identify Contractors for Building Electrification	-	Yes	-
Review Local Ordinances	Yes	-	-
Make a Plan for Building Electrification	-	Yes	-
Track Progress	-	-	Yes
Increase On-Site Renewable Energy Generation	**Short-Term Priority (2023)**	**Medium-Term Priority (2024–2028)**	**Long-Term Priority (2028+)**
Engage and Educate Community Stakeholders on Renewable Energy	Yes	-	-
Connect with Neighboring Communities to Learn Best Practices	Yes	-	-
Investigate the Possibility of Community Solar Projects	-	Yes	-

Improve Infrastructure Conditions to Enhance Resilience	Short-Term Priority (2023)	Medium-Term Priority (2024–2028)	Long-Term Priority (2028+)
Install Permanent Backup Generators	-	Yes	-
Procure Mobile Backup Generators	-	Yes	-
Install Generator Quick-Connect Panels	-	Yes	-
Install Dedicated Generator Fuel Storage	-	Yes	-
Engage With Utility to Add Loops to Distribution	Yes	-	-
Procure Dual-fueled Equipment at End of Life	-	Yes	-
Explore Placing Generating Asset at End of Radial Circuit	Yes	-	-
Develop/Exercise Robust Emergency Outage Recovery Plans	Yes	-	-
Engage with Utility on Distribution and Transmission System Maintenance	Yes	-	-

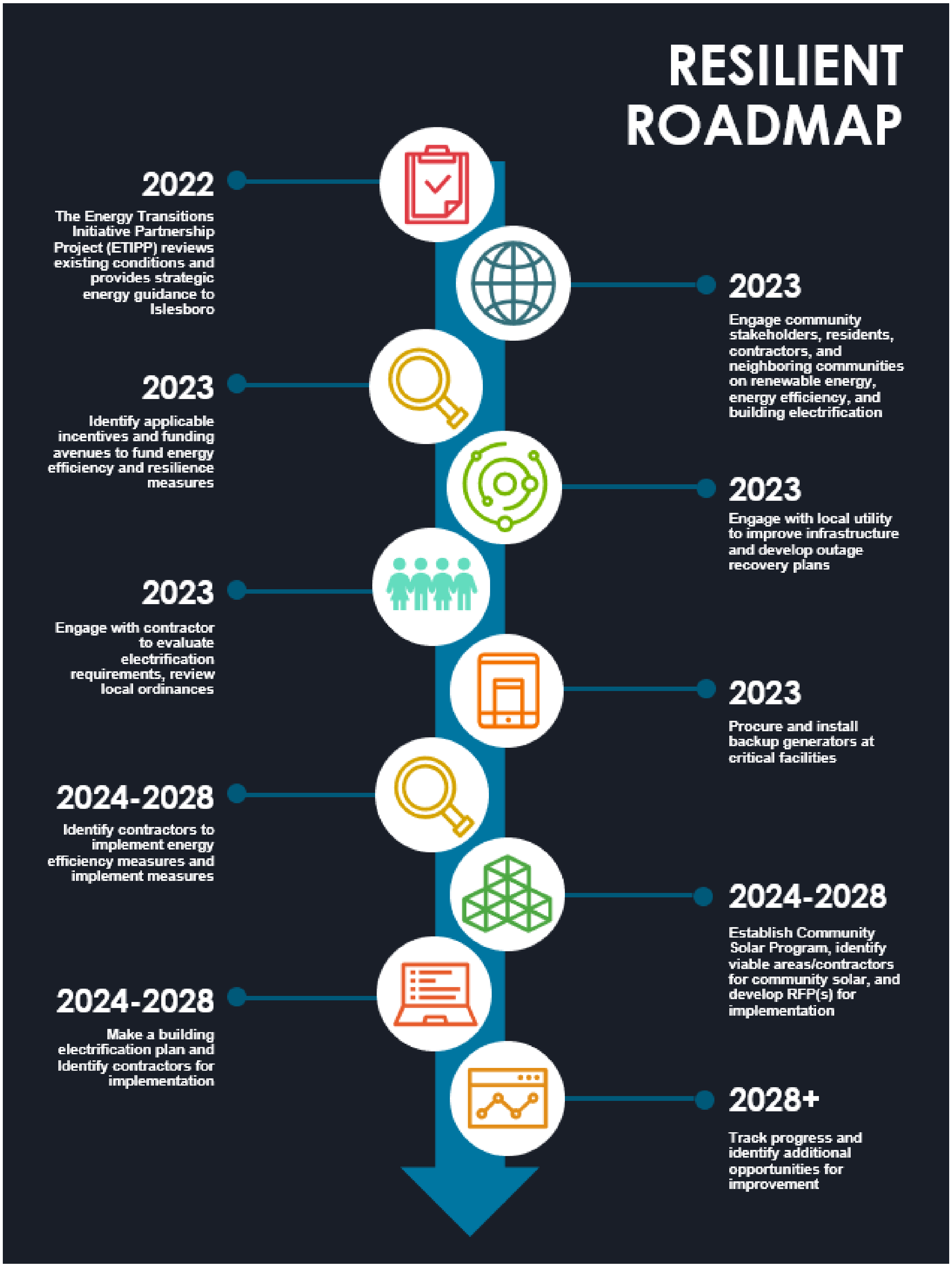

Figure 7-1: Islesboro roadmap.

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Appendix A – Project Goals and Metrics

This appendix provides a summary of the goals, metrics, and targets developed by the labs team in collaboration with Islesboro stakeholders as part of the Energy Transitions Initiative Partnership Project (ETIPP). The goals and metrics were used to guide the project work and can continue to be used by Islesboro to track the current and future performance of their energy systems.

The first phase of the ETIPP effort for Islesboro focused on establishing a scope of work (SOW) that outlined the technical assistance to be provided by the labs. Islesboro's application to ETIPP highlighted the island's vision of an island community that is "100% fossil-fuel free, in which all inhabitants benefit equitably from low-cost, emergency-resilient electricity produced in large measure locally." By engaging key island leadership and stakeholders, the labs developed an SOW that investigated options to realize the island's vision with the goal of providing Islesboro's Energy Committee (IEC) with a prioritized list of actions for implementation. Table A.1 describes Islesboro's ETIPP goals and the analysis performed for each. The metrics used to evaluate each goal are shown in Table A.2.

Table A.1: Islesboro ETIPP Goals

Goal	Description	Analysis Considerations
Achieve 100% fossil-fuel-free energy systems on Islesboro	Transform Islesboro's energy systems and eliminate fossil fuel use on the island	The key drivers of fossil fuel use on Islesboro are transportation, building heating, and electricity generated from fossil fuel sources. The ETIPP labs team performed techno-economic analyses to evaluate opportunities for reducing fossil fuel consumption on the island. The study focused on energy used by buildings, although transportation was considered where possible as an added component to the island's power system. The project scope did not include creating a comprehensive transportation fuel usage model.
Enhance the resilience of the island's power system	Enhance the resilience of the island's power system by lowering vulnerability to external hazards and increasing backup power capabilities on the island	The analysis assessed pathways for Islesboro to reduce its reliance on the local utility provider, Central Maine Power (CMP), by increasing local power generation. Alternatives to existing diesel backup power generators for critical buildings and for the island as a whole were evaluated as part of the resilience options assessment.
Ensure equitable access to low-cost, resilient energy on Islesboro	Implement energy projects that provide equitable, low-cost access to resilient electricity for island residents.	Part of Islesboro's energy vision is to ensure that all island residents benefit from energy resilience projects implemented on the island. While quantifying the energy burden on Islesboro households was not part of the scope, the labs team qualitatively evaluated how the energy opportunities identified on Islesboro could help assuage energy burden concerns for residents.
Identify key actions for implementation of Islesboro's energy vision	Create an implementation plan for Islesboro energy projects that outlines crucial actions in	The implementation plan will be created for the optimized option analyzed and selected as part of ETIPP.

	the short-, medium-, and long-term time frames.	

The labs evaluated several energy system configurations to determine the optimal approach for Islesboro to meet its energy goals. Table A.2 describes the metrics that were used in evaluating each configuration and, where applicable, long-term targets that the island can pursue to align with their goals. The targets were determined to be technically viable, but the timeframe could not be specifically determined because it will depend on Islesboro's ability to implement energy projects on the island.

Table A.2: Proposed Metrics

Metric	Units	Description	Long-term Target
Percentage of Energy that is Fossil Fuel Based	Percentage of total energy consumed that is sourced from fossil fuels [%]	Measures the percentage of Islesboro's total building-related energy consumption sourced from fossil fuels. This metric can be used to track the island's progress toward achieving 100% fossil-fuel-free energy.	0% of building-related energy consumption is sourced from fossil fuels
Greenhouse Gas Emissions from Building-Related Energy	Tons of carbon dioxide equivalent per year [TCO2e/year]	Measures the quantity of emissions resulting from building-related energy consumption on Islesboro. This metric can be used to track the island's progress toward achieving 100% fossil-fuel-free energy.	0 tons of CO2e/year of emissions from building-related fossil fuel energy consumption
Electricity Consumption	Kilowatt-hours of electricity consumed per year [kWh/year]	Measures the quantity of electricity consumed on the island during a given year. This metric can be used to track changes in consumption resulting from heating fuel switching and energy efficiency strategies.	Minimize electricity consumption from the grid
Fuel Consumption[15]	Unit of fuel consumed per year	Measures the quantity of fuel consumed on the island during a given year.	100% transition to efficient electric sources as primary heating source
Percentage of Electricity from Local Renewable Generation	Percentage of total energy consumed that is generated from local renewable generation [%]	Measures the percentage of Islesboro's total electricity consumption that is generated by local renewable generation.	Increase the amount of island electricity generated from local renewable sources[16]

[15] Note: a separate metric will be used for every fuel type, e.g., heating oil, kerosene, firewood, etc. The metric may be adjusted from gallons to another appropriate unit as needed.
[16] Note: Maine has a renewable portfolio standard (RPS) that establishes that 100% of the state's electricity must be supplied from renewable sources by 2050. Local renewable energy production can enhance the island's resilience against power outages. The level of local production that is achievable will be confirmed through analysis

Metric	Units	Description	Long-term Target
Energy Cost	USD per year [$/year]	Measures the cost to provide energy to buildings on the island.	Reduce or maintain the total cost of energy on the island
Capital Investment	USD	Measures the rough order of magnitude capital investment required to implement the option.	No specific target

Each alternative was also evaluated qualitatively in the following categories:

- Resilience: refers to the ability of Islesboro's energy systems to absorb and recover from external hazards, such as outages caused by windstorms.
- Constructability and Phasing: refers to Islesboro's ability to implement the proposed alternative while minimizing disruptions to island residents and ensuring adequate funding.
- Access: refers to the ability of island residents to access energy system options and proposed technologies.

Appendix B – Collection

The labs worked with the Islesboro Energy Committee (IEC) to collect data on the island's existing energy infrastructure conditions and historical energy consumption. Table B.1 shows the list of data requests, the data received, and remaining data gaps and impacts to the analysis.

Table B.1: Islesboro Data Collection Summary

Data Request	Data Received	Data Gaps and Analysis Impacts
Existing Buildings List of buildings on Islesboro, including building type, occupancy type, age, and size	•Islesboro Type of Occupancy List List of buildings and occupancy types (full-time residence, seasonal residence, business, or organization) collected for the island's broadband study in 2016 with additional information on installed backup power generators (and capacities where available). •Islesboro Critical Building List List of critical buildings on the island as identified by the IEC and ranked by importance.	The provided data indicated whether a building fit into one of four occupancy categories but did not provide information on the building size (square footage) or its type (office, restaurant, retail, etc.). The labs used public tax and real estate data as well as satellite imagery to estimate the sizes of buildings. In addition, the labs made assumptions on the types of buildings listed based on publicly available data. The IEC stated that the COVID-19 pandemic increased island population, and multiple seasonal housing units became occupied full-time. Year-round population on the island increased by 22 people from 2019 to 2020. Assuming an average occupancy of two people per household, this increase represents an addition of 11 full-time households. Assuming this rate of increase remained through the end of 2021, it was assumed that 5% of the existing seasonal housing stock was converted to full-time residences when developing forecasts.
Island Growth Plans Existing plans for island development, e.g., master plans and capital improvement plans	•2017 Island Comprehensive Plan The plan includes seasonal and full-time population estimates and housing growth on Islesboro.	At the time of this study, the island had not yet determined the extent of the changes in housing needs resulting from the COVID-19 pandemic nor assessed whether the demand for housing has increased. The labs assumed that the growth rate included in the comprehensive plan (two new seasonal and one new full-time residence per year) was accurate and applicable through the year 2030.

Data Request	Data Received	Data Gaps and Analysis Impacts
Risks and Hazards Previous studies of natural risks and hazards that affect Islesboro's energy systems	• 2017 Present and Future Vulnerability to Coastal Flooding at Grindle Point and The Narrows Report This report summarizes a study requested by Islesboro to understand the threat of coastal flooding at two locations on the island where critical transportation infrastructure is vulnerable to storms and sea level rise. • 2013 A Climate of Change: Climate Change and New England Fisheries Report This report summarizes a workshop conducted by the Island Institute with stakeholders in the Maine community that discussed the impact of climate change on fisheries and identified recommendations to adapt to changes. • Raw Power Outage Data 2016–2021 This data lists the date, duration, and direct cause of power outages (e.g., downed conductor, damaged pole, etc.) affecting Islesboro.	The raw outage data did not include information on the external hazard or risks that led to the outage, such as ice storms, animal damage, etc.
Historical Electrical Loads Historical electricity consumption on Islesboro as measured by utility bills.	• Historical electricity consumption and cost for 11 municipal buildings • Hourly electrical load data at the Lincolnville feeder (island-wide) level from January 1, 2021, through December 15, 2021, provided by CMP (with gaps) • Monthly electrical consumption data by customer class (residential, commercial, industrial, and exterior lights) from 2016 to 2021 provided by CMP	The data provided included both island-level and customer-class-level data. This data was used to calibrate the island-level energy model that the labs used to determine baseline energy usage and to develop load forecasts.

Data Request	Data Received	Data Gaps and Analysis Impacts
Electricity Cost Average cost per kWh of electricity paid by island residents and businesses	• Historical electricity consumption and cost for 11 municipal buildings • Confirmation that island residents typically use CMP's residential service rate without time of use or load management	Information on the typical rate paid by commercial customers on Islesboro was not available. The rate for commercial buildings was estimated using CMP's Small General Service utility tariff.
Historical Fuel Consumption Historical fuel consumption on Islesboro as measured by utility bills.	• Three years (2019, 2020, and 2021) of fuel quantities delivered to Islesboro based on the dangerous material manifests filled for ferry transportation • High-level estimates on cords of firewood and number of households served for 2020	Not all firewood suppliers could provide information on the amount of firewood delivered to Islesboro residences.
Fuel Costs Average cost per unit of fuel paid by island residents and businesses	• Historical (2018–2021) fuel cost data from one fuel supplier for one municipal building The average cost per gallon of fuel oil was $2.28/gallon for this period.	IEC members stated that the average fuel cost for island residents was higher than that paid by municipal buildings. The labs used the fuel costs provided by the IEC for the analysis.

Data Request	Data Received	Data Gaps and Analysis Impacts
Installed Renewable Energy and Energy Storage Projects Installed capacity and annual energy generation (if applicable) for existing renewable energy and energy storage projects on Islesboro	• Islesboro Installed Technology Data List from 2018 Includes a list of locations on the island where window inserts, solar photovoltaic (PV), heat pump heating, solar hot water, heat pump water heaters, and LED lighting have been installed. The list also includes whether the household has an electric or hybrid vehicle. • Islesboro Solar Installations List of solar installations on Islesboro showing combined data obtained from CMP and Revision Energy. • Island Institute Waypoints: Connect Report Report provides data on the status of Maine's coastal infrastructure system. Key data relevant to ETIPP includes data on home heating fuels and use of technology such as heat pumps. • Efficiency Maine Heat Pump Rebate Data Includes the number of rebates for electrical heat pumps awarded by Efficiency Maine to households on Islesboro from 2014 to 2019.	The data provided in the Installed Technology Data List was 3 years out of date, and the IEC stated that additional technologies have been installed in residences across the island since 2018. The solar installations data included information on system sizes but not annual generation capacity. The heat pump data provided by the Island Institute and the Efficiency Maine rebates was used to assess the level of penetration of heat pump technology for home heating on Islesboro.
Renewable Energy and Energy Storage Costs Cost for the installation of renewable energy and energy storage projects on Islesboro based on historical data	• Power Purchase Agreement (PPA) Proposal for the Islesboro Transfer Station A document describing Revision Energy's proposal for the installation of a solar PV system under a PPA at Islesboro's Salt Shed.	The upfront cost of the Salt Shed solar PV system is approximately $3.3/watt of installed capacity. No costs for energy storage projects were provided. The labs assumed that $3.3/watt is the typical cost of a solar PV installation on Islesboro and used other published data sources to identify installation costs for different technologies.

Data Request	Data Received	Data Gaps and Analysis Impacts
Installed Backup Power Generation Backup power systems such as generators installed on the island, including capacity and fuel storage	• Islesboro Type of Occupancy List with Generator Data List of buildings and occupancy types collected for the island's broadband study in 2016 with additional information on installed backup power generators (and capacities where available).	The IEC worked with island fuel suppliers to collect the number of permanent diesel-fueled and propane-fueled generators installed at buildings across the island. No information on generator sizing, location, or the number of portable generators could be provided.
Previous Energy Studies Existing energy audits and other energy studies for Islesboro buildings	• 2019 Energy Study Energy audit report for the Town Office, Health Center, Fire Barn, Library and Transfer Station.	No specific data gaps were identified.

Appendix C – Historical Energy Use and Emissions

Buildings on Islesboro can be divided into three broad categories: residential (including seasonal and full-time housing), commercial, and municipal and other buildings. This appendix summarizes building-related energy consumption and emissions for Islesboro between 2019 and 2021.

C.1 Historical Electricity Consumption

CMP provided island-level hourly electrical load data for 2021 and monthly energy consumption data by customer class (residential, commercial, and industrial) for the years 2016 through 2021. Figure C.1 shows the breakdown of electricity consumption by customer class for the years between 2019 and 2021. Residential energy consumption has historically accounted for over 80% of all electricity consumption on Islesboro, which is expected given that the majority of buildings on the island are residential. The data also shows that residential electricity consumption increased after 2019, likely due to the impact of the COVID-19 pandemic.

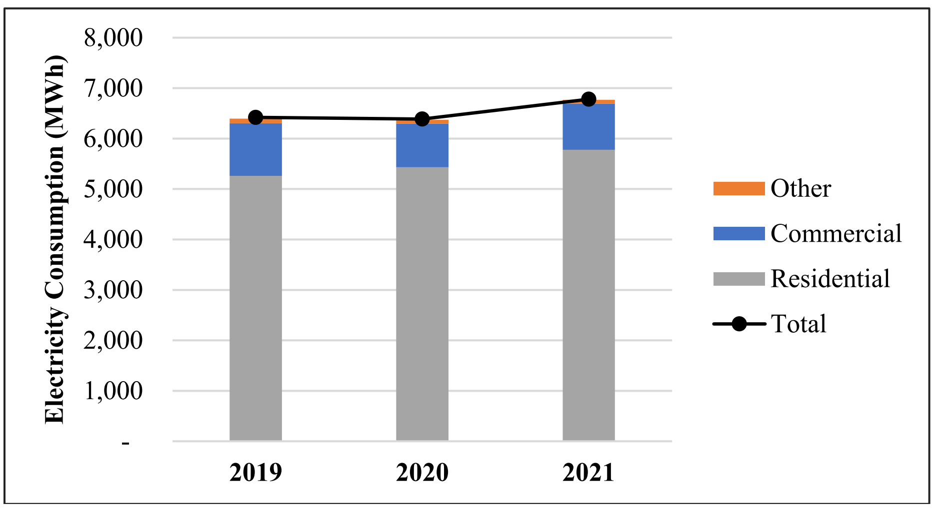

Figure C.1: Islesboro historical electricity consumption.

Figure C.2 shows the monthly energy consumption and maximum power demand (instantaneous power need) for the island using the data provided by CMP. The island's maximum power demand occurs in the summer, when there is increased population, but remains relatively high during the winter months as well.

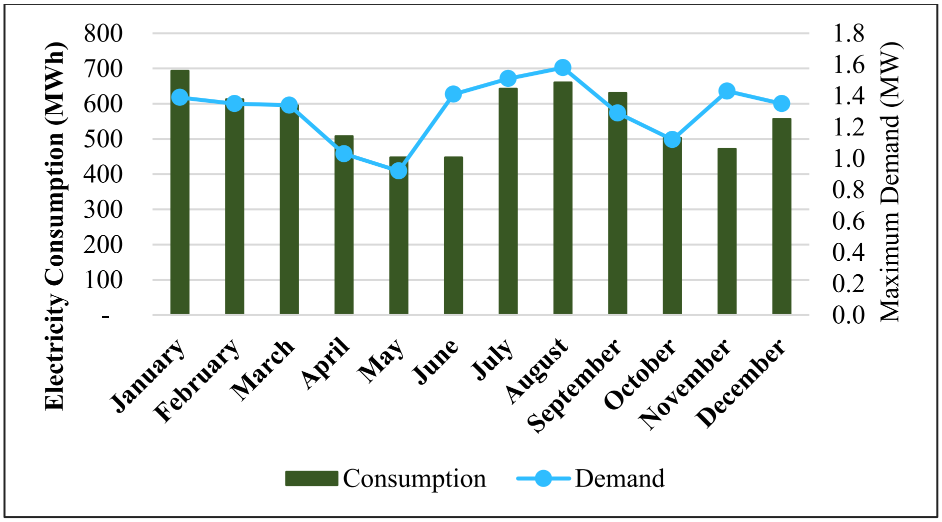

Figure C.2: Electricity consumption and demand in 2021 using CMP data.

The IEC provided Islesboro fuel delivery data for 2019, 2020, and most of 2021. Due to the combination of regular power outages and extreme winter weather, most buildings on Islesboro rely on multiple fuels for heating. According to one of the suppliers, Vinal Energy, fuel oil and kerosene are the two primary fuels used for heating. Propane is used for heating, cooking, and backup power generators. Nearly all the diesel fuel is used for tractors and machinery, with less than 1% used for heating.

Figure C.3 shows the consumption amount in gallons of each fuel from 2019 to 2021. Diesel consumption has consecutively decreased each year, possibly due to the pandemic affecting the farming and fishing industries. Propane use has increased in the same period, which aligns with more homes purchasing propane generators. Zero gallons of kerosene were delivered to the island for five consecutive months in 2021, with smaller than usual amounts delivered in the fall. This could mean more buildings are beginning to rely on fuel oil for heat, which is why fuel oil consumption significantly outweighs the others.

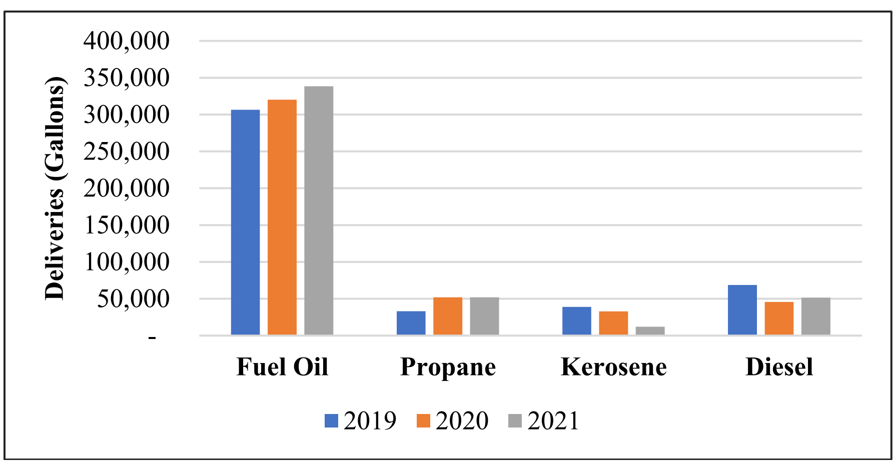

Figure C.3: Islesboro historical fuel consumption.

C.2 Historical Wood Consumption

Wood is commonly used by Islesboro residents as a heating source in their homes. Many residents collect their own wood, but some purchase it in bulk from commercial suppliers. The IEC worked with wood suppliers on the island to collect historical data on wood deliveries to residences on Islesboro. The wood suppliers documented that in 2021, approximately 177.5 tons of wood pellets (118 cords of wood) were delivered to 42 households, which translates to an average rate of 4.2 tons of wood per home.

C.3 Historical Energy Emissions

Figure C.4 shows the total energy consumption by energy source when translated into the same units of energy, million British thermal units (MMBtu), as well as the total tons of carbon dioxide equivalent (CO_2e) emissions associated with that energy. This figure shows that historically, fuel oil use for heating and hot water supply are the major sources of building energy-related consumption on the island. It also shows that energy consumption and emissions on Islesboro have been increasing over time. The conversion factors used to translate energy consumption by source into the same units as well as emissions factors can be found in Appendix G.

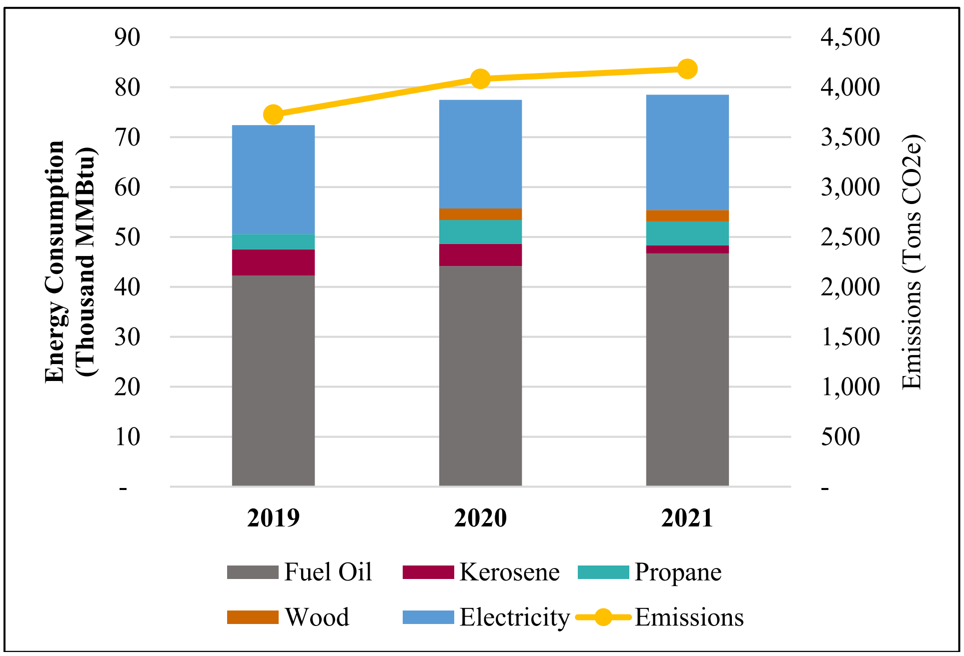

Figure C.4: Annual building energy emissions on Islesboro by fuel type.

Appendix D – Islesboro Energy Model Development and Results

An energy model of the majority of Islesboro's building stock was created using the Facility Energy Decision System (FEDS) Software, version 8.1, to better understand the breakdown of energy use on the island and create a baseline for future load estimates, opportunities assessment, and alternatives analysis. This appendix outlines the key assumptions made in the development and calibration of the energy model.

D.1 Building Type, Age, and Sizes

The first step in creating an energy model of the buildings on Islesboro was to estimate the total area occupied by each building type as well as the age of the buildings. The 2016 broadband study data classified buildings into broad categories (seasonal and full-time residences, businesses, and organizations) but did not provide detailed information on building types and sizes. The labs team reviewed Islesboro's Real Estate Commitment Book, but this source did not include home size information. Therefore, size estimates had to be developed separately. Initial size estimates were developed using published data sources such as RECS and CBECS and refined with real estate listing information, tax records, and satellite imagery.

D.1.1 Residential Buildings

As shown in Section F.1, residential buildings constitute the majority of buildings on Islesboro. The following data sources were used to estimate the home sizes to be used in the model:

- Real estate listing information for 146 homes sold between 2017 and 2021. Information such as home size, year of construction, heating and hot water fuel and system type, and envelope construction was collected from these listings.
- Islesboro tax records, which were used to cross-check the listings and determine whether the homes had year-round or seasonal occupancy.

Based on this data, the following assumptions were made in the energy model:

- Home Vintage: buildings built before and after 1960 are likely to have significantly different construction styles, so these two home vintages were assessed separately. Approximately 44% of seasonal homes and 42% of year-round homes studied were built before 1960. It was assumed that this split is applicable not only to the subset of houses reviewed but to the entire housing building stock.
- Home Size: The average size of the houses reviewed varied depending on whether the home was occupied year-round or seasonally. Seasonal homes were between 17% and 54% larger on average than year-round homes depending on their vintage. Table D.1 shows a summary of the estimated size and numbers of residential buildings used in the analysis.

Table D.1: Estimated Size of Residential Buildings

Building Vintage and Occupancy Type	Average House Size (Square Feet)	Total Number of Buildings	Total Area (Square Feet)
Seasonal Homes Pre-1960	3,023	237	715,915
Seasonal Homes Post-1960	2,233	299	668,143
Year-round Homes Pre-1960	1,959	115	225,095
Year-round Homes Post-1960	1,911	159	304,062

D.1.2 Commercial, Municipal, and Other Buildings

Islesboro also has commercial, municipal, and other public buildings that contribute to the island's energy consumption. In the model, the buildings labeled as businesses in the broadband study were included in the Commercial category, and the other buildings were allocated to the Municipal or Other category. Only the buildings that could be assigned a building type for modeling purposes were included in this analysis. Satellite imagery was used to estimate building sizes where public information was not available. Table D.2 shows the list of commercial, municipal, and other buildings that were included and their estimated sizes, vintages, and modeled building type.

Table D.2: Estimated Size of Municipal and Other Buildings

Building Name	Building Type	Modeled Building Type	Year Built	Estimated Building Size (Square Feet)
Town Office[a,b]	Municipal	Office	Pre-1960	9,400
Library[a,b]	Municipal	Assembly	Pre-1960 (1918[17])	2,550
Transfer Station[a,b]	Municipal	Other	Pre-1960	575
Lighthouse Museum[a,b]	Municipal	Assembly	Pre-1960 (1849[18])	390
School[a,c]	Other	Education	Pre-1960 (1928[19])	48,000
Ferry Crews Quarters[d]	Other	Lodging	Post-1960	9,900

[17] Library Link
[18] Lighthouse Link
[19] School Link

Building Name	Building Type	Modeled Building Type	Year Built	Estimated Building Size (Square Feet)
Tarratine Golf Club[a,b]	Commercial	Food Service	Pre-1960 (1896[20])	14,500
Grindle Point Ferry Terminal[a,b]	Other	Service	Pre-1960	1,000
Boardman Cottage[a,c]	Commercial	Lodging	Post-1960 (2005[21])	11,600
Islesboro Community Center[a,c]	Other	Assembly	Post-1960[22]	13,400
Commercial Buildings (11 Total)[d]	Commercial	Retail	-	3,600 per building/ 39,600 total

[a]Size obtained from satellite imagery
[b]One-story building
[c]Two-story building
[d]Size obtained from CBECS

Table D.3 shows the total estimated footprint of buildings on Islesboro that was used in the analysis. Seasonal buildings represent the majority of the building footprint, and more than double that of year-round residential homes. Note that only 833 of the 862 buildings estimated to exist on Islesboro were modeled.

Table D.3: Islesboro Building Summary

Building Type	Number of Buildings	Total Area (Square Feet)	Percent of Total
Full-time Housing	274	529,157	26%
Seasonal Housing	536	1,384,058	67%
Commercial	11	65,700	3%
Municipal	7	12,915	<1%
Other	5	72,300	3%
Total	833	2,064,130	-

[20] Tarratine Club Link
[21] Boardman Cottage Link
[22] Islesboro Community Center Link

D.2 Building Envelope Construction

Envelope construction for buildings on Islesboro was determined using the *Maine Single-Family Residential Baseline Study* report created for Efficiency Maine, which leveraged on-site audits of 41 single-family homes and telephone surveys of 164 homes throughout Maine to develop a representative baseline for these types of residential buildings in Maine (NMR Group 2015). This study provided information on the envelope characteristics (level of insulation, types of windows, etc.) for typical homes in Maine for different construction types. The real estate records reviewed for the majority of the houses reviewed had wood frame construction, so this was assumed to be the typical construction type for houses on the island. For modeling purposes, houses were assumed to have uninsulated basements, open attics with shingle roofs, and double-pane windows. Table D.4 summarizes the performance of the envelope components.

Table D.4: Islesboro Building Summary

Envelope Component	Pre-1960 Performance	Post-1960 Performance
Roof	R-29 Insulation	R-38 Insulation
Walls	R-13 Insulation	R-19 Insulation
Windows	Wood or vinyl frame, double-pane	Wood or vinyl frame, double-pane

D.3 Heating and Domestic Water Heating Fuels and Systems

To create an energy model in FEDS that would be representative of the building stock on Islesboro, the labs team developed estimates on the number of buildings that used fuels like fuel oil, kerosene, propane, wood, and electricity to provide heating and domestic water heating (DHW) and the types of systems that served each of the buildings. These assumptions were developed primarily by reviewing Islesboro real estate listing data that included heating system fuel and type information and were supplemented by NMR Group (2015). A few key takeaways from this review that informed the heating inputs into the model are listed below:

- Real Estate Data Takeaways
  - The real estate listings data did not indicate whether a home was used seasonally or year-round, so the percentages listed here were assumed to apply to the entirety of the Islesboro building stock.
  - The majority of buildings listed fuel oil as their only heating fuel, especially for buildings built before 1960 (~50% of pre-1960 buildings vs. ~30% of post-1960 buildings).
  - Approximately 15% of buildings showed fuel oil as the primary heating fuel, with wood, electricity, kerosene, and propane serving as supplemental fuels.
  - Approximately 10% of pre-1960 and 13% of post-1960 buildings use electricity as their primary heating fuel, with another 9% of pre-1960 and 12% of post-1960 buildings using a mix of electricity and wood. Based on information provided by the Island Institute on heat pump rebates provided by Efficiency Maine to households on Islesboro, it was assumed that of the all-electric buildings, 5% used heat pumps and the rest used electric baseboards.
  - The use of wood, kerosene, or propane as the only heating fuel was most common in post-1960 buildings.
  - Approximately 10% of pre-1960 buildings and 16% of post-1960 buildings listed a combination of

more than three heating fuels. These were categorized as "Other" heating systems in the FEDS model.

- NMR Group (2015) Takeaways
  - Nearly three quarters (72%) of the homes surveyed reported using oil as their primary fuel, and another 12% reported using a combination of oil with either wood or electricity.
  - All other primary fuel types together (kerosene, propane, gas, etc.) account for 16% of the homes.
  - The distribution of heating fuels is slightly different than on Islesboro, but there is alignment in that fuel oil alone or a combination of fuel oil with a supplemental fuel is the most common heating fuel arrangement for single-family homes in Maine.
  - The most common heating equipment type in Maine is boilers, followed by furnaces. Figure D.1 shows the breakdown of heating equipment types extracted from NMR Group (2015).

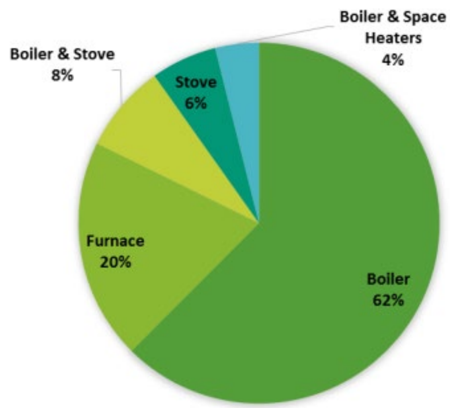

Figure D.1: 2015 Efficiency Maine study results on primary heating system type.

  - Supplemental heating equipment in homes that use more than one fuel account for approximately one quarter (26%) of the total installed heating capacity. It was assumed that this split would apply to homes on Islesboro with multiple heating fuels.
  - Most domestic hot water systems in homes surveyed used fuel oil or electricity.
- Islesboro Energy Committee Takeaways
  - Wood use for heating is common throughout Islesboro and is not necessarily represented by wood cords or pellet deliveries because many people use wood harvested on their properties.
  - According to information provided by one of Islesboro's fuel delivery companies, roughly 10–20% of the propane delivered to homes is used for heating and the remainder is used for cooking or for generators.
  - In April 2022, the Islesboro Energy Committee conducted a survey of 46 year-round homes to assess the heating and cooling systems and fuels that were used:
    - The majority of homes (59%) use fuel oil or fossil fuels as the primary heating source.
    - Homes that use electric baseboards all have wood as supplemental heating.
    - Approximately 13% of homes use wood as the primary heating fuel.
    - Of the 46 homes surveyed, 16 had heat pumps for either primary or supplemental heating. This

corresponds to ~2% of all homes on Islesboro (16 out of 810), which is lower than the 5% adoption rate used in the FEDS model.

This information was combined to inform the heating fuels and system inputs for residential buildings in the FEDS model, which are summarized in Table D.5. For the FEDS model, it was assumed that the primary fuel used for heating was the same as the domestic hot water fuel.

Table D.5: Heating Fuels and System Inputs for Residential Buildings in the FEDS Model

Heating Fuel and System Combination	Total Number of Homes	Percentage of Homes
Fuel Oil Only (Furnace)	81	10%
Fuel Oil Only (Boiler)	244	30%
Electricity Only (Baseboard)	56	7%
Electricity Only (Heat Pump)	38	5%
Kerosene Only (Furnace)	27	3%
Wood Primary (Stove) – Supplemental Electricity (Baseboard)	132	16%
Oil Primary (Boiler) – Supplemental Wood (Stove)	88	11%
Other (Mix of Propane, Kerosene, Electricity, etc.)	144	18%

Commercial and municipal buildings were assumed to use fuel oil and boilers for space and water heating. A limited number of buildings were assumed to have cooling because cooling is not prevalent in Maine.

D.4 Lighting, Cooking, and Other Loads

Besides the envelope characteristics and heating fuels and systems, the other key inputs to the energy model were the types of lighting, cooking, and other equipment used in each type of home:

- Lighting: Using NMR Group (2015) as a reference, Islesboro homes were modeled as having mostly compact fluorescent lamp (CFL) lighting, followed by other fluorescent (T12 and T8s) and incandescent lighting, as well as a small fraction of LED lighting.
- Cooking: Based on information provided by the IEC, most homes were modeled as using propane for cooking. This aligns with the April 2022 survey conducted by the IEC, which showed 50% of the year-round homes surveyed used gas stoves.
- Other Equipment Loads: Refrigeration and other miscellaneous equipment loads were modeled using industry-standard defaults for each building.

D.5 Schedules and Seasonality

The occupied and unoccupied hours of the residential buildings modeled in FEDS were adjusted to account for occupancy patterns in single family homes. The occupancy of seasonal homes was also adjusted based on the time of year. Commercial building occupancy was adjusted based on published schedules where possible.

D.6 Energy Model Calibration

Once the energy model was created using the inputs described in Sections D.1 through D.5, the results were calibrated to match the average annual energy consumption for each energy source as determined by the data provided by IEC and CMP. The average measured consumption for 2017 through 2021 was used as the basis for calibration to set a more consistent baseline that was not skewed by the effects of the COVID-19 pandemic. Table D.6 shows the comparison of annual energy consumption by source. The sections in this appendix further break down the comparison and considerations for each source.

Table D.6: Modeled vs. Measured Annual Energy Consumption by Source

Fuel Type	Modeled Consumption	Measured Consumption[1]	Modeled vs. Measured Difference[2]
Electricity (kWh)	6,120,661	6,354,022	−4%
Fuel Oil (Gallons)	363,429	321,645	13%
Propane (Gallons)	46,869	45,615	3%
Kerosene (Gallons)	36,621	35,948	2%
Wood (Tons)	648	140	363%[3]

[1] Average consumption between 2017 and 2021
[2] A negative number indicates that the modeled consumption is lower than the measured
[3] Measured wood data was limited, but this difference was assumed to be acceptable given what is known about wood use on Islesboro. See Section C.2 for more information.

D.6.1 Electricity Modeling

Electricity consumption and demand on Islesboro peak in August. This is likely due to the influence of seasonal residents and visitors on the island. The energy model for Islesboro was adjusted to reflect this by adjusting the assumptions around seasonal occupancy and reducing the use of electricity for heating in the model. The comparisons between the modeled and measured monthly average consumption and monthly peak demand data are shown in Figure D.2 and Figure D.3. The model overestimated consumption and peak demand in the summer months and underestimated in the winter. This is likely due to the simplified assumptions that were made in the model around seasonal occupancy and the fact that not all buildings and electricity end uses, such as street lighting, were included in the model. However, these differences were considered to be acceptable for the purposes of the opportunity analysis the model was used for.

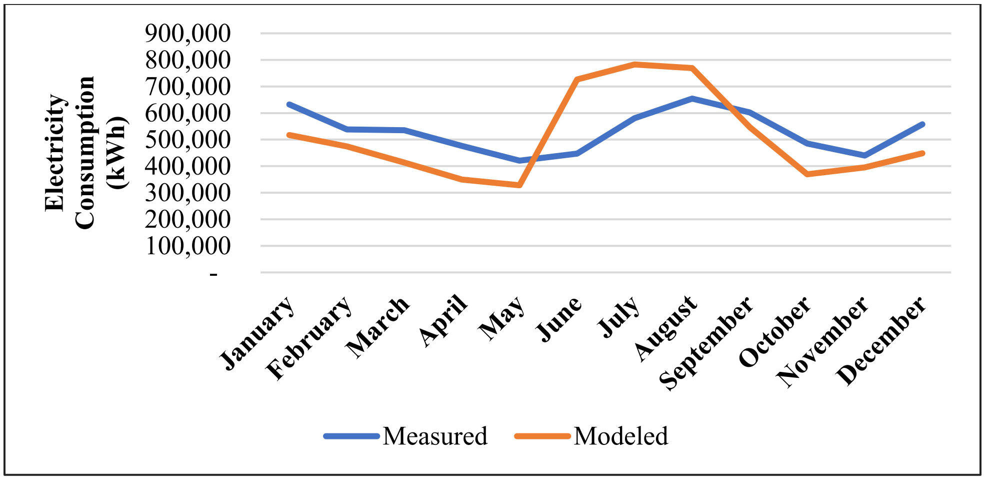

Figure D.2: Modeled vs. Measured Monthly Electricity Consumption (kWh).

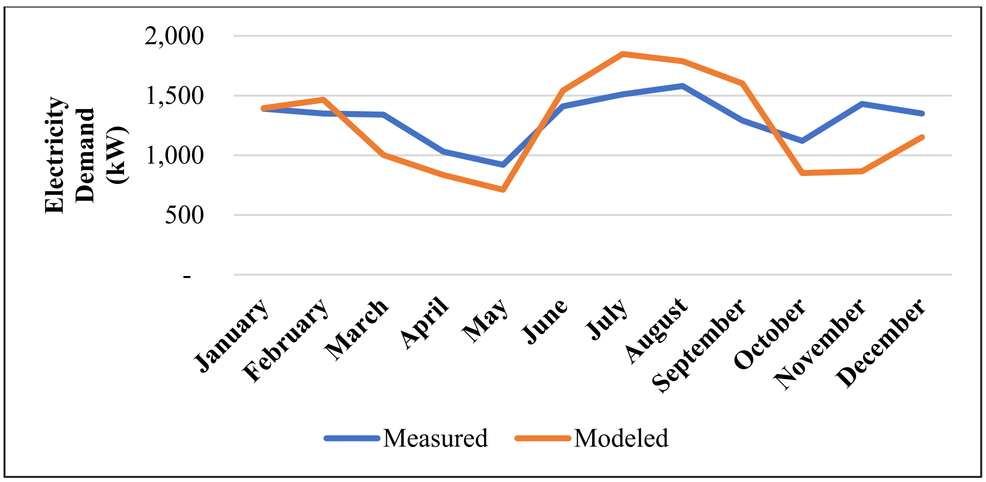

Figure D.3: Modeled vs. Measured Monthly Electricity Demand (kW).

D.6.2 Fuel Oil, Propane, and Kerosene Modeling

With the exception of propane, building fossil fuel consumption on Islesboro is largely driven by the heating needs of the year-round residences. Figure D.4 through Figure D.6 show the comparison between measured and modeled fuel oil, propane, and kerosene consumption. Of the three fuels, fuel oil was the most overestimated in the model. This is likely due to assumptions around heating system types and efficiencies used in the buildings. Note that the measured fuel consumption was based on fuel deliveries rather than actual measured consumption, so it is likely that the fuel delivery periods do not align with when the fuel was consumed. As a result, the model was considered to be more representative of when fuel is used on Islesboro.

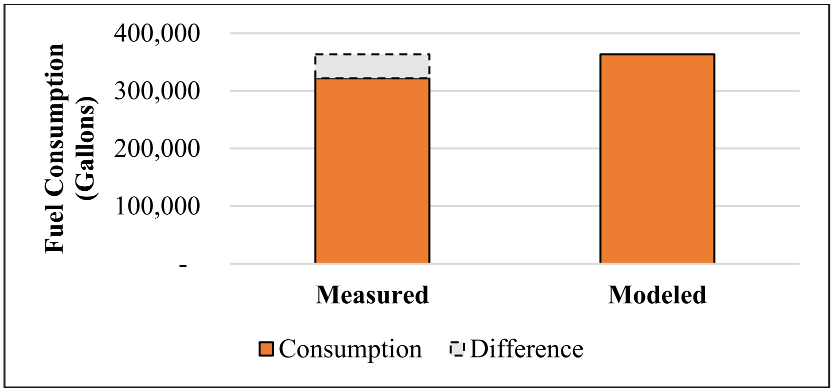

Figure D.4: Measured vs. modeled fuel oil consumption.

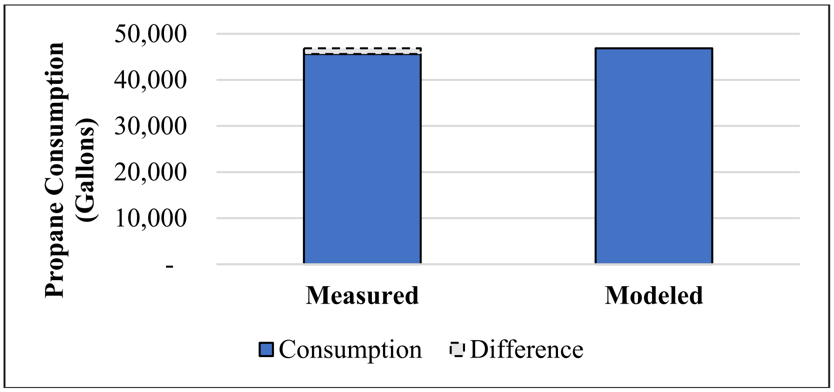

Figure D.5: Measured vs. modeled propane consumption.

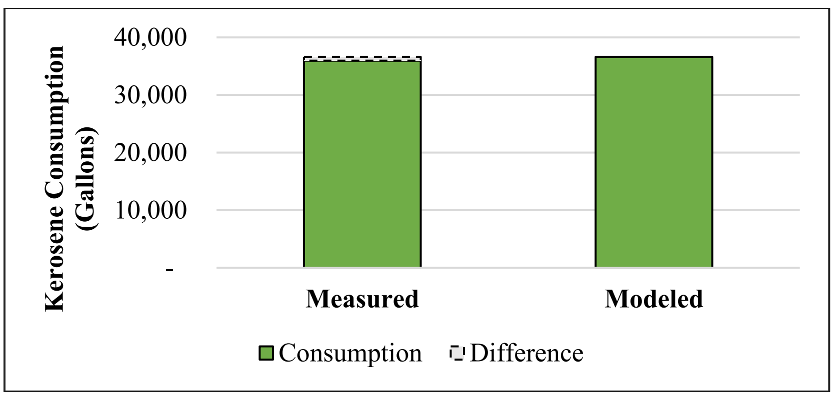

Figure D.6: Measured vs. modeled kerosene consumption.

D.6.3 Wood Modeling

Information obtained from the sources described in Section D.3 suggested that approximately 132 homes on Islesboro use wood for heating. The modeled wood consumption results from the FEDS model align with this estimate. Because measured wood consumption data was limited, the results from the FEDS model were assumed to more adequately represent wood consumption on Islesboro.

D.7 Energy Use and Costs

The energy model of the buildings on Islesboro was used to create an estimated breakdown of how energy is used by building and end use type and to estimate the typical annual costs and emissions associated with that energy.

D.7.1 Energy Use Results

Energy end uses are the different ways in which energy is used within a building. Table D.7 shows the energy use intensity estimated for each building type based on the model.

Table D.7: Energy Use Intensity Breakdown by Building Type

Building Type	Energy Use Intensity (kBtu/SF)
Year-round Homes	67
Seasonal Homes	31
Commercial	97
Municipal	78

Figure D.7 shows that the majority of energy is used in seasonal housing (seasonal housing is estimated to represent more than double the footprint of year-round housing).

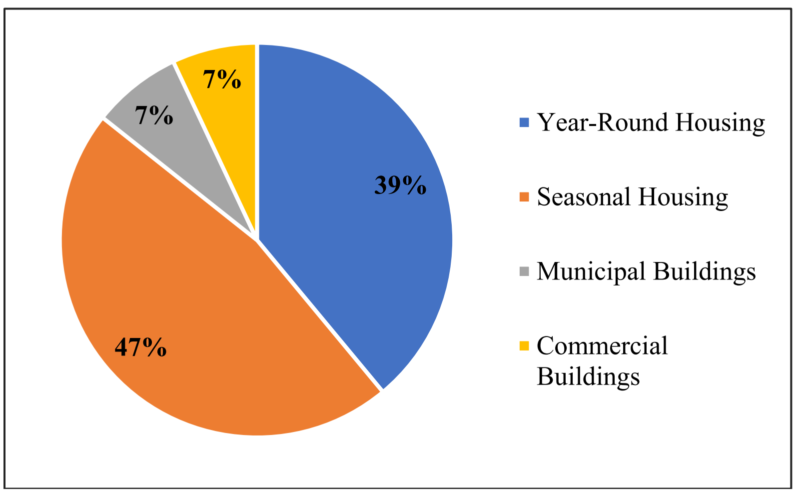

Figure D.7: Overall building energy use on Islesboro by building type.

Figure D.8 shows that approximately 64% of the energy used in buildings provides space heating, followed by hot water and cooking/other energy uses. All of these end uses are fossil-fuel intensive, so addressing them can have a significant, positive impact on Islesboro's emissions. Figure D.9 shows that seasonal homes use more of their annual energy on heating than year-round homes, although their overall energy use intensity is lower than in year-round homes.

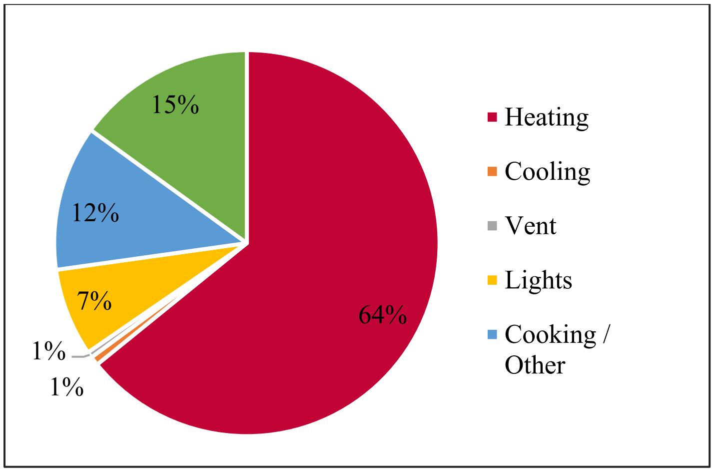

Figure D.8: Overall building energy use on Islesboro by end use.

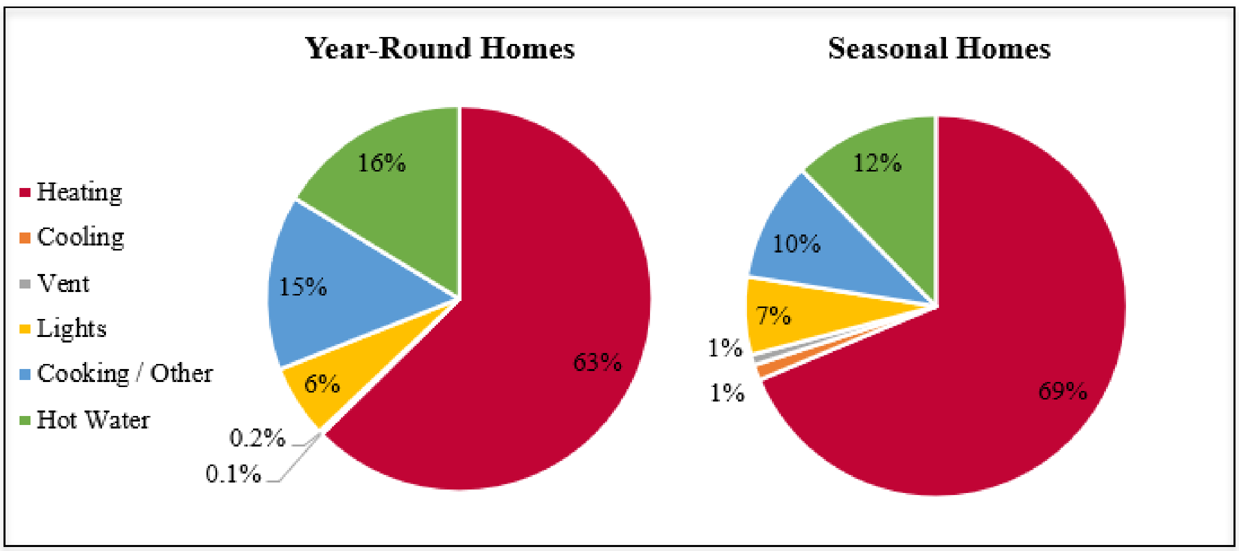

Figure D.9: Building energy use split in year-round vs. seasonal homes.

D.7.2 Energy Cost Estimates

Table D.8 and Table D.9 show the estimated annual energy costs for Islesboro (calculated using the energy commodity costs shown in Section G.1) broken down by fuel and building type. Table D.9 also shows the total average energy cost per square foot for each building type. Year-round homes have a higher cost per square foot given their increased need for heating in the winter.

Table D.8: Estimated Annual Energy Costs for Islesboro by Energy Source

Energy Source	Annual Cost ($/Year)	Percent of Total Energy Costs
Fuel Oil #2	1,230,000	41%
Propane	165,000	5%

Energy Source	Annual Cost ($/Year)	Percent of Total Energy Costs
Kerosene	140,000	5%
Wood Pellets	170,000	6%
Electricity	1,280,000	43%
Total	2,990,000	-

Table D.9: Estimated Annual Energy Costs for Islesboro by Building Type

Energy Source	Annual Cost ($/Year)	Average Cost per Square Foot ($/SF)	Percent of Total Energy Costs
Year-Round Housing	1,200,000	2.3	40%
Seasonal Housing	1,360,000	1	45%
Commercial Buildings	220,000	3.4	7%
Municipal Buildings	210,000	2.5	7%

D.7.3 Energy Emissions

Table D.10 shows the annual energy emissions by energy source and end use estimated using the energy model.

Table D.10: Estimated Annual Energy Emissions for Islesboro by Energy Source and End Use

Energy Source	Heating	Cooling	Vent	Lights	Cooking/ Other	Hot Water	Total
Electricity (Ton CO2e)	370	90	60	890	1,130	220	2,760
Fuel (Ton CO2e)	2,830	-	-	-	-	890	3,720
Kerosene (Ton CO2e)	370	-	-	-	-	-	370
Propane (Ton CO2e)	110	-	-	-	160	-	270
Wood (Ton CO2e)	1,080	-	-	-	-	-	1,080
Total	4,760	90	60	890	1,290	1,110	8,200

D.8 References

NMR Group, Inc. 2015. *Maine Single-Family Residential Baseline Study*. Prepared by NMR Group, Inc., for Efficiency Maine. https://www.efficiencymaine.com/docs/2015-Maine-Residential-Baseline-Study-Report-NMR.pdf.

Appendix E – Opportunities Assessment

E.1 Energy Efficiency

Energy efficiency measures (EEMs) were identified and chosen for evaluation by reviewing existing studies (including past studies conducted by the Islesboro Energy Committee [IEC] and the Island Institute) and consulting with residential energy experts. A major source of information for the type of EEMs that would be applicable for homes in Maine's climate is Amann et al. (2021), which was reviewed for residential energy deep retrofit packages, with a specific focus on retrofits for cold and coastal climates. In this report, the American Council for an Energy-Efficient Economy provided climate-specific recommendations designed to meet energy efficiency goals while considering the unique challenges posed by varying climates. Measures that were recommended in the cold and marine deep retrofit packages were taken into consideration for Islesboro homes. These measures were then discussed with residential energy-efficiency experts at Pacific Northwest National Laboratory (PNNL), and a final list of measures was selected for analysis.

The measures were modeled using the Facility Energy Decision System (FEDS) software to modify the energy models developed as part of the loads assessment and, where applicable, were supplemented by industry-standard calculations.

E.1.1 Energy-Efficiency Measure Description

The following is a description of each of the measures evaluated, and what the proposed upgrades may entail.

Lighting Upgrades

Buildings on Islesboro currently have a mixture of compact fluorescents, incandescent lighting, and halogen lighting (both interior and exterior). Replacing these technologies with more energy-efficient lighting such as ENERGY STAR qualified or LED light bulbs and fixtures reduces electricity consumption and costs in a home or business without compromising the amount of lighting provided.

Lighting Sensors/Controls

Buildings on Islesboro are assumed to have limited use of lighting controls, such as dimming switches, timers, or occupancy sensors. Adding these types of lighting sensors or controls can reduce lighting energy use by shutting off specific lights at a predetermined time (most applicable to outdoor lighting) or when people are not in the room.

Insulation Upgrades

Properly insulating a home or business will improve occupant comfort while reducing heating and cooling usage and costs. Insulation can take different forms depending on the type of building and its characteristics, but in homes it can typically be added to the attic, crawl space or basement, and exterior walls.

Window Upgrades

Installing more energy-efficient windows can improve the performance of a building's envelope, helping save energy and improving comfort in the process. Upgraded and properly sealed windows can also prevent unwanted air infiltration into the building.

Weatherization

Weatherization or weatherproofing refers to the practice of sealing a building to prevent air from infiltrating the home and increasing heating and cooling needs. Buildings can typically be weatherized by sealing air leaks around windows, doors, fireplaces, walls, and other places exposed to the outdoors.

Programmable Thermostats

Programmable thermostats are devices that can replace manual HVAC system controls and be programmed to automatically regulate a building's temperature. When combined with temperature setbacks, they can help reduce energy consumption related to heating and cooling.

Temperature Setbacks

The temperature setpoint for heating and cooling systems is an important factor in the energy consumption of those systems. Reducing the heating setpoint and increasing the cooling setpoint by a few degrees can reduce energy consumption for space heating and cooling.

Upgrading Heating Equipment

As shown in Section D.7.1, over 60% of the total energy use in Islesboro homes is for home heating. In Maine's heating-dominated climate, having a high-efficiency heating system can reduce heating energy use and costs for a typical home. Two types of heating equipment upgrades were evaluated as part of this EEM:

- Lower Efficiency: Given the age of buildings on Islesboro, it was assumed that many home heating systems are performing at an efficiency of approximately 70%. Newer, non-condensing heating systems typically perform at an efficiency of 80% or greater.
- Higher Efficiency: Certain types of heating systems, such as condensing boilers and furnaces, can perform at an efficiency greater than 90%.

Upgrading Water Heating Equipment

Water heating is a significant energy end use in residential buildings. Installing more energy-efficient water heating equipment can reduce the amount of energy required for supplying hot water.

Pipe and Equipment Insulation

Uninsulated pipes and tanks that contain hot water for domestic use as well as space heating should be insulated to minimize heat loss to the environment.

High-Efficiency Plumbing Fixtures

High-efficiency plumbing fixtures are showerheads, faucets, and other plumbing fixtures designed to reduce water flow without compromising water pressure. By saving on water use, these fixtures can also result in energy savings.

Upgrade Cooling Equipment

Although energy use for cooling on Islesboro is minimal, wherever a cooling system is needed, installing high-efficiency equipment (for example, ENERGY STAR certified window air conditioning units) can reduce the energy required for cooling.

E.1.2 Energy Savings and Cost Estimates

Energy and cost savings for each of these measures were calculated and extrapolated to the entire portfolio of Islesboro buildings, based on building type, age, and seasonal occupancy. Table E.1 shows an estimate of the total potential energy savings from the implementation of EEMs in all buildings on Islesboro. Savings for each energy source are shown as a percentage of annual consumption for that source, but the table also includes the overall savings by measure both as total energy (in million British thermal units [MMBtu]) and as a percentage of the total energy use on the island. For example, if lighting fixture upgrades were to be implemented in all buildings on Islesboro, the measure would save approximately 21% of the annual electricity consumption for the island, but result in a 3%, 2%, 1%, and 2% increases in fuel oil, kerosene, propane, and wood consumption, respectively, due to interactive effects. On the whole, the measure can save 3% of the total energy use on the island.

Table E.1: Energy Savings from Energy-Efficiency Measures

Measure	Electricity (%)	Fuel Oil (%)	Kerosene (%)	Propane (%)	Wood (%)	Total Savings (MMBtu)	Total Savings (%)
Lighting Fixture Upgrades	21%	−3%	−2%	−1%	−2%	2,500	3%
Lighting Control Upgrades	0.5%	−0.1%	−0.1%	0%	0%	30	0.04%
Insulation Upgrades	2%	12%	11%	4%	10%	7,900	9%
Window Upgrades	2%	15%	14%	6%	14%	10,500	11%
Weatherization	1%	5%	6%	2%	6%	3,600	4%
Programmable Thermostats	0.2%	1%	1%	1%	2%	700	1%
Temperature Setbacks	1%	2%	1%	0.7%	1%	1,100	1%
Heating Equipment Upgrades (Lower and Higher Efficiency)	0%	8–15%	12–21%	5–9%	12–21%	6,300–11,400	7–12%
Water Heating Equipment Upgrades	0%	2%	0%	0%	0%	1,100	1%

Measure	Electricity (%)	Fuel Oil (%)	Kerosene (%)	Propane (%)	Wood (%)	Total Savings (MMBtu)	Total Savings (%)
Pipe Insulation	0%	1%	0%	0%	0%	400	0.4%
High-Efficiency Plumbing Fixtures	1%	3%	0%	0%	0%	1,800	2%
Upgrade Cooling Equipment	1%	0%	0%	0%	0%	300	0.3%
Total[1]	29%	45–52%	43–52%	18–22%	43–52%	36,000–41,100	39–44%

[1] The lower end of the range represents the "Minimum Efficiency" heating upgrades, while the upper end represents the "Maximum Efficiency" upgrades.

Measure costs were determined from the FEDS software and from market research. Two types of costs were evaluated:

- Full costs: an estimate of the full cost required to implement an EEM if completed outside previously planned or required maintenance. Example: replacing an existing heating system before the end of its life.
- Marginal costs: an estimate of the difference in cost between higher-performing equipment and a planned or required like-for-like equipment replacement as part of typical maintenance. In other words, marginal cost is the premium paid for replacing a building system at the end of its life with a higher-performing version. Example: installing an LED light bulb instead of an incandescent or fluorescent light bulb when the original light bulb goes out. Note that not all EEMs have a marginal cost.

Costs for each measure were broken down to a $/SF value in order to extrapolate to other buildings based on square footage. Incentives provided by Efficiency Maine and, where applicable, Spark Grants by the Island Institute, were estimated to provide a more complete financial picture for each ECM. Table E.2 shows the full and marginal costs per square foot used and a list of available incentives for each measure.

Table E.2: EEM Costs per Square Foot and Incentives

Measure	Full Cost ($/SF)	Marginal Cost ($/SF)	Available Incentives
Lighting Fixture Upgrades	0.47	0.02	Efficiency Maine works with specific retailers to offer discounted LED light bulbs. The Island Institute provides Spark Grants for lighting upgrades.
Lighting Control Upgrades	0.11	0.11	-
Insulation Upgrades	1.45	1.45	Efficiency Maine offers an incentive of 50% of cost up to $5,000 per home, and 90% or up to $9,000 for low-income homes.
Window Upgrades	2.74	0.56	-
Weatherization	0.5	0.5	Programs and rebates available from Efficiency Maine based on income.
Programmable Thermostats	0.23	0.1	-

Measure	Full Cost ($/SF)	Marginal Cost ($/SF)	Available Incentives
Temperature Setbacks	0.05	0.05	-
Heating Equipment Upgrades (Lower Efficiency)	2.24	0.39	None for fuel-based systems. Up to $6,000 from Efficiency Maine for biomass boilers and furnaces.
Heating Equipment Upgrades (Higher Efficiency)	1.83	0.51	None for fuel-based systems. Up to $6,000 from Efficiency Maine for biomass boilers and furnaces.
Water Heating Equipment Upgrades	1.67	1.67	-
Pipe Insulation	0.5	0.5	-
High-Efficiency Plumbing Fixtures	0.19	0.19	-
Upgrade Cooling Equipment	0.2	0.2	Efficiency Maine offers incentives and rebates for certain types of cooling equipment, including heat pumps.

E.2 Renewable Energy Assessment

This section provides information on the assumptions and inputs used in the renewable energy assessment.

E.2.1 Solar Photovoltaics

The island's potential capacity for solar photovoltaic (PV) installation was assessed using two types of PV—rooftop and ground-mounted. The following assumptions were made when assessing the potential for PV:

- General Assumptions
  - Using NREL's PVWatts tool,[23] it was estimated that each kW–direct current (DC) of installed PV has the potential to generate between 1,214 and 1,303 kWh of electricity annually. For this analysis, a value of 1,256 kWh per kW-DC of installed capacity was used. Annual generation can vary year to year depending on weather and other factors.

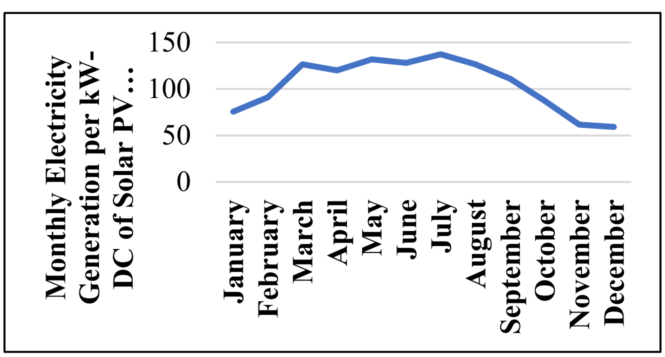

Figure E.1: Monthly generation potential per kW-DC of installed solar PV.

[23] NREL PVWatts

- Rooftop PV
  - Approximately one-third (33%) of buildings on Islesboro are compatible with PV
    - A building may not be compatible with PV depending on its location and surrounding shading or its roof area and condition. Because Islesboro is a mostly wooded island, a conservative estimate of the compatibility of buildings was made. The compatibility of PV for each building should be evaluated independently.
    - The total roof area for compatible buildings is 10% greater than that building's floor area (for example, if a building has 1,000 square feet of floor area, it has 1,100 square feet of roof area). Of a building's total roof area, 40% was assumed to be usable for PV.
- Ground PV
  - Islesboro has several open, unwooded areas that could potentially be used for PV. Only a few of these sites were included in this initial assessment. Each potential PV site should be evaluated independently to assess its potential and understand limitations from local property rights and other factors.

E.2.2 Wind Energy

According to data collected by NREL in the resource map shown in Figure E.2, Maine's potential for wind power generation ranges from fair to outstanding along most of its coast. In the areas surrounding Islesboro, this potential is primarily fair to good. However, due to the community's concerns around having land-based wind power on Islesboro and Maine's law prohibiting offshore wind energy projects in state waters used for recreation and fishing (State of Maine 2021), wind energy was not considered a viable technology for Islesboro at this time.

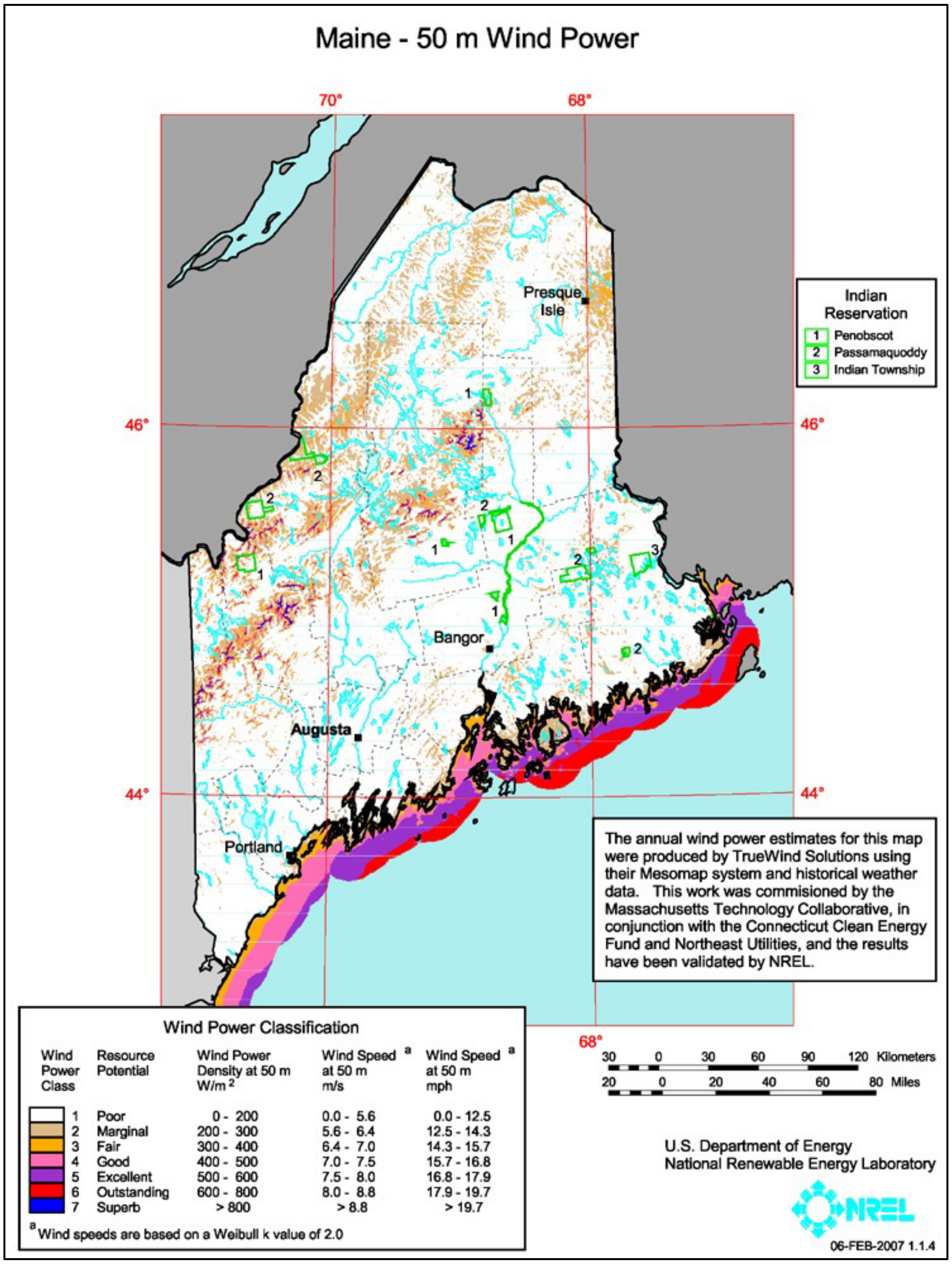

Figure E.2: Maine 50-meter wind power map (WINDExchange n.d.).

E.2.3 Tidal Energy

Tidal energy is a possibility in Maine due to the amplification of tidal ranges caused by tidal resonance in the Bay of Fundy. Large tidal ranges combined with inlets, foreland/headlands, or narrow passageways between islands serve to create water currents strong enough to power tidal energy harvesting devices, i.e., turbines. This comes with the stipulation, however, that high-resource areas are co-located with electricity infrastructure to transfer power. Islesboro is a sheltered island in West Penobscot Bay, where tides range between 2 and 4 m.

The feasibility of harnessing tidal energy around the island was assessed using Xtide, an open-source software commonly used by government and industry to predict tides and currents at various reference and substations around the maritime United States. Predictions and forecasts are based off of tidal harmonics calculated from data collected using 1–3-month tide gage and current meter deployments, typically conducted by the National Oceanic and Atmospheric Administration (NOAA). Tidal harmonics are accurate for approximately 100 years.

Forecast data was collected from 14 water current stations around the island for 30 days, from May 1 through May 30, 2022. Average speed was calculated from the absolute value of current velocity, and maximum speed is the fastest speed seen at either ebb or flood tide. Water current stations about the island consistently forecast max speeds around 0.35 m/s, with the strongest flow around the northeast corner of the island (Turtle Head Point) that can hit 0.55 m/s. These low speeds are not surprising for a large bay like Penobscot, and in Maine it appears the strongest tidal flows occur between islands farthest out from the mainland in the Gulf of Maine.

Figure E.3 and Figure E.4 show the maximum and average flow velocities, respectively, at 14 locations about the island labelled *a*–*n*. Figure E.5 shows the exceedance probability curve for Turtle Head Point, the location of the fastest flow. To run a turbine, water will ideally be flowing at or above the turbine's cut-in speed—the water speed necessary to overcome resistance in the generator—at least 50% of the time. For current technology, the cut-in speed ranges between 0.8 and 1.5 m/s. Water velocity at Turtle Head Point is only above 0.19 m/s 50% of the time.

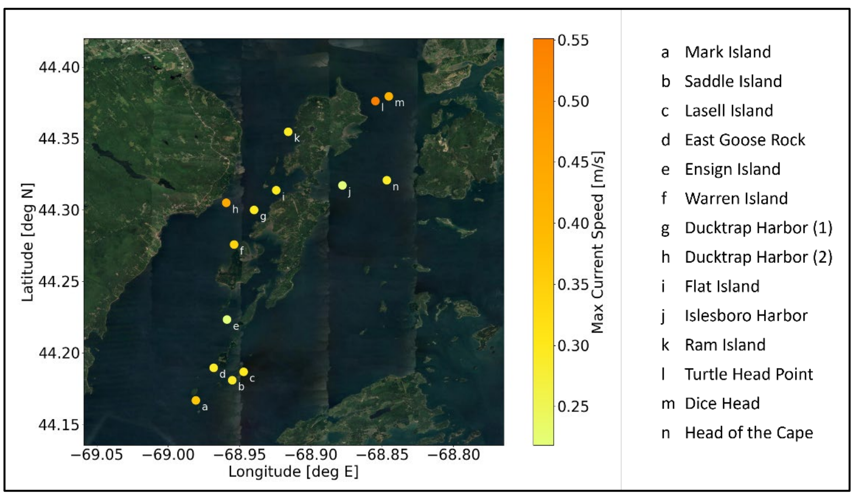

Figure E.3: Maximum water current speeds around Islesboro, Maine.

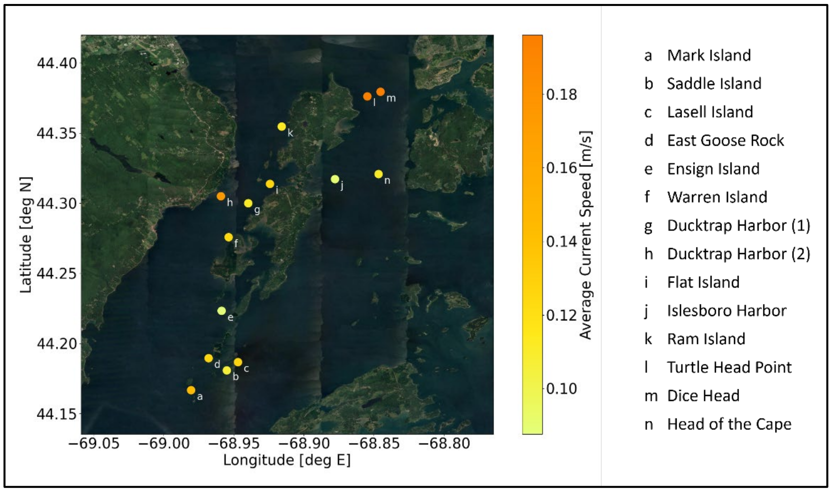

Figure E.4: Average water current speeds around Islesboro, Maine.

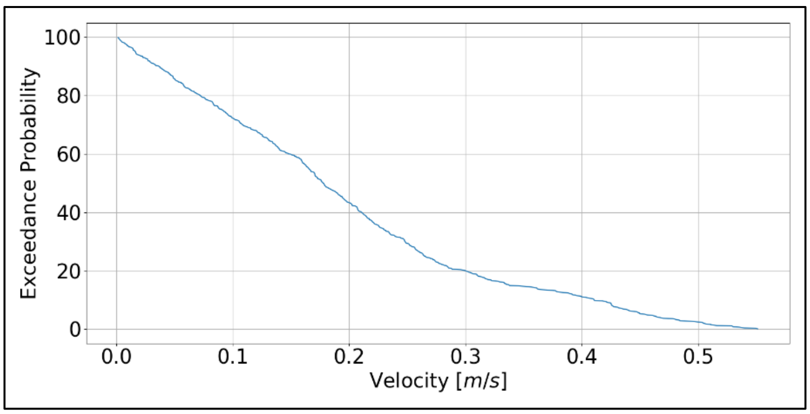

Figure E.5: Exceedance probability curve for Turtle Head Point (site L).

For reference, Cobscook Bay and the Western Passage are prime resources for marine renewable energy in Maine. Both have resources up to 2.5 m/s, which is enough current speed to run hydrokinetic turbines that output in the ballpark of 30–150 kW apiece, and infrastructure that a turbine can be powered by and send power to (Yang et al. 2020). The company ORPC is permitted to and has been utilizing a site in Cobscook Bay to test a 150 kW module of their turbine design since 2012 (Tethys 2020). Areas such as Cobscook Bay, i.e., those capable of delivering grid-scale power, are limited and are outlined for the United States in a report by NREL (Kilcher et al. 2021).

Wave energy, the other form of marine renewable energy, is also not substantial in the region, which not atypical for the eastern seaboard (Kilcher et al. 2021). There is a low level of theoretical resource, but the technical viability of wave harvesting is low enough to be unfeasible.

E.3 References

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Appendix F – Load Forecast Projections

PNNL developed forecasts for the future load on Islesboro considering factors such as population and building growth and transportation electrification to provide a more holistic picture of energy use on the island and a basis for the alternatives analysis that was conducted using HOMER. This appendix provides additional detail on how the forecasts and their different components were modeled.

F.1 Existing Buildings and Growth Drivers

Islesboro has a population of 600 year-round residents with an additional 1,400 seasonal residents during the summer months. According to U.S. Census data published in the 2017 Island Comprehensive Plan, the total number of residences on Islesboro has increased by approximately 39% since 1990, but the number of full-time residences remained relatively flat. See Figure F.1 for reference.

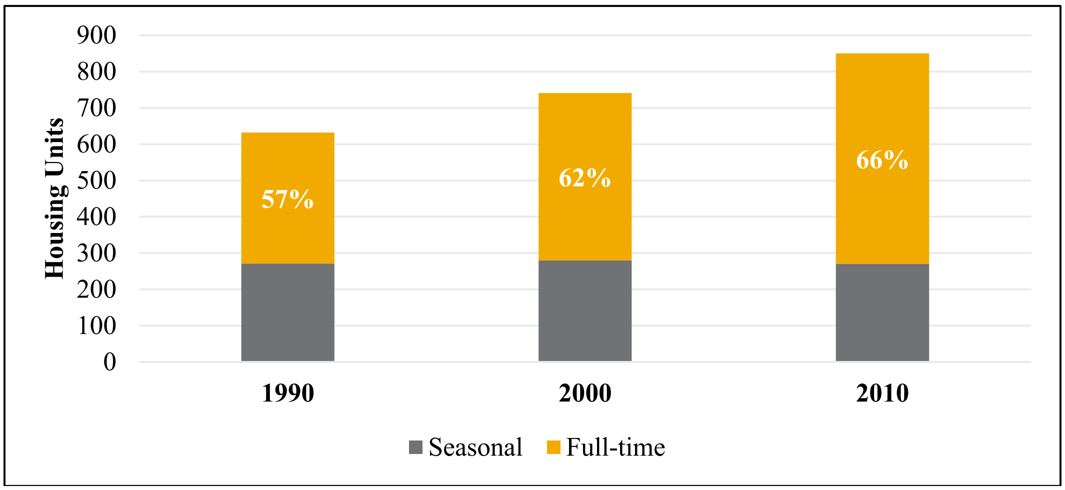

Figure F.1: Islesboro housing growth since 1990.

Source: 2017 Island Comprehensive Plan for Islesboro

In 2016, Islesboro conducted a survey of existing housing units on the island as part of its broadband installation project. As of 2016, over 90% of the buildings on the island were residences, and 65% of all buildings surveyed at the time were used only as summer residences. According to the Islesboro Energy Committee (IEC), the total number of housing units on Islesboro and the distribution of full-time and seasonal housing is likely to have changed as a result of the ongoing COVID-19 pandemic. Census data showed that the year-round population on the island increased by 22 people from 2019 to 2020. Assuming an average occupancy of two people per household, this increase represents an addition of 11 full-time households. It was assumed that this rate of increase in full-time households was maintained through 2021 and that in total, 5% of the existing seasonal housing stock was converted to full-time housing. Table F.1 shows the number and types of buildings on Islesboro pre- and post-pandemic.

Table F.1: Islesboro Building Summary

Building and Occupancy Type	Pre-Pandemic Building Count[1]	Post-Pandemic Building Count
Summer Residence	564	536
Year-round Residence	246	274
Commercial Buildings	13	13
Municipal and Other Buildings	39	39
Total	862	862

[1]Source: Islesboro Broadband Survey, 2016

Figure F.2 shows the overall percentage breakdown post-pandemic by building type.

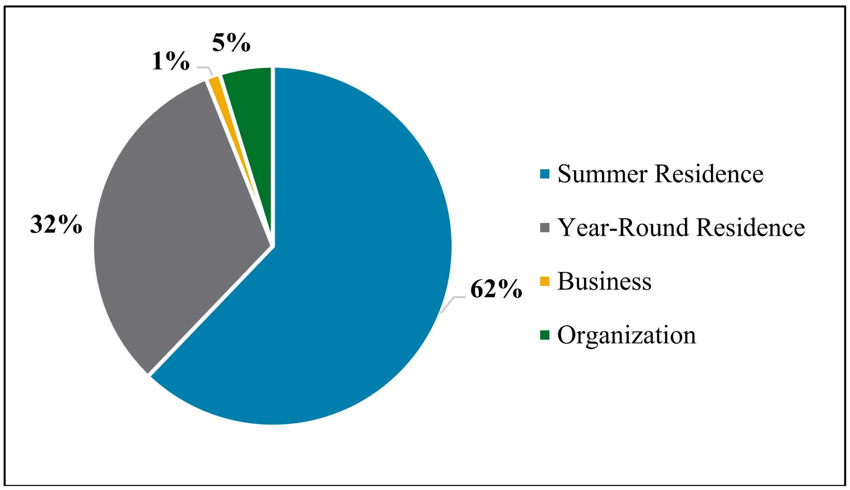

Figure F.2: Existing building percentage split by type.

F.1.1 Critical Buildings

The IEC identified 18 public buildings as critical facilities. In the case of a power blackout or other emergency, these buildings are equipped to become shelters and food supply centers and to provide all necessary aid to island residents. The facilities were grouped into five areas and ordered by their important to Islesboro's emergency activities. Table F.2 lists these critical facilities and related information.

Table F.2: Islesboro Critical Buildings

Area Name	Building Name	Street Address Islesboro, ME 04848	Services / Notes
Town Center	Town Office (Health Center, Town Offices, Emergency Services)	150 Main Rd	• Solar array • Diesel backup power generator • No pharmacy at health center
Town Center	Safety Building Department	150 Main Rd	-

Area Name	Building Name	Street Address Islesboro, ME 04848	Services / Notes
Town Center	Island Market Grocery Store	113 Main Rd	• Food supply
Town Center	Boardman Cottage Assisted Living	131 Main Rd	• Diesel backup power generator
Town Center	Second Baptist Church (Food Bank)	108 Main Rd	-
Town Center	Pre-School / Daycare	150 Main Rd	-
Town Center	Islesboro Community Center (Emergency Shelter)	103 Pendleton Point Rd	• Primary emergency shelter • Diesel backup power generator
Town Center	Post Office	114 Main Rd	-
Town Center	Library	309 Main Rd	• Town resource
School	Islesboro Central School	159 Alumni Dr	• Diesel backup power generator
Northern Islesboro	Islesboro Marine Enterprises	129 Marshall Cove Rd	• Boat storage and maintenance • Mussel harvesting
Northern Islesboro	North Island Transfer Station	1299 Meadow Pond Rd	• Solar array
Northern Islesboro	Sporting Club	1294 Meadow Pond Rd	• Social activities • Food preparation (for sale) • Backup power generator
Northern Islesboro	Durkee's General Store	867 Main Rd	• Food supply • Relies on portable generators for backup power
Dark Harbor	Tarratine Club	Ferry Rd	-
Dark Harbor	Christ Church Dark Harbor	105 Christ Church Rd	-
Dark Harbor	The Summer Shop	509 Pendleton Point Rd	-
Maine State Ferry Landing	Ferry	Terminal, Maine State Ferry Service Islesboro, Ferry Rd	• Backup power generators

Source: Islesboro Energy Committee

F.2 Modeling Future Buildings

One of the factors that will affect future energy use on Islesboro is the increase in the island's population and the addition of new buildings. Islesboro's 2017 Island Comprehensive Plan estimates that two new seasonal and one new year-round residence will be added on Islesboro per year. Based on input from the IEC, the labs assumed that this growth rate would be maintained through 2030.

New buildings were modeled in FEDS using a similar approach as with existing buildings while also updating the building system performance characteristics to align with the applicable Maine energy code, which is based on the 2015 International Energy Conservation Code (BECP 2023). Two cases were modeled—one where all new buildings use fuel oil for heating and hot water and propane for cooking, and one where those systems are electric. The estimated increase in Islesboro's overall energy consumption that could result from the addition of new buildings between now and 2030 is 1% for all-electric buildings and 1.7% for buildings using fuel oil. Because this energy impact is small, future buildings were typically not included in the load cases.

F.3 Transportation Electrification

As of 2018, only five of the 636 electric vehicles registered on Islesboro were fully electric. Although the number of electric vehicles has likely increased since then, electric vehicle adoption on the island has remained low. This is expected to change as more electric vehicles are sold in the state of Maine. In fact, the 2021 Maine Clean Energy Transportation Roadmap projects that 44–60% of all vehicles sold in the state in 2030 will be electric (Cadmus 2021). The potential added electrical load per new electric vehicle registered on Islesboro was estimated using NREL's EVI-Pro tool[24] using the following assumptions: average daily miles driven is 35; 50% of new electric vehicles will be sedans, the remainder will be SUVs; and 100% of electric vehicle users have access to and preference for home charging.

Figure F.3 shows the estimated daily load profile associated with charging one electric vehicle. These profiles were extrapolated as needed to develop the load forecasts.

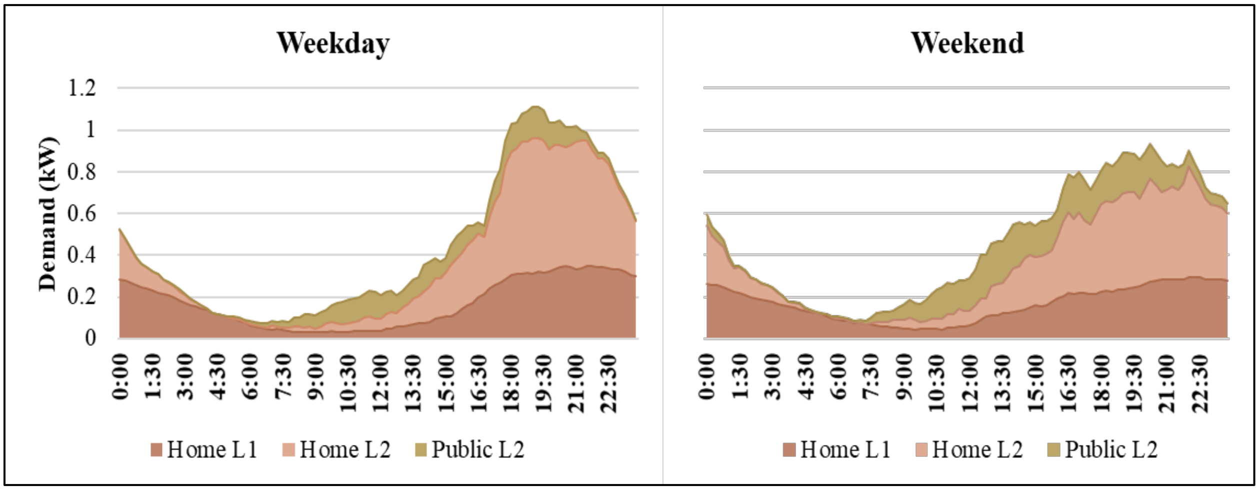

Figure F.3: Estimated electricity load profile per electric vehicle on Islesboro.

Based on these load profiles, converting all vehicles on Islesboro to all-electric vehicles would increase annual electricity consumption by 40% and overall annual energy use by approximately 9%.

F.4 Load Forecast Scenario Development

Three load scenarios were developed that combined the various growth factors and opportunities that exist on Islesboro to evaluate the combinations of renewable energy and energy storage systems that could help increase resilience on Islesboro and identify a pathway for it to achieve its energy vision.

F.4.1 Case 1: Baseline Load Scenario

This load scenario includes only the load of the existing buildings, existing electric vehicles, and existing

[24] NREL EVI-Pro Tool

renewable energy on Islesboro and excludes future building growth, additional electric vehicle electrification, energy efficiency measures, or building heating electrification. Figure F.4 shows the projected annual emissions under this load scenario through 2050. In this scenario, Islesboro's emissions in 2050 are reduced an estimated 34% from 2021 due to improvements in Central Maine Power's (CMP's) emissions factor. Energy consumption and costs do not change in this scenario.

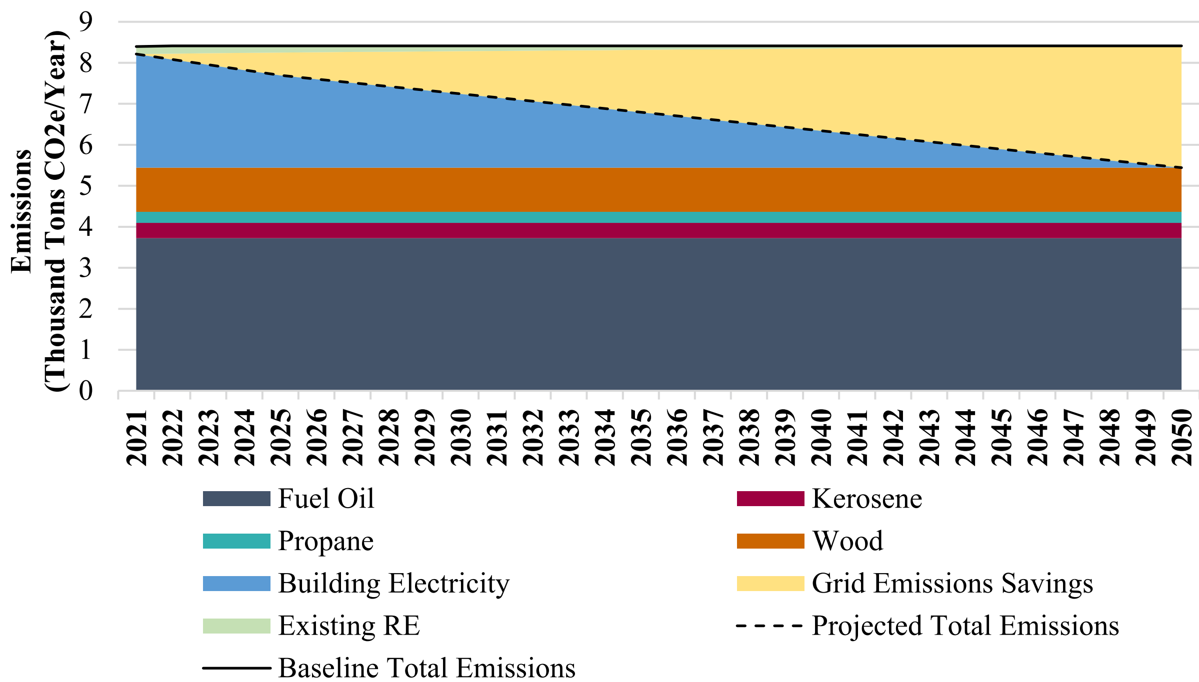

Figure F.4: Load Scenario 1 – Projected emissions through 2050.

F.4.2 Case 2: All-Electric Load

This load scenario assumes that all heating, hot water, and cooking systems in all existing buildings (including all building types) are converted to electricity and that no other EEMs are implemented. In addition, it assumes that 100% of all vehicles registered on Islesboro are replaced with electric vehicles. This load case was modeled to represent a high-electric-use scenario with no efficiency to offset the increase in overall electricity use. This scenario was included to provide a bookend to what is likely to be the future scenario on Islesboro, one in which there is some combination of system electrification, EEM implementation, and EV adoption.

Figure F.5 shows the projected Islesboro-wide energy reductions for Case 2. Heating, hot water, and cooking fuel conversion to electricity can achieve an overall energy reduction of 37% if implemented in all buildings. However, if vehicles are also electrified, energy consumption would only be reduced by 28%.

On average, Islesboro's building energy-related GHG emissions are 34% from electricity use, 53% from fossil fuel (fuel oil, kerosene, and propane) use, and 13% from wood use. Because of this split, reductions in fossil fuel use as well as the electricity emissions factor can significantly reduce overall emissions. As shown in Figure F.6, the adoption of all-electric systems, as described in this case, combined with CMP's planned emissions factor improvements could result in an 87% reduction in emissions by 2050 from the baseline case.

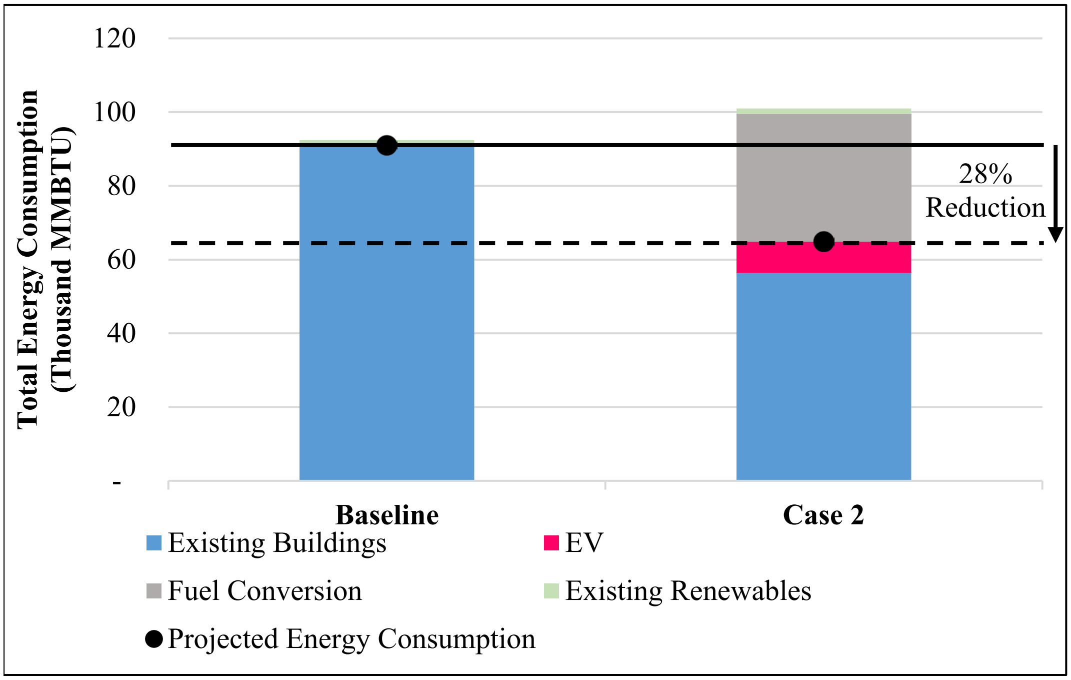

Figure F.5: Case 2 – Projected energy reduction.

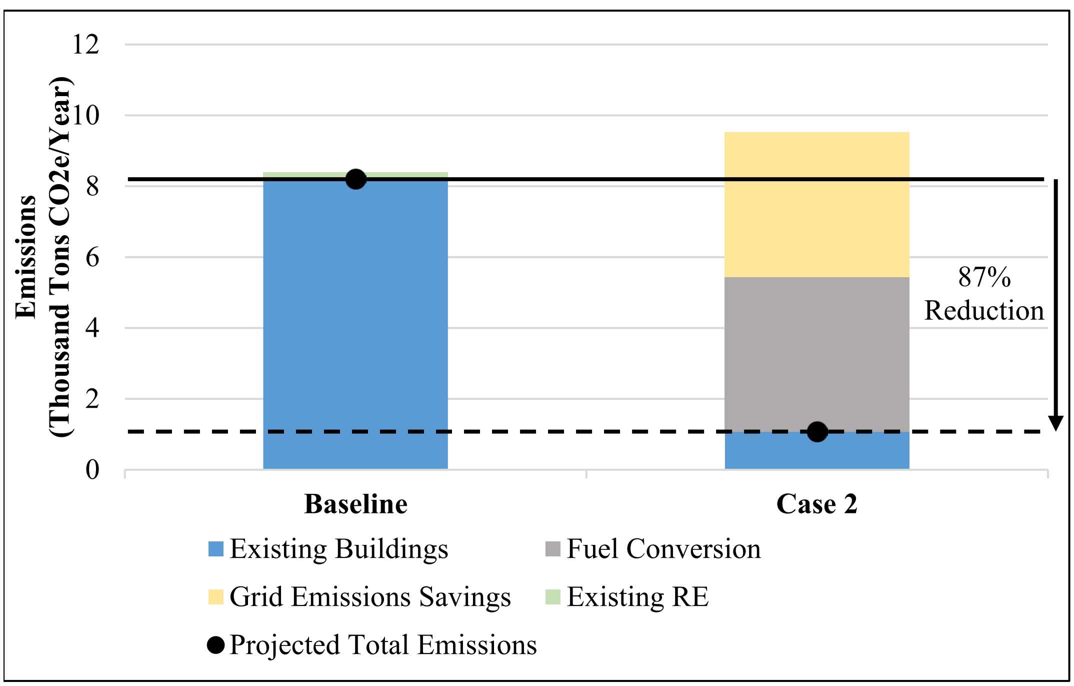

Figure F.6: Case 2 – Projected emissions reduction.

F.4.3 Case 3: Efficiency and Fuel Switching

A third load case was analyzed that included a combination of EEM implementation and heating, hot water, and cooking equipment fuel conversion but no additional electric vehicle adoption. This case is intended to represent a more realistic scenario of measure implementation on Islesboro by considering different levels of measure adoption by building type. However, it is important to note that this scenario may still not become reality in practice. Assumptions on EEM and fuel conversion adoption in different building types were made as follows:

- Year-round Housing
  - All cost-effective EEMs are adopted in 100% of year-round households, and all heating, hot water, and cooking in these households is converted to electricity.
- Seasonal Housing
  - Given that seasonal homes are mostly used during the summer months, they were assumed to be less likely to adopt some of the more costly measures that primarily reduce winter energy use. This case assumes 20% of seasonal households implement insulation and window upgrades paired with fuel conversion of heating and hot water systems.
  - 100% adoption of lighting upgrades, which is the most cost-effective measure for seasonal homes.
  - No other EEMs or fuel conversion of cooking systems were included.
- Commercial and Municipal Buildings
  - 100% adoption of lighting upgrades.
  - 20% adoption of other cost-effective EEMs such as insulation upgrades, window upgrades, and weatherization.
  - 50% adoption of heating and hot water fuel switching.

Figure F.7 and Figure F.8 show that the projected energy and emissions savings in this load case are 33% and 66%, respectively.

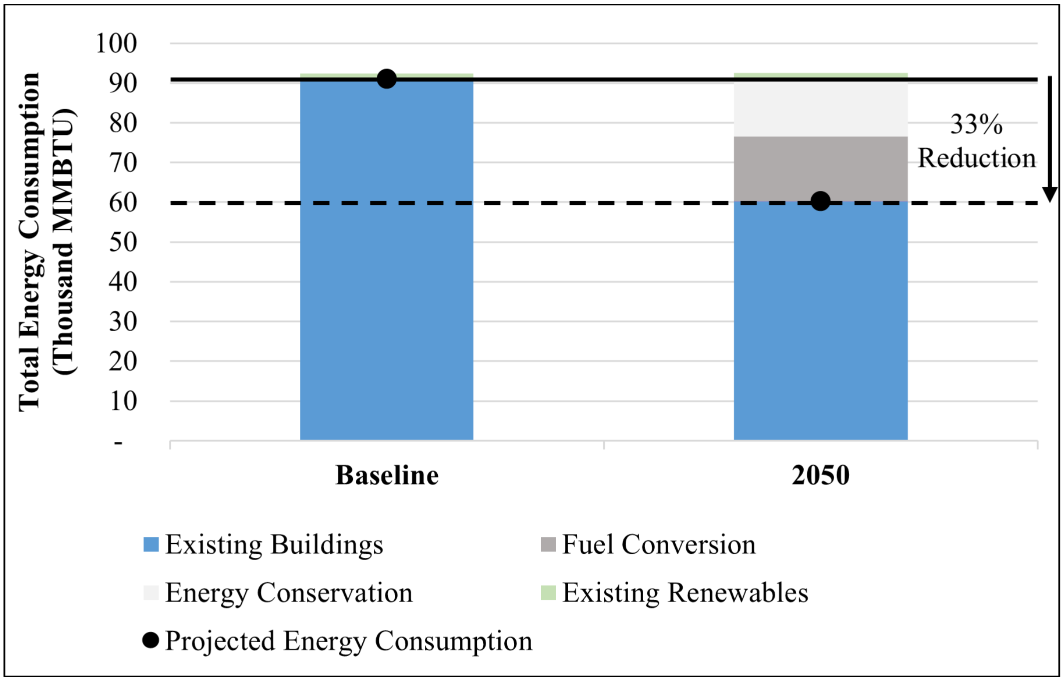

Figure F.7: Case 3 – Projected energy reduction.

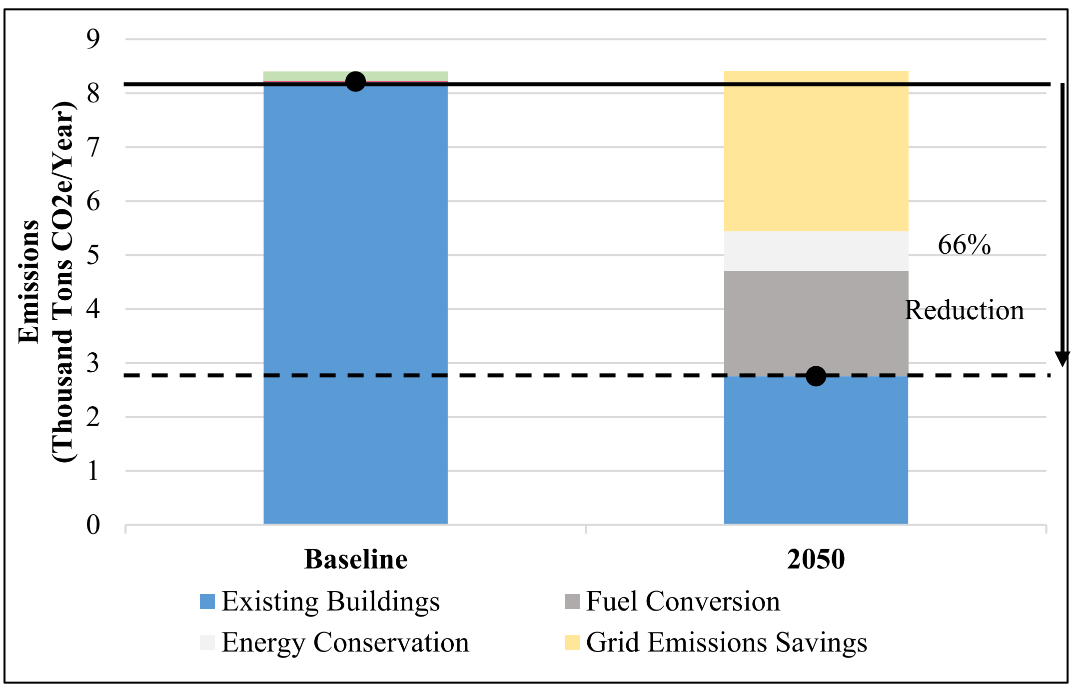

Figure F.8: Case 3 – Projected emissions reduction.

F.5 References

BECP. 2023. "BECP Status of State Energy Code Adoption." Building Energy Codes Program, Pacific Northwest National Laboratory. Last Modified January 12, 2023. Accessed December 2022 https://public.tableau.com/app/profile/doebecp/viz/BECPStatusofStateEnergyCodeAdoption/ResidentialDashboard.

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Appendix G – Key Analysis Inputs

G.1 Energy Commodity Costs

Electricity is provided to Islesboro by Central Maine Power (CMP), while other fuels are purchased from a variety of providers on- and off-island and transported to Islesboro via the ferry. The average energy costs per unit used in the analysis is shown in Table G.1 for each energy source. These average costs are based on utility bills and information provided by the IEC and were applicable as of May 2022. However, it is important to note that costs change frequently and that any future cost-benefit analyses for energy projects should be conducted using the most up-to-date costs.

Table G.1: Estimated Cost per Unit of Energy

Energy Source	Cost per Unit ($)
Fuel Oil #2	$3.39 / Gallon
Propane	$3.53 / Gallon
Kerosene	$3.85 / Gallon
Wood Pellets	$268 / Ton
Electricity	21 cents / kWh

G.2 Electricity Emissions Factors

The electricity emissions factors used in the analysis were obtained from the Uniform Disclosure Labels that are produced by CMP and submitted quarterly to the government of Maine.[25] These labels show information on the types of generation resources, fuels, and associated emissions that were used by CMP to supply their customers as part of their Standard Offer, which is what Islesboro residential customers primarily purchase. The emissions factors for CMP's electricity have been steadily decreasing over the past few years, as shown in Figure G.1, and in 2021 were approximately 37% lower than in 2017.

[25] Maine Standard Offer Disclosure Labels

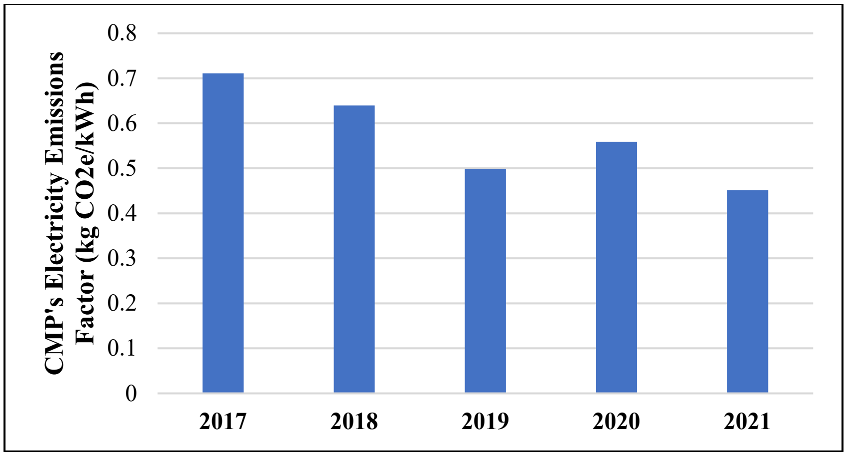


Figure G.1: CMP electricity emissions factors 2017–2021.

The emissions factor for electricity is expected to continue to decrease in the future as AVANGRID, CMP's parent company, implements its sustainability plans. According to their 2020 Sustainability Report, AVANGRID's climate goal is a 35% decrease in Scope 1 greenhouse emissions intensity (grams of carbon dioxide per kilowatt-hour of energy produced) by 2025 compared with 2015, and to be completely Scope 1 carbon neutral by 2035. According to Maine's Climate Council, the state is planning to increase its Renewable Portfolio Standard (RPS) from 40% to 80% by 2030 and has a goal of 100% clean energy by 2050 (MCC n.d.). These two plans were used to project the future electricity emissions factor, and it was assumed that CMP will be able to provide 100% carbon-free electricity to Islesboro by 2050.

G.3 Other Emissions Factors

Emissions associated with fossil fuels and wood consumption were obtained from the U.S. Environmental Protection Agency (EPA) Emission Factors for Greenhouse Gas Inventories (EPA 2022). All factors used are summarized in Table 17 in units of carbon dioxide equivalent (CO2e), which includes the global warming potential of not only carbon dioxide, but also of methane and nitrous oxide.

Table 8-1: Greenhouse Gas Emissions Factors by Energy Source

Energy Source	Emissions Factor (kg CO2e per Unit)
Fuel Oil #2	10.2 kg CO2e / Gallon
Propane	5.7 kg CO2e / Gallon
Kerosene	10.2 kg CO2e / Gallon
Wood Pellets	1,662 kg CO2e / Ton

G.4 References

EPA. 2022. "Emission Factors for Greenhouse Gas Inventories." Environmental Protection Agency. Last Modified April 1, 2022. Accessed January 2022 https://www.epa.gov/system/files/documents/2022-04/ghg_emission_factors_hub.pdf.

MCC. n.d. "Energy." Maine Climate Council. Accessed January 2022 https://climatecouncil.maine.gov/strategies/energy#:~:text=To%20encourage%20more%20lower%2Demission,created%20by%20law%20in%202019.

Appendix H – Detailed HOMER Results for Key Cases

H.1 Case 1: Island-Wide Scenario Baseline – Grid Connected Only

In this scenario, electricity supply to the entire island is considered, with the existing electric load based on 2021 data. Except for electricity provided by the existing 352 kW of solar photovoltaics (PV) installed on the island, all the electricity is supplied by Central Maine Power (CMP). In this scenario, as in all other island-wide scenarios, we assume a five-consecutive-day interruption in service late in the year, intended to provide a worst-case scenario that can be used by HOMER to size appropriate backup resources to improve energy availability.

H.1.1 Annual Energy Exchange Data

Because the existing PV only supplies approximately 6% of the island's energy needs, the net draw of power from CMP is positive at all times (as visible in the "Energy Sold to Grid" panel of Figure H.1, which is always zero). Peak power draw is in the summer, as a result of the influx of part-time residents during that time. Periods of high power draw are also seen in the early part of the year, resulting from electric heating (space and water) associated with approximately 4% of all residences. The lowest electric loads occur in the spring before the influx of part-time residents. In the HOMER model, electricity charges are trued up at the end of the year. In this model, the assumption is made that all electric charges are for energy only, at $0.215/kWh, with no demand charges.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
April	[illegible]	0	[illegible]	[illegible]	$0	$0
May	343,010	0	343,010	737	$0	$0
June	683,470	0	683,470	1,510	$0	$0
July	790,102	0	790,102	1,853	$0	$0
August	772,925	0	772,925	1,885	$0	$0
September	612,635	0	612,635	1,831	$0	$0
October	374,993	0	374,993	832	$0	$0
November	386,095	0	386,095	868	$0	$0
December	387,729	0	387,729	990	$0	$0
Annual	6,150,713	0	6,150,713	1,885	$1,322,403	$0

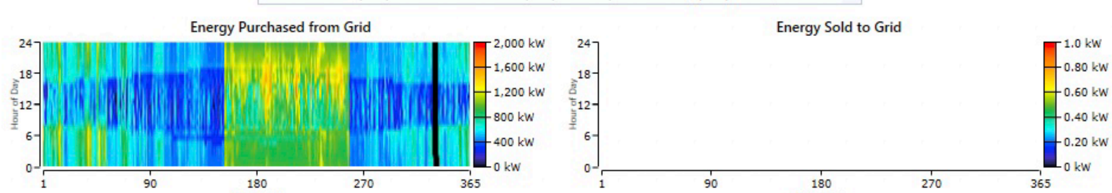


Figure H.1: Energy exchange for Case 1.

H.1.2 Cash Flow

For this case, annual cash flow only results from electricity bills because there are no upfront capital costs. The assumed discount rate is 6%, while inflation is 3%. The annual electricity charges adjusted for inflation and discount rate are presented in Figure H.2. Under these assumptions, the present value of a constant electricity bill is reduced more the further into the future the bill is. We note that the net present cost, which is used in both optimizing the system and in calculating the levelized cost of energy, is the sum of all future charges adjusted for inflation and discount rate.

Figure H.2: Cash flow for Case 1.

H.1.3 Noteworthy Features of Grid-Only Baseline

- Strong summer peak due to influx of residents
- High electricity use in January and February during non-daylight hours, likely resulting from electric heating loads and, to a smaller extent, increased lighting during longer hours of darkness.
- ~$1.3M yearly electricity bill, corresponding to a levelized cost of energy of $0.20/kWh. We note that the cost of energy is less than the cost of energy purchased from CMP ($0.215/kWh) due to the contribution of existing PV, which is assumed to be fully amortized.

H.2 Case 2: Island-Wide Scenario Baseline with PV

This scenario is in all ways the same as for Case 1, but we allow for the installation of additional PV on the island to offset purchases from CMP. The intent of this scenario is to determine to what extent energy costs can be reduced by the installation of PV. Despite additional costs due to the island location, PV can still be a source of low-cost energy. The assumptions are as follows:

- Installed cost of new PV is $2,569/kW, based on NREL ATB, with an expected lifetime of 25 years
- Yearly cost of O&M for PV is $10/kW (accounting for cleaning and minor repairs)
- New PV is installed with a panel tilt of 20° to maximize summer performance
- The minimum inverter is sized at 100% of the DC output of the array
- System derating (from panel soiling, connection losses, shading, and other factors) is 86%
- Inverter cost is $300/kW, with an expected lifetime of 15 years and a conversion efficiency of 95%
- Net energy credits at the end of each month can be used to offset energy charges for a period of 12 months, but there is no compensation for any excess energy exported to the CMP grid.

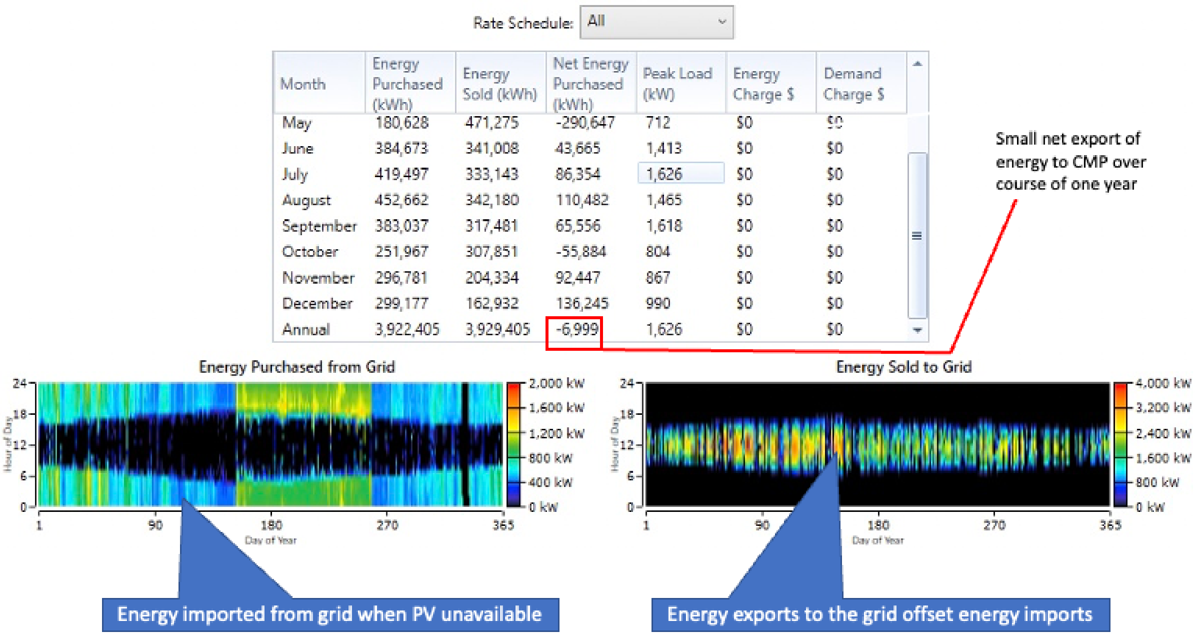
Based on this, HOMER recommends the installation of a 4.75 MW array, which corresponds to a required land area of approximately 21 acres. A practical perspective of a 21-acre size array located near the Islesboro airstrip is shown in Figure H.3.

Figure H.3: 4.75-MW/21-acre PV array, shown in comparison to the Islesboro airstrip.

The net present cost of this system is $15.3M, corresponding to a levelized cost of energy of $0.131/kWh.

H.2.1 Annual Energy Exchange Data

The energy exchange with CMP over the course of a year is shown in Figure H.4. The peak PV output is approximately twice as large as the maximum load, so net exports to the CMP grid occur almost daily, except during cloudy days. The monthly energy exchange data table shows that in some months there is a net energy sale to CMP, while in other months there is a net purchase. The actual billing arrangement with CMP is that the customer can use an energy credit in one month to offset net energy consumption in any of the following 12 months. HOMER does not allow for this specific arrangement in the model, but a close approximation is to true-up energy sales and purchases at the end of each year. With this arrangement, the CMP grid serves the function of a large battery that can store excess PV at no cost. It is not surprising, therefore, that optimal PV array sizes recommended by HOMER tend to produce just enough energy so that the yearly balance is zero.



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
May	180,628	471,275	-290,647	712	$0	$0
June	384,673	341,008	43,665	1,413	$0	$0
July	419,497	333,143	86,354	1,626	$0	$0
August	452,662	342,180	110,482	1,465	$0	$0
September	383,037	317,481	65,556	1,618	$0	$0
October	251,967	307,851	-55,884	804	$0	$0
November	296,781	204,334	92,447	867	$0	$0
December	299,177	162,932	136,245	990	$0	$0
Annual	3,922,405	3,929,405	-6,999	1,626	$0	$0

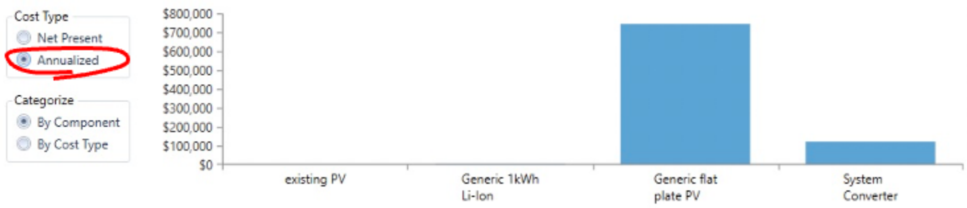
Figure H.4: Energy exchange for Case 2.

H.2.2 Cash Flow and System Costs

The cash flow for this system, shown in Figure H.5, is very different from the one for the grid-only case shown in Figure H.2. Instead of yearly electricity bills, there is a Year 1 investment of $13.7M for the installation cost of the PV and inverter, a Year 15 replacement cost for the inverter, and a Year 25 cash inflow from the salvage value of the inverter. There are no electricity bills because there is a net export of energy at the end of each year. The O&M costs are too small to display at the pixel resolution of the chart.

Figure H.5: Cash flow for Case 2.

It is also interesting to consider tabulated system costs, shown in annualized mode in Figure H.6. The role of each system component is clear in this table, in which the cost of the PV array dominates at 85% of the total, the cost of the inverter is next at about 14%, and the other components (including a small battery specified by the optimizer likely as a numerical approximation) make up less than 1% of the total. We also note that the levelized cost of electricity is the annualized total system cost divided by the total energy used by the island loads.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
existing PV	$0.183	$0.00	$0.00	$0.00	$0.00	$0.183
Generic 1kWh Li-Ion	$3,127.86	$2,033.38	$1,000.00	$0.00	-$508.64	$5,652.60
Generic flat plate PV	$694,650.61	$0.00	$47,546.40	$0.00	$0.00	$742,197.01
System Converter	$81,296.69	$52,849.79	$0.00	$0.00	-$13,220.13	$120,926.36
System	$779,075.34	$54,883.17	$48,546.40	$0.00	-$13,728.77	$868,776.15

LCOE = $868,776/6,622,583kWh = $0.131/kWh

Figure H.6: System costs for Case 2.

H.2.3 Noteworthy Features of the Lowest-Cost Baseline Scenario

- Levelized Cost of Energy (LCOE) is reduced by 35% compared to the grid-only scenario.
- Cost reduction is made possible by a combination of the low cost of PV and the availability of the grid as a zero-cost virtual storage for excess PV generation.
- Upfront investment is high but could be converted to an annual payment that is lower than the annual existing electricity bill by a suitable financial arrangement.
- PV alone does not eliminate loss of power during a grid outage.

H.3 Case 3: Island-Wide Scenario of High Electrification with PV

This scenario is in all ways the same as for Case 2, but the island-wide electric load is much higher due to electrification of heating loads (space and water) and transportation (100% EV penetration). As is the case with Case 2, HOMER recommends a large PV array that produces enough electricity to offset the electricity consumption from all the loads over the course of the year, using the CMP grid as a virtual zero-cost battery to store excess PV generation drawn from it during times of low PV generation. HOMER recommends installing 12.2 MW of PV. HOMER does not recommend where the PV should be located. It is likely that if this system were to be implemented, it would be in the form of several smaller arrays (on the order of 2 MW) spread through the island. However, for illustrative purposes, two 6.1 MW/24 acre arrays are shown close to the Islesboro airstrip in Figure H.7.

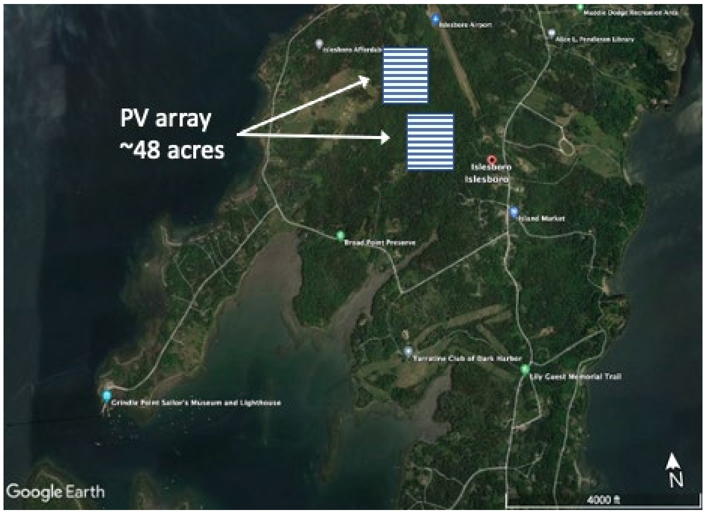
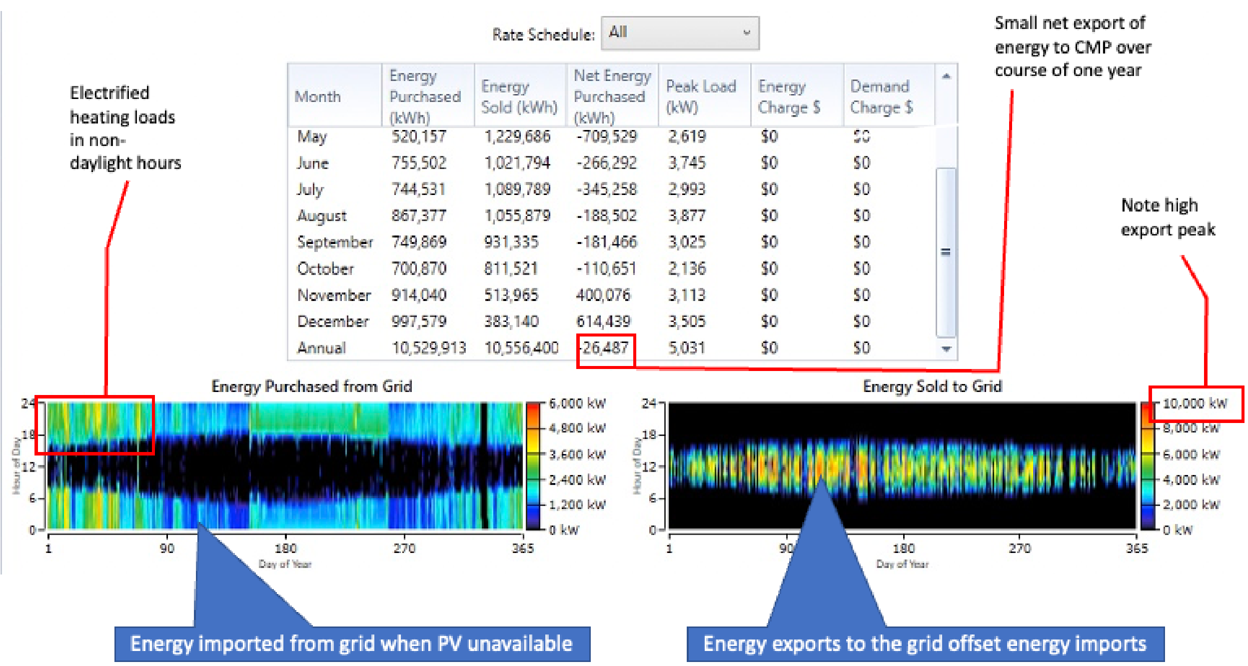


Figure H.7: 12.2-MW/48-acre array near the Islesboro airstrip.

H.3.1 Annual Energy Exchange Data

The energy exchange in the high-electrification, lowest-cost scenario (Figure H.8) is qualitatively very similar to the baseline lowest-cost scenario. The only difference is quantitative –energy exchanges are more than double those for the baseline scenario. There is a net export of energy at the end of the year that is small relative to the monthly energy purchases or sales.



Rate Schedule: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
May	520,157	1,229,686	-709,529	2,619	$0	$0
June	755,502	1,021,794	-266,292	3,745	$0	$0
July	744,531	1,089,789	-345,258	2,993	$0	$0
August	867,377	1,055,879	-188,502	3,877	$0	$0
September	749,869	931,335	-181,466	3,025	$0	$0
October	700,870	811,521	-110,651	2,136	$0	$0
November	914,040	513,965	400,076	3,113	$0	$0
December	997,579	383,140	614,439	3,505	$0	$0
Annual	10,529,913	10,556,400	-26,487	5,031	$0	$0

Figure H.8: Energy exchange for Case 3.

H.3.2 Cash Flow

The cash flow is very similar to the baseline lowest-cost case, except that the magnitudes are more than double. There is a Year 1 expenditure of $35M resulting from installation of the PV array and inverter, a Year 15 replacement of the inverter, and a Year 25 salvage cost recovery from the sale of the inverter. Small O&M costs are barely visible in the first 7 years, but become too small (they are discounted) in Years 8 and above for the resolution of the interface. The LCOE is $0.136/kWh, only slightly higher than with the baseline, owing to the reduced savings (as a fraction of the total) from the existing PV.

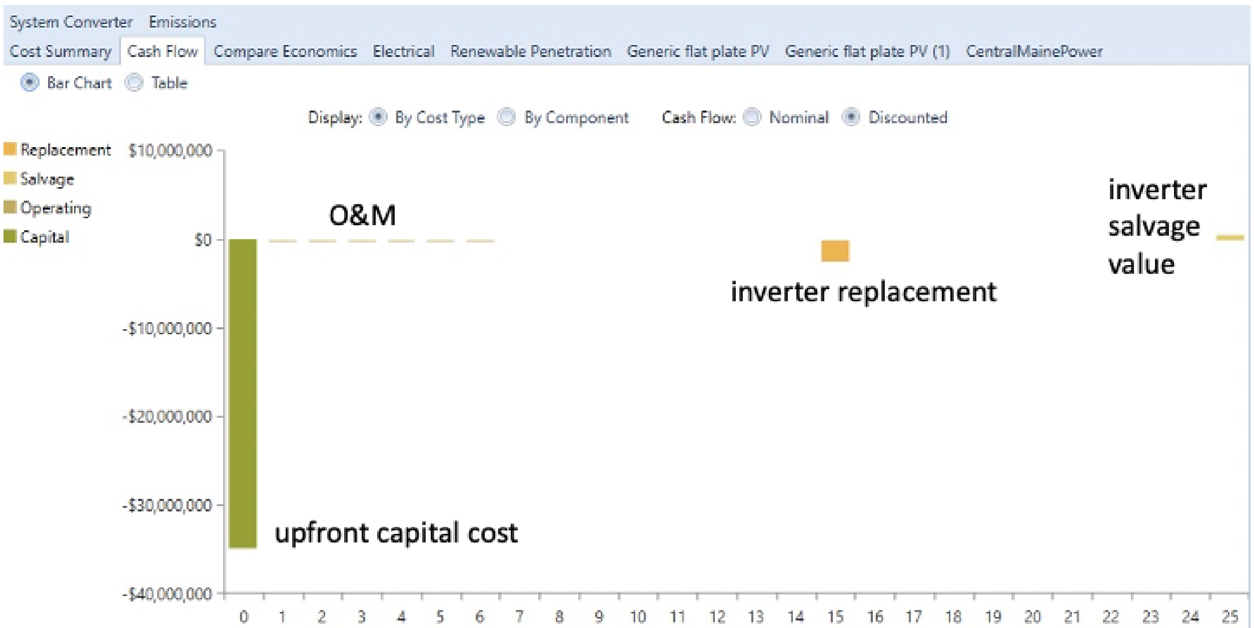


Figure H.9: Cash flow for Case 3.

H.3.3 Noteworthy Features of the High-Electrification Scenario

- LCOE is reduced by 32% compared to the grid-only scenario, but costs are higher due to increased electricity costs. However, these are likely offset by reduced fossil energy costs (heating fuel and gasoline).
- There is a $22M increase in initial investment for the larger PV array and inverter. Perhaps this could be used instead to finance energy-efficiency measures.
- PV alone does not eliminate loss of power during a grid outage.

H.4 Case 4: Island-Wide Scenario of High Electrification, High Efficiency, with PV

This scenario is in all ways the same as for Case 3, but the increase in electric load due to electrification of heating loads (space and water) and transportation (100% EV penetration) is largely offset by energy-efficiency measures. As with Case 3, HOMER recommends a PV array that produces enough electricity to offset the electricity consumption from all the loads over the course of the year, using the CMP grid as a virtual zero-cost battery to store excess PV generation draw from it at during times of low PV generation.

HOMER recommends the installation of a total 6.3MW of PV. For illustrative purposes, the 6.3 MW / 25 acre array is shown close to the Islesboro airstrip, in Figure H.10. This is only 4 acres larger than the array for the baseline case.

Figure H.10: 6.3-MW/25-acre array near the Islesboro airstrip.

H.4.1 Annual Energy Exchange Data

The energy exchange for the high-electrification, high-efficiency lowest cost scenario (Figure H.11) is qualitatively and quantitatively very similar to the baseline lowest-cost scenario. There is a net export of energy at the end of the year that is small relative to the monthly energy purchases or sales.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
May	242,883	619,296	-376,413	1,128	$0	$0
June	378,143	491,651	-113,508	1,664	$0	$0
July	385,321	502,735	-117,414	1,662	$0	$0
August	437,921	502,097	-64,176	1,798	$0	$0
September	379,885	449,403	-69,519	1,611	$0	$0
October	341,640	406,658	-65,018	1,125	$0	$0
November	451,729	260,928	190,801	1,479	$0	$0
December	486,842	191,754	295,088	1,758	$0	$0
Annual	5,180,767	5,212,495	-31,728	2,615	$0	$0

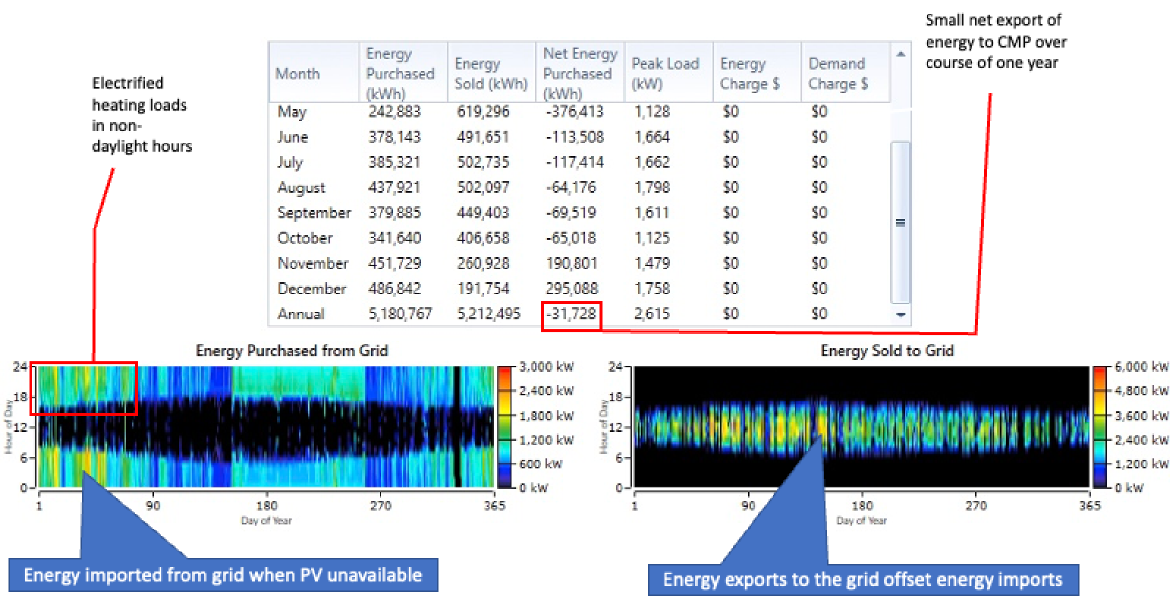


Figure H.11: Energy exchange for Case 4.

H.4.2 Cash Flow

The cash flow, shown in Figure H.12, is very similar to the baseline least-cost case, with slightly larger magnitudes. There is a Year 1 expenditure of $18M resulting from installation of the PV array and inverter, a Year 15 replacement of the inverter, and a Year 25 salvage cost recovery from the sale of the inverter. Small O&M costs are barely resolved in the first 8 years, but become too small (they are discounted) in Years 9 and above. The LCOE is $0.133/kWh, which is only slightly higher than for the baseline least-cost option.

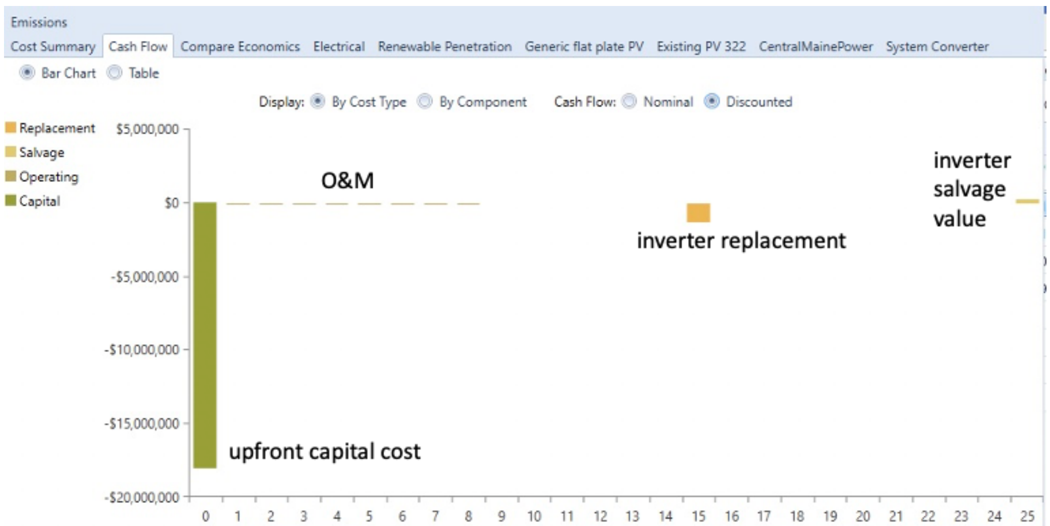


Figure H.12: Cash flow for Case 4.

H.4.3 Noteworthy Features of High-Electrification, High-Efficiency Scenario

- LCOE is reduced by 33.5% compared to the grid-only scenario, and costs are slightly higher due to increased electricity cost. However, these are likely offset by reduced fossil energy costs (heating fuel and gasoline).
- There is an $18M initial investment for the PV array and inverter, which is $17M smaller than for the high-electric option with no investment in efficiency.
- As in the other cases, PV alone does not eliminate loss of power during a grid outage.

H.5 Case 5: Island-Wide Scenario High Electrification, High Efficiency, Renewable Microgrid

This scenario is based on the high-electrification, high-efficiency case, with a zero tolerance for loss of service, meaning that local resources must be able to support the entire island's load in case of a grid outage. Moreover, power must be provided entirely by emissions-free resources. For this case, HOMER recommends a combination of an 8.8 MW PV array and a 29.5 MWh Li-ion battery. The 8.8 MW / 36-acre array is shown close to the Islesboro airstrip in Figure H.13. While not shown here, space for battery storage should also be considered, likely in the vicinity of the array. With this combination, there is no loss of service even during a 5-consecutive-day grid outage. We note that the battery has an installed capital cost of $550/kWh, a 5,000-cycle/15-year life expectancy, and a $10/kWh/yr O&M cost.

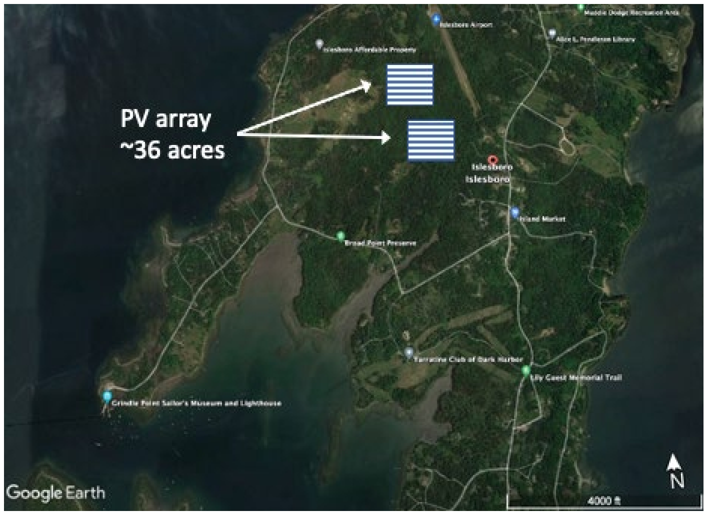
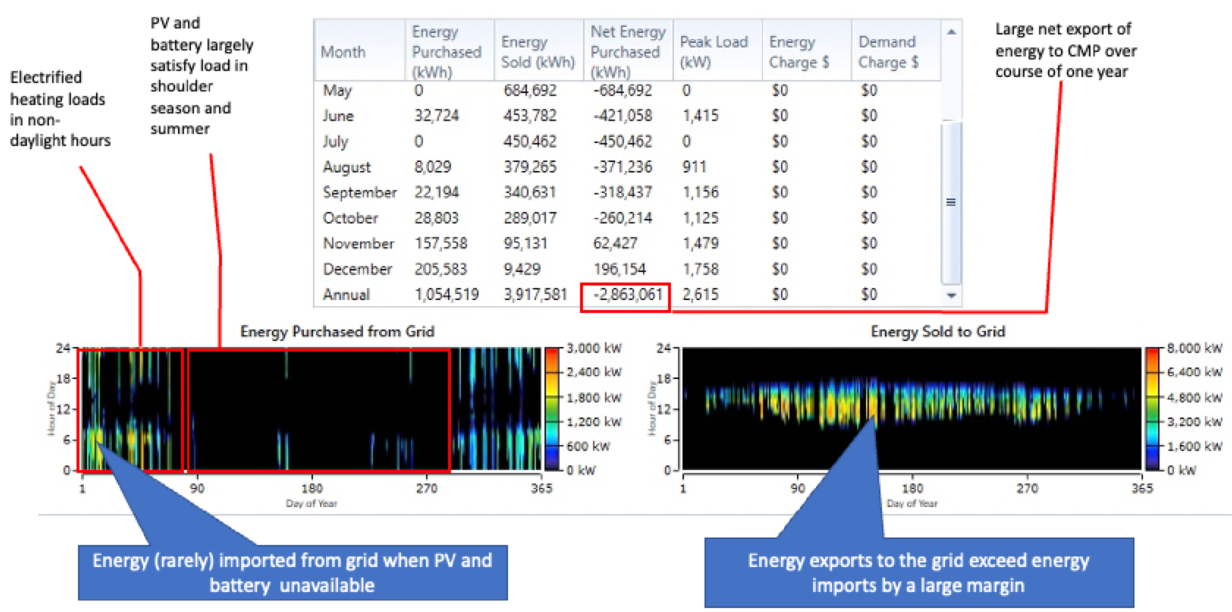


Figure H.13: 8.8-MW/36-acre array near the Islesboro airstrip.

H.5.1 Annual Energy Exchange Data

The energy exchange for the high-electrification, high-efficiency, high-resilience scenario is shown in Figure H.14. By inspection, it is clear that the energy exchange with CMP is both qualitatively and quantitatively very different from the other scenarios. Rather than exchange electricity with the grid, the HOMER controller charges the battery when there is excess PV and discharges it when PV is not available. Only during the cold season, when energy consumption due to heating loads is high and PV generation is reduced, does the controller import grid energy. Overall, a large quantity of energy is exported to the grid for no compensation. This is a result of oversizing the PV array, which was made necessary to provide enough energy to satisfy loads and charge batteries during the 5-consecutive-day grid outage.



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
May	0	684,692	-684,692	0	$0	$0
June	32,724	453,782	-421,058	1,415	$0	$0
July	0	450,462	-450,462	0	$0	$0
August	8,029	379,265	-371,236	911	$0	$0
September	22,194	340,631	-318,437	1,156	$0	$0
October	28,803	289,017	-260,214	1,125	$0	$0
November	157,558	95,131	62,427	1,479	$0	$0
December	205,583	9,429	196,154	1,758	$0	$0
Annual	1,054,519	3,917,581	-2,863,061	2,615	$0	$0

Figure H.14: Energy exchange for Case 5.

The utilization of the battery is shown in Figure H.15. The battery management system utilized by HOMER clearly prioritizes use of the battery to use of the grid to satisfy the load. The battery SOC heat map indicates that the battery is generally fully charged by noon, remains at full charge until around 6:00 p.m., and then discharges to satisfy loads until the early hours of the morning. This battery management strategy is economical because, even though the battery degrades during charge/discharge, in this case the 15-year lifetime is still the factor that limits battery life. As a result, there is no economic downside to using the battery to power loads. In a real situation, a building owner might still choose to maintain the battery at a fixed SOC unless there is a grid outage or other reason to prefer the battery to the grid as a form of storing excess PV. On the other hand, this operating strategy is favorable to CMP because it limits excess backfeed of PV power on the feeder and counteracts the “duck curve” by serving loads in the afternoon and evening.

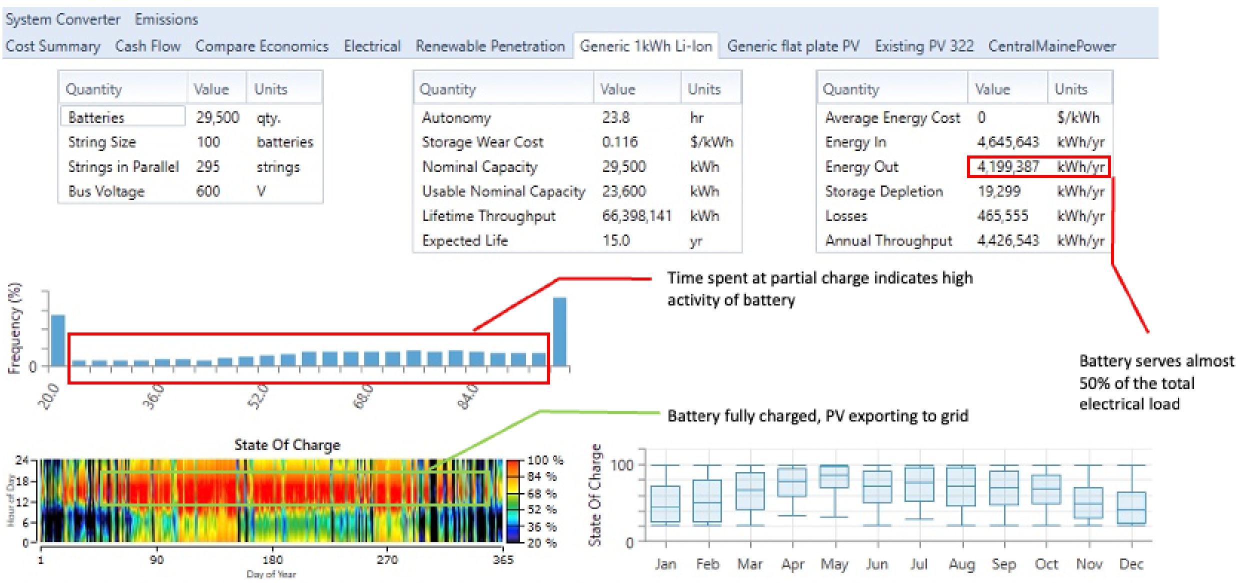


Figure H.15: Utilization of the battery for Case 5.

H.5.2 Cash Flow

The cash flow, shown in Figure H.16, is dominated by capital costs for initial installation and replacement of components. The PV array is the highest initial cost at over $20M, followed closely by the Li-ion battery at approximately $15M, with the inverter cost constituting the smallest contribution at ~$2M. Both the battery and inverter are replaced at Year 15, and some cost is recovered at Year 25 from the salvage value of battery and inverter. Some relatively small O&M costs are also visible, largely attributable to the battery. Because of the oversized PV array compared to the least-cost option, the associated oversized inverter, and the added expense of the battery system, the LCOE is high at $0.377/kWh, almost double the price of the grid-only option.

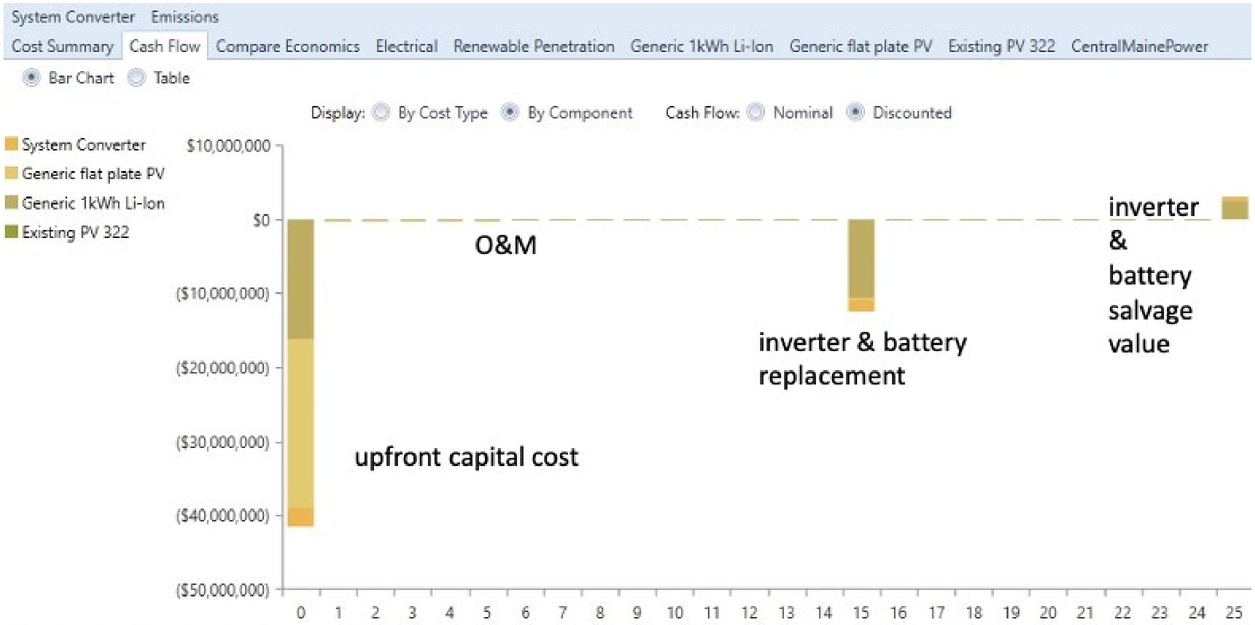


Figure H.16: Cash flow for Case 5.

H.5.3 Noteworthy Features of the Grid-Only, High-Electrification, High-Efficiency Scenario

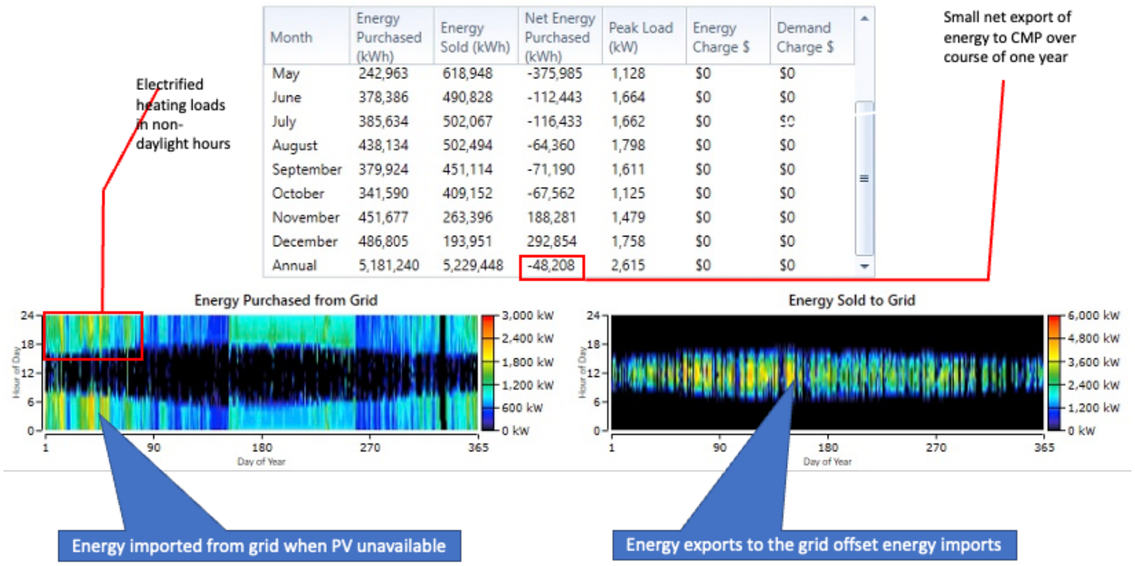
- It is possible to ensure 100% availability of service with a renewables-only system, but at a price. The LCOE is double than that of the grid-only system.
- Optimal battery management should be addressed to optimize battery life by taking advantage of the grid where possible.
- Because of the ability of a system with large storage to be a good grid citizen, the possibility of using the system to provide certain grid services that could offset the high cost of the system should be pursued.

H.6 Case 6: Island-Wide Scenario of High Electrification and a High-Efficiency, Diesel-Backup Microgrid

This case, like Case 5, is based on the high-electrification, high-efficiency case with a zero tolerance for loss of service, meaning that local resources must be able to support the entire island's load in case of a grid outage. However, the renewables-only restriction on the backup source (which results in high energy cost) is removed so that diesel backup generation can also be considered. For this case, HOMER recommends a combination of a 6.3 MW PV array and a 3.3 MW diesel genset. The diesel genset is sized so that, together with the PV array, it can support all of the load during the 5-consecutive-day grid outage. The 6.3-MW/25-acre array has the same footprint as that shown in Fig. H.10 for Case 4.

H.6.1 *Annual Energy Exchange Data*

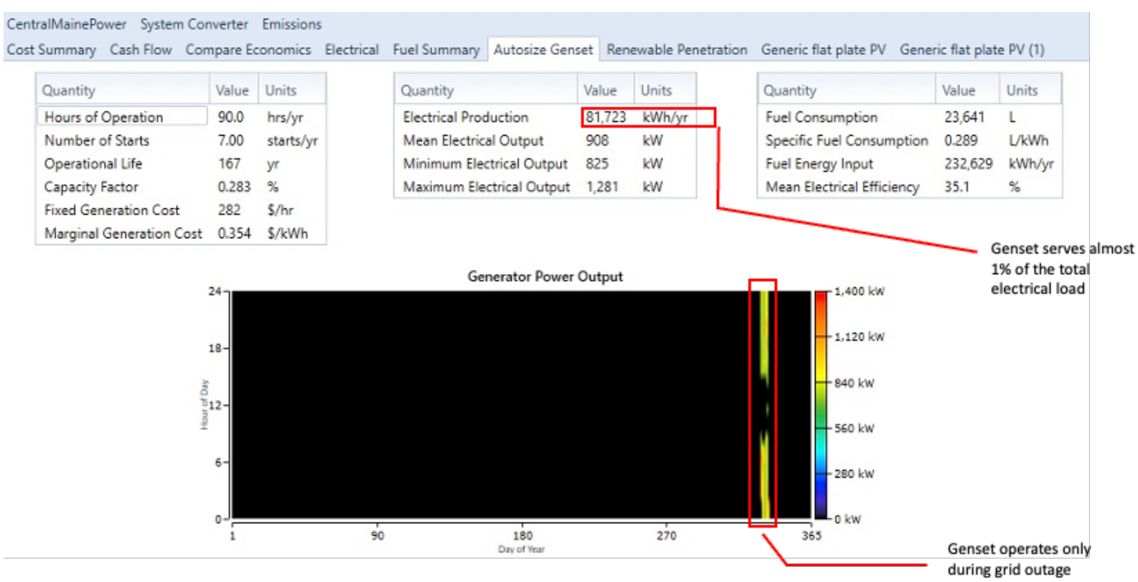
The energy exchange for the high-electrification, high-efficiency, high-resilience diesel-backup scenario is shown in Figure H.17. Energy exchange with CMP is almost identical to the lowest-cost scenario, Case 4.



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
May	242,963	618,948	-375,985	1,128	$0	$0
June	378,386	490,828	-112,443	1,664	$0	$0
July	385,634	502,067	-116,433	1,662	$0	$0
August	438,134	502,494	-64,360	1,798	$0	$0
September	379,924	451,114	-71,190	1,611	$0	$0
October	341,590	409,152	-67,562	1,125	$0	$0
November	451,677	263,396	188,281	1,479	$0	$0
December	486,805	193,951	292,854	1,758	$0	$0
Annual	5,181,240	5,229,448	-48,208	2,615	$0	$0

Figure H.17: Energy exchange for Case 6.

The utilization of the genset is shown in Figure H.18. The diesel genset operates only during the grid outage and only when PV-generated power is insufficient, serving approximately 1% of the yearly energy needs.



Quantity	Value	Units
Hours of Operation	90.0	hrs/yr
Number of Starts	7.00	starts/yr
Operational Life	167	yr
Capacity Factor	0.283	%
Fixed Generation Cost	282	$/hr
Marginal Generation Cost	0.354	$/kWh

Quantity	Value	Units
Electrical Production	81,723	kWh/yr
Mean Electrical Output	908	kW
Minimum Electrical Output	825	kW
Maximum Electrical Output	1,281	kW

Quantity	Value	Units
Fuel Consumption	23,641	L
Specific Fuel Consumption	0.289	L/kWh
Fuel Energy Input	232,629	kWh/yr
Mean Electrical Efficiency	35.1	%

Figure H.18: Utilization of the genset for Case 6.

H.6.2 Cash Flow

The cash flow, shown in Figure H.19, is dominated by capital costs for initial installation and replacement of components. The Year 1 capital cost of $19.7M is dominated by the PV array and inverter, with only approximately 10% of the cost resulting from the genset. There is a larger than usual O&M component of the cost, resulting from the cost of fuel to run the genset during grid outages. As with previous cases, the inverter is replaced after Year 15 and there is some residual value at Year 25. The LCOE for this system is $0.143/kWh, which is slightly higher than the lowest-cost option but still 28.5% lower than the grid-only cost. One of the main drawbacks to running the diesel generator as a backup is that emissions are non-zero, at 62.4 tons of CO_2/year. However, this is still only 3.5% of the emissions for the grid-only case, which is 1,775 tons of CO_2/year.

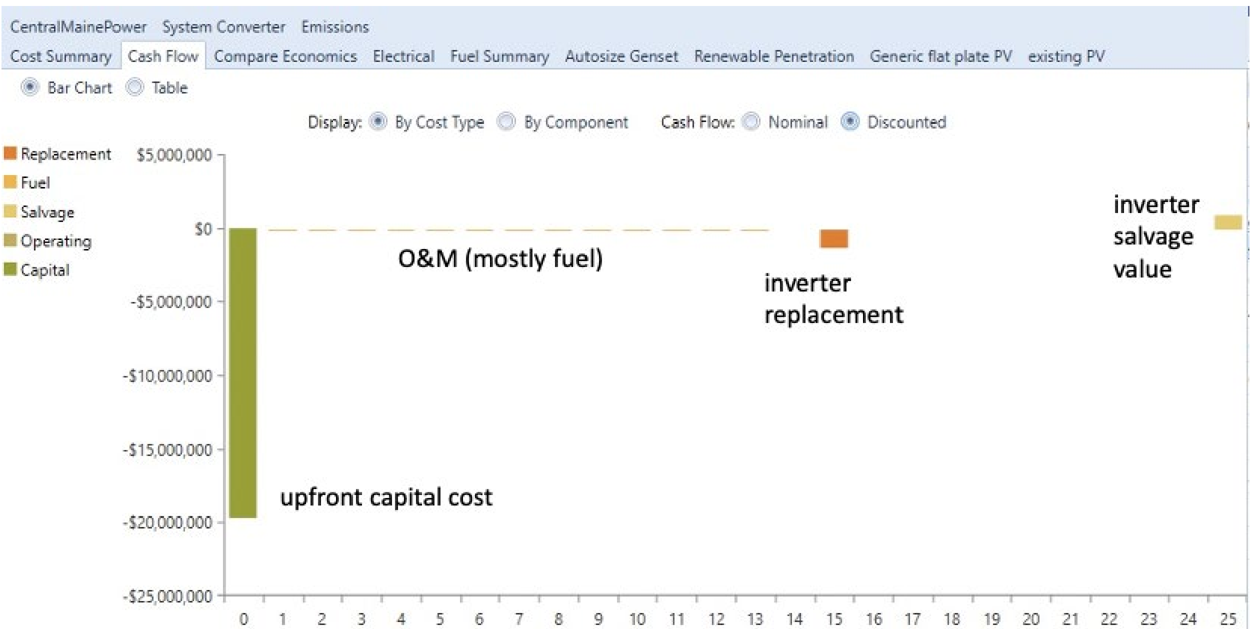


Figure H.19: Cash flow for Case 6.

H.6.3 Noteworthy Features of the Grid-Only, High-Electrification, High-Efficiency Scenario

- It is possible to ensure 100% availability of service with a diesel backup system at a modest premium compared to the lowest-cost system, but this is still considerably less expensive than the grid-only baseline.
- The diesel backup generator operates only during grid outages.
- Yearly, CO_2 emissions resulting from operating the diesel backup are 3.5% of the baseline grid-only CO_2 emissions.

H.7 Case 7: Multiple Building Microgrid at the Islesboro Town Center – Renewable Energy Microgrid

As an alternative to providing a microgrid for the entire island to serve resilience needs, it is also interesting to consider enhancing the resilience of individual buildings or clusters of buildings that could provide critical services to the community in the case of a long-duration grid outage at a much lower cost. While we considered several building-level resilience sites, we provide detail for two cases—the town center all-renewable microgrid (Case 7), and the town center diesel-backup microgrid (Case 8), both of which ensure continuous supply of electricity even during a 5-consecutive-day grid outage. The town center building resilience cluster is shown in Figure H.20. It consists of eight buildings located along a 0.3-mile stretch of Main Street, including a health center, a town office building, a grocery store, a Post Office, and a community center.

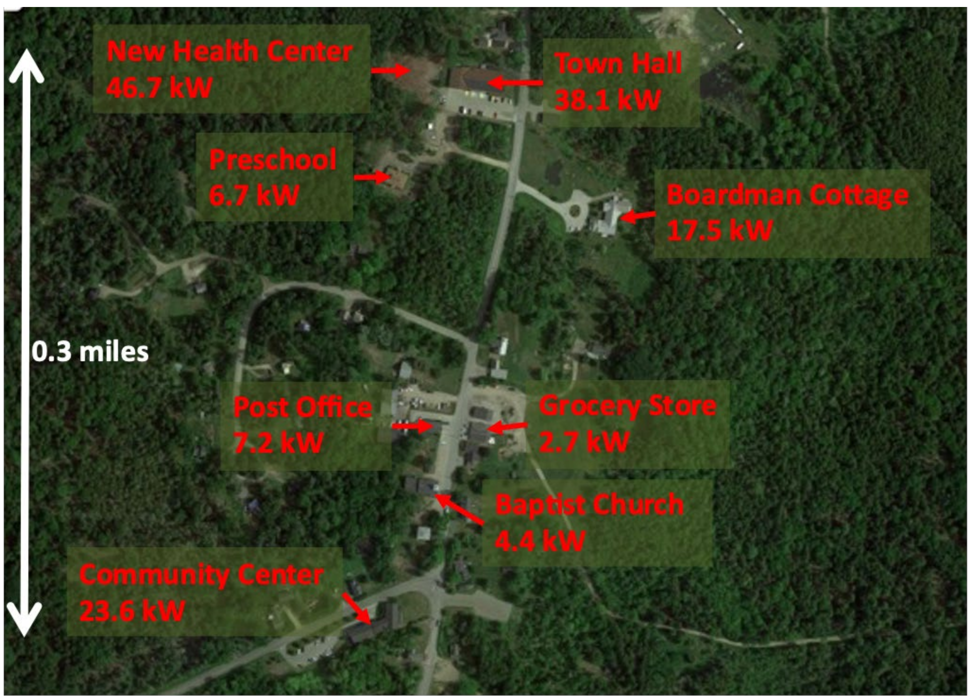


Figure H.20: Town center resilience cluster.

Loads for the building were obtained using a combination of data sources and tools. Energy consumption data for the town center building were available. The NREL tool REopt was used to reconstruct hourly data for an entire year based on the monthly bills. The total energy use for other buildings in the cluster was determined by scaling energy use for the town office building, and then REopt was used to obtain the hourly profile, as summarized in Table H.1.

Table H.1: Assumptions for Building Cluster Energy Profiles

Building Name	Street Address	ReOpt Profile Used	Peak Demand (kW)	Annual Energy (MWh)	Profile Basis
New Health Center	150 Main Rd	80% outpatient, 20% hospital	46.7	174.4	150% of Town Hall
Town Hall	150 Main Rd	60% small office, 40% outpatient	38.1	116.3	Monthly billing data
Islesboro Community Center	103 Pendleton Rd	Retail Store	23.6	76.5	Previous profile annual energy – 76,541 kWh
Boardman Cottage Assisted Living	131 Main Rd	Small Hotel	17.5	77.3	Previous profile annual energy – 77,344 kWh
Post Office	114 Main Rd	Office Medium	7.2	17.4	25% of Town Hall office portion annual energy, 17,442 kWh
Pre-School/Daycare	152 Main Rd	Primary School	6.7	18.8	Previous central school profile annual energy, 18,816
Second Baptist Church (Food Bank)	108 Main Rd	Retail Store	4.4	14.4	Previous commercial profile annual energy, 3,155 sqft
Island Market Grocery Store	113 Main Rd	Supermarket	2.7	11.7	Previous commercial profile annual energy, 2,570 sqft
Cumulative			**136.5**	**506.9**	

The cumulative load profile for the town center microgrid is shown in Figure H.21. The 507 MWh annual electricity consumption accounts for a 46 kW PV array installed on the roof of the town office building. There is a strong warm season peak visible before summer break, and nightly setback is noticeable.

Figure H.21: Cumulative load profile for the town center microgrid.

In the present case of the fully renewable microgrid, HOMER recommends a 738 kW PV array and a 1,647 kWh Li-ion battery. The scale of the PV array, and a potential location for it, is shown in Figure H.22.

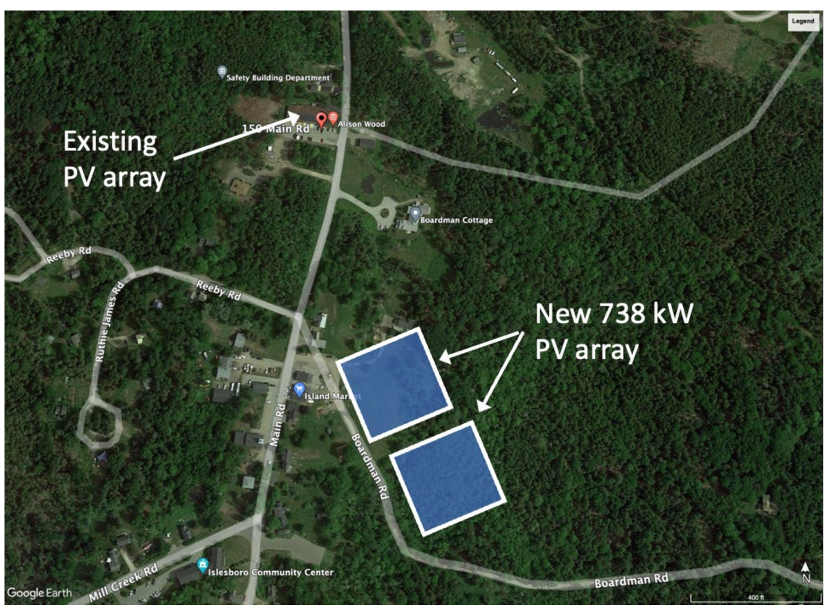


Figure H.22: Scale and potential location of the new PV array, located in close proximity to the town center building cluster.

H.7.1 Annual Energy Exchange Data

As was the case for the whole-island microgrid, the battery and the large PV array are able to serve the entire load for the cluster with zero energy bills. The battery utilization is shown in Figure H.23. As was the case for the whole-island renewable microgrid case, the battery energy storage is prioritized compared to using the grid as virtual storage.

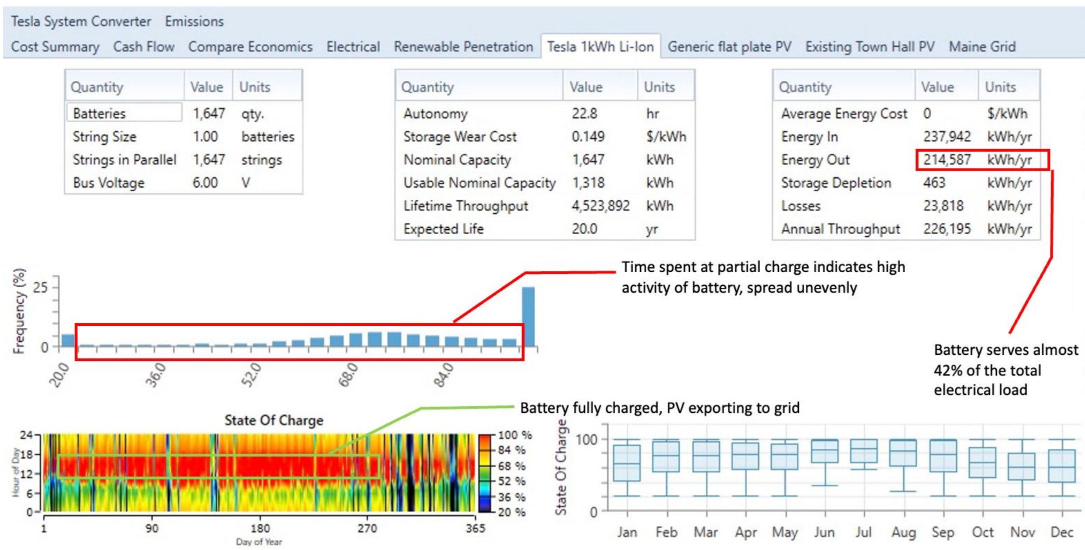


Figure H.23: Battery utilization for Case 7.

H.7.2 Annualized Energy Costs

Because the cost of grid energy plays no role, the LCOE can be understood by analyzing the annualized costs for the individual system components, as shown in Figure H.24. The annualized cost of the battery and the PV constitute the bulk of the cost, in equal parts, with the inverter constituting 15% of the total cost. As was the case with the whole-island renewable microgrid, it is possible to obtain excellent power availability with all-renewable resources, but the LCOE is high at $0.531/kWh.

H.8 Case 8: Multiple Building Microgrid at Islesboro Town Center: Diesel-Backup Microgrid

This case is similar to the previous case because it also requires 100% power availability even in the case of a prolonged CPM grid outage. However, relaxation of the 100% renewable energy requirement means that a diesel genset could be considered as a power source. For this case, HOMER recommends a 333 kW PV array and a 160 kW diesel genset. The scale of the PV array, and a potential location for it, is shown in Figure H.24. The size of the PV array is less than half that of the array recommended for the all-renewable case. The 160 kW generator is sufficient to meet the cumulative peak load for the building cluster.

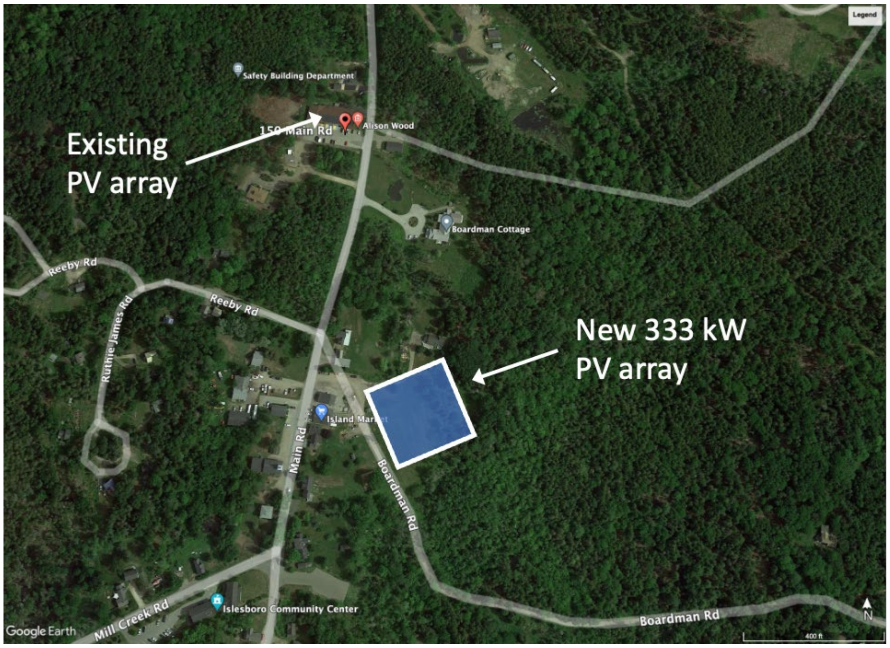


Figure H.24: Scale and potential location of the new 333-kW PV array, located in close proximity to the town center building cluster.

H.8.1 Annual Energy Exchange

As was the case with the whole-island microgrid, the diesel genset only runs during grid outages, as shown in Figure H.25. For the rest of the time, the grid serves as an infinite and cost-free virtual storage.

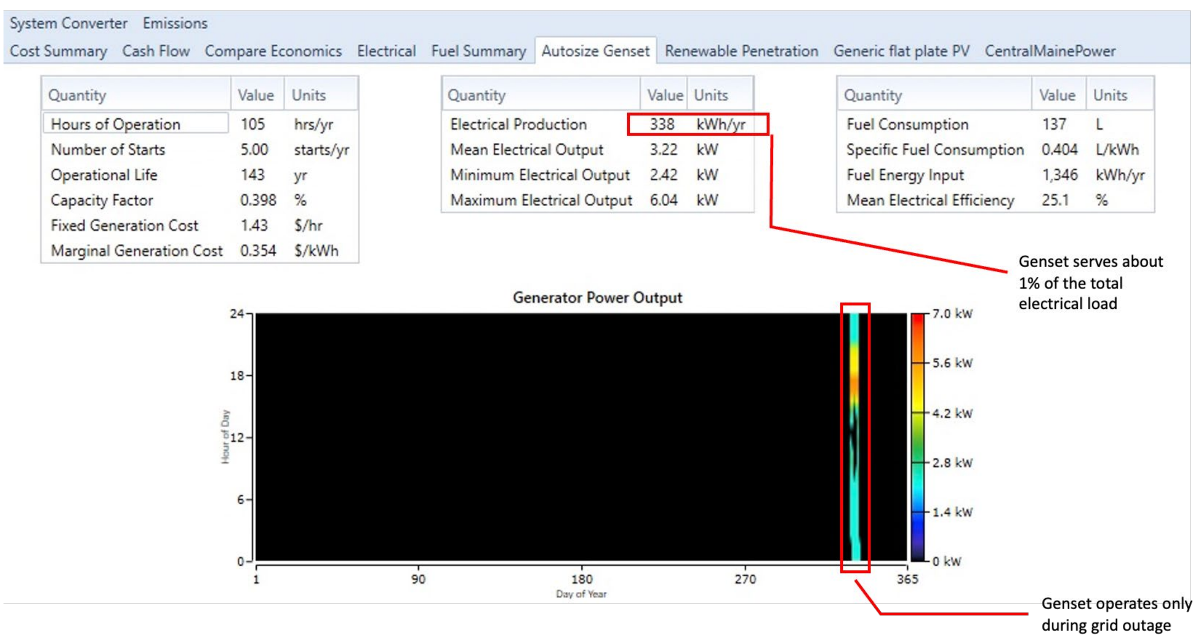


Figure H.25: Operation of the diesel genset.

H.8.2 Energy Costs

The LCOE can be reduced substantially compared to grid-only operation by adding PV, as was the case for the whole-island scenarios. On the other hand, the cost of the generator and the cost of fuel to run it during grid outages add a small percentage to the LCOE compared to operation with the lowest-cost option. Overall, the LCOE with the diesel backup option is $0.15/kWh, or approximately 25% lower than with the grid-only option. The upfront cost for the diesel-backup system is $1.01M, while the Net Present Cost is $1.34M (compared to the Net Present Cost with the existing system of $1.65M, due to electricity costs). The diesel generator uses 1,480 liters/year of diesel fuel and emits 3,905 kg/y CO_2 (compared to 95,160 kg/y for the grid-only case). Furthermore, when considering emissions, the emissions embedded in the manufacture of the battery should be considered.

H.8.3 Noteworthy Features of the Grid-Only High-Electrification, High-Efficiency Scenario

- It is possible to ensure 100% availability of service with a diesel backup system at a modest premium compared to the lowest-cost system, but this is still considerably less expensive than the grid-only baseline.
- The diesel backup generator operates only during grid outages.
- Yearly CO_2 emissions resulting from operating the diesel backup are 4.1% of the baseline grid-only CO_2 emissions.