Optimizing and Implementing a Renewable Micro-Grid for a Remote Alaskan Village

Optimizing and Implementing a Renewable Micro-grid for a Remote Alaskan Village

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Abstract

Renewable power is quickly becoming a driving force behind a global energy renaissance. Despite the magnitude of this phenomenon and the often-significant cost savings, there are remote locations that utilize none or very little alternative energy. Paradoxically, the places that could benefit most from this technology, namely small villages heavily reliant on the import of fossil fuels, are often far behind.

The goal of this study was to examine the energy needs, challenges, and resources of one small and remote Alaskan village, Akhiok, and to determine the optimal composition of a renewable microgrid. The main research question was "What is the ideal renewable energy solution to address Akhiok's electricity need?" While this research may not produce a definitive answer, teasing out the data from the potential options will better inform the villagers, so their priorities and budgetary constraints may guide their choices.

The hypotheses tested included: 1) an energy solution for Akhiok comprised of a wind turbine, photovoltaics, battery storage, and a fossil fuel powered generator would be the most efficient mix, especially if previously wasted heat can be captured; and 2) a cogeneration plant using CHP, thermal storage, and a district distribution system provides heat with the lowest carbon footprint/LCOE possible. Also, I examined 3) if the project is cost effective with limited upfront cost, and a third party handles the funding and operation of the micro-grid, the townspeople will support the endeavor.

The residents of Akhiok were surveyed to get a general understanding of their energy consumption and to learn how their lifestyles can most be improved by a

community wide upgrade. The existing energy infrastructure of the village was evaluated and determined to be in a significant state of disrepair; their present condition was found to be at best unreliable and at worst extremely unsafe. Grid optimization software was utilized to generate the most efficient configurations of batteries, solar panels, a wind turbine, and cogeneration heat and power. Net Present Cost and Levelized Cost of Energy calculations were used to compare options and inform the village so they can ultimately make a determination that best matches their priorities and budgetary constraints.

Five different models produced a corresponding number of potential grid choices. In one model, an addition of $50,000 in battery storage reduced energy costs by roughly $520,000 over 25 years and reduces wasted (excess) energy by 98%. Adding photovoltaic cells was found to do little to drive down cost, but it would reduce annual fuel use by 3,896 gallons. The incorporation of a wind turbine reduced forecasted KWh cost from $0.63 with PV and battery storage down to $0.38. Fuel usage would plummet to 7,767 gallons, a reduction of over 17,000 gallons from the current paradigm. Cogeneration heat and power was explored and found to reduce wasted heat, but to be potentially too capital expensive to be feasible.

The economics of an upgrade are undeniable, but the availability of money to conduct such an overhaul is in doubt. An examination of grants, leases, and other funding mechanisms was conducted to provide a financial path forward for the cash-strapped community.

Dedication

To my thoughtful and beautiful son Wyatt, who has taught me more about patience and love than I learned in the 33 years before his birth. His presence on this earth has solidified my resolve to make it a better and healthier place.

Acknowledgements

I would like to thank the following for their support during the 5 years it took me to complete this degree while serving on Active Duty, making 3 large moves, and becoming a father.

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Chapter I

Introduction

Global energy demand has grown since World War II and is expected to increase by more than one-third by 2035 (Toka, Iakovou, Vlachos, Tsolakis, & Grigoriadou, 2014). The United States uses more energy per-capita than any other country on earth, and Alaska is one of the highest per-capita energy use states (Salari & Javid, 2016). The energy economy in Alaska is unlike anywhere else on the planet. It's a place where abundant supplies of fossil fuels are found in the same regions where costs are at their highest.

Alaska is geographically huge, sparse in population, and has immense energy resources and needs. The people of Alaska live much farther apart than those in the lower-48; in fact, New Jersey has about 1,000 times the population density of Alaska. Most communities in Alaska do not have access to the bulk power grid, and due to the tremendous challenge of delivering fossil-energy through some of the world's toughest terrain and weather, there is a growing emphasis towards the pursuit of less costly energy mixes. There are, however, no one-size-fits-all strategies to implementing changes to make the grids of Alaska function more efficiently, especially in some of the far-flung Native villages (Bernal-Agustín & Dufo-Lopez, 2009).

The pursuit of clean energy production and storage technologies has accelerated far slower here than in most of the lower-48. Development has been dogged in Alaska for reasons ranging from logistical and economic to social and political (Carley, 2009). For island villages, in particular, oceangoing vessels deliver fuel oil for heating and electricity over hundreds and thousands of miles at some of the highest prices in the world. Areas with extensive and pristine coastline are the backdrop to this oversea transport, and have experienced contamination from catastrophic discharges in the past that reduced, and in some cases, destroyed plant and animal populations (Peterson, 2001). Bringing millions of gallons of heating oil to these villages can be dangerous and exposes some of America's last untouched ecosystems to undue risks.

Achieving greater degrees of energy independence reduces the direct financial burden of powering the homes and businesses of the residents of rural Alaska. Providing this relief might also slow the rate at which rural Alaskans choose to migrate to more urban areas (Berman, 2017). Bringing less fuel to the villages could also have the second-order effects of reducing fossil-fuel discharges during transportation and pollution of the air and water once the fuel has arrived at the village.

According to Allen, Brutkoskia, Farnswortha and Larsen (2016), "About 200 of the state's rural villages have unsustainably high electric utility and energy costs" (p. 4); in a state with so few people this is a widespread issue. Of those 200 rural cities, only 7 have populations over 2,000 (Stromberg, 2015). Alaska is, however, home to many rich sources of renewable energy and the state has recently begun to undergo an energy renaissance, though not as rapidly or to as widespread a degree of many lower-48 clean-energy leaders. A state-wide study visited 30 communities throughout Alaska, finding lofty renewable energy targets ranging from 50-100%, and many community leaders having the goal of being "diesel-off", a turn away from decades of almost sole reliance on diesel for power generation, (Allen et al., 2016). As stipulated in state law, the goal is to get to 50% renewable energy statewide by 2025 (Alaska Statute, 2007). Geothermal, hydrokinetic, wind, and even solar energy are abundant in Alaska, though their concentrations are varied. Wind energy potential is high throughout most of Alaska, and some of North America's best wind conditions are found in the state. According to the Renewable Energy Alaska Project Meteorological (2015), "..the largest areas of class 7 (superior) wind power in the United States are located in Alaska" (p. 17). There has been recent growth in installed wind-energy capacity, but efforts by state-level policy makers were slow until 2008 (Delmas, & Montes-Sancho, 2011). When coupled with the challenges of constructing renewable installations in Alaska, this dynamic has acted to stunt the growth of adoption. Wind is a technology that heavily relies on economies of scale and the populations and load sizes of villages don't often lead to efficient wind implementation.

Small villages would benefit greatly from reducing their reliance on expensive and distantly procured diesel that predominantly powers generators and home heating units. In similar climate conditions in nearby Russia, many similar difficulties are being faced and whole of government approaches to renewable adoption are seen to be most effective (Boute, 2016). In northern Russia and Alaska, the delivered retail price of diesel is both high and volatile, and when financial resources are limited the strain of high, unpredictable pricing can often force households to endure cold and unhealthy conditions. Costs are higher still when they are "fully burdened", factoring in values measuring health and environmental harm. However, the cost-benefit analysis of switching to renewable energy in rural villages must be critically analyzed.

Research Significance and Objectives

This study is an in-depth analysis of the current energy use regime in one particular village, Akhiok, located on the very southern end of Kodiak Island in the Gulf of Alaska. Providing a business case analysis for a switch to renewable energy for this village is useful to inform citizen attitudes and help promote the development of public policy for eventual implementation. While my analysis and findings are specific to Alaska, the process and even some of the results will be broadly applicable. From rural micro-grids in other small island-communities to far-flung African villages, there is a nascent, worldwide energy revolution unfolding. My research had three objectives:

- To consult with the Akhiok community, assess their current energy profile, and develop an energy solution that better meets their needs
- To compare the current system with various, custom renewable energy system models to determine relative efficiency, feasibility, reliability, and cost
- To identify other communities that have undertaken similar initiatives and how they have overcome financial and logistical challenges to achieve a more renewable grid

Background

The costs of renewable power generation have, broadly speaking, been falling over the past several decades. Myriad technological improvements across the grid, along with increasingly sophisticated analytical software, have positively impacted the feasibility of renewable adoption. Siting can now be accomplished in locations with previously prohibitive hard costs. Thanks to widespread adoption and the resulting economies of scale, procurement, installation, and maintenance costs have fallen and should continue to do so. Soft costs have fallen as well. Legal, accounting, real estate, and independent engineering fees are trending downward thanks to standardized approaches to installation (Holloway, 2017).

Key to the viability of these projects in the context of a small village is the assurance of power-availability during intermittency episodes, often through a reliable storage mechanism where excess power during high output periods can be sent (Khan & Iqbal, 2005). Advances in modeling software allow various system configurations to be "operated" over an entire life cycle, demonstrating reliability and economic performance (Lambert, Gilman, & Lilienthal, 2006). There are several commonly used modeling software suites, and many studies have used the HOMER (Hybrid Optimization of Multiple Energy Resources) suite of software, which provides optimization and sensitivity analysis to assess reliability and maximize cost-benefit (Lambert, Gilman, & Lilienthal, 2006). Employing this modeling software can help inform the relevant decision makers so they may achieve the goals of increasing reliability and reducing costs.

Energy Use and Costs in Rural Alaska

The average cost of total energy used per person in the lower 48 is $4,421. For Alaskans that figure jumps to $9,596 (Department of Energy, 2015). According to Allen et al. (2016) "Some rural Alaska households spend as much as 47 percent of their income on energy, an amount 5 times greater than that spent by the state's urban households," (p.

22). These are staggering costs for economically depressed regions and they stand in sharp contrast to the relative energy abundance in Alaska, that ironically, ranks 4th for production of energy, but second in cost of electricity generation (U.S. Energy Information Administration, 2015). While the average cost of electricity throughout the state is $0.20 per kwh, the average cost in the villages is somewhere between $0.50 and $1.50, up to roughly five times the price of the nation's highest electricity cost state, Hawaii (U.S. Energy Information Administration, 2015).

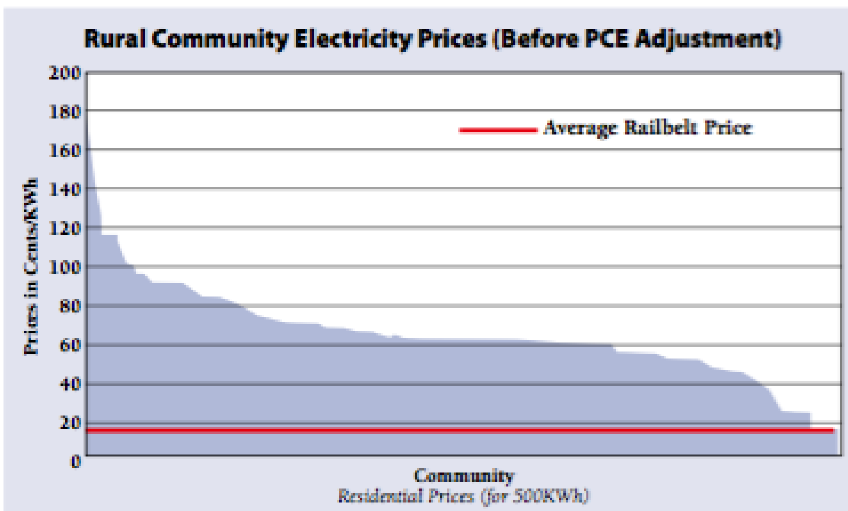

Figure 1. KWh cost of energy in 170 Alaskan communities (ISER-UA, 2003). The x-axis depicts all of Alaska's communities plotted in order, from highest to lowest electricity cost. The y-axis depicts the price of electricity without adjustment for Personal Consumption Expenditure.

The exorbitant price premiums that rural Alaskan residents pay for electricity are clear when plotted and compared to the "Average Railbelt Price" (the Railbelt refers to the urban population centers connected by the rail and road system from Fairbanks in the interior through Anchorage to Homer in the South Central region) (Figure 1). Despite recent decreases in the price of oil, Alaskan villagers pay up to $9 per gallon for heating oil as compared with the current average of only $1.98 per gallon across the United States (U.S. Energy Information Administration, 2015).

Partly in response to these costs, rural Alaska has experienced rapid wind-power installation over the past decade, from personal grid size systems to whole-community solutions. At 63 MW of installed capacity, penetration is still weak, especially when compared to a similarly populated state such as Wyoming, with 1,410 MW wind power and a similar availability of this natural resource (Renewable Energy Alaska Project, 2013). Given the distance from utility-scale grids, Alaskan villages are often times more akin to a small village in a third world country, than to the average mainland American town. Working within Alaska provides a test bed for renewable manufacturers and installers without the hassle of international travel and customs costs (American Council on Renewable Energy, 2014). In choosing a site to conduct a feasibility and business case analysis, I have decided on a place with good potential for large reductions in petroleum import.

Ahkiok, Kodiak Island, as a Case Study

Kodiak Island is the second largest island in the United States (behind the big island of Hawaii), with fewer than 14,000 people living in one main town and six smaller villages. The island is home to the eponymous Kodiak brown grizzly bear and the Kodiak National Wildlife Refuge, comprising 1.9 million acres. A sensitive ecosystem, with 1,343 miles of coastline (Dunham, 2010), Kodiak is a nearly pristine ecosystem surrounded by often-tumultuous seas that can make village logistics difficult. The main town of Kodiak, with its roughly 6,000 residents, has received much notoriety for its conversion from an exclusively diesel based electrical grid to a nearly 100% renewable one. A large hydropower plant and 6 - 1.5MW wind turbines, with a back-up diesel plant ready in case of an interruption, generate Kodiak's electricity.

The remaining six communities operate grids with varying levels of renewable source implementation from none, in Akhiok, Karluk, Port Lions, and Old Harbor, to a mix of hydropower plants and diesel generation in Larsen Bay and Ouzinkie. These villages do not incorporate an energy storage solution and produce only a small amount of their total energy requirement. The farthest flung village from the city of Kodiak is Akhiok, an Alutiiq village home to approximately 70 residents (2010 Census). Figure 2 provides a visual depiction of the layout of the village.

Diesel is delivered to Akhiok via ocean going fuel barge, burned in boilers for home heating and used as fuel for generators to provide electricity. The climate for Akhiok is oceanic, with 7462 HDDs (Heating Degree Days), that when compared to a lower latitude city like Boston at 5826 HDDs highlights the energy intensity of heating the community (BizEE , 2015). Akhiok's distance from the city of Kodiak means if a project can be feasible there, it will most likely be feasible elsewhere on the island and in other far-flung places. This determination would help other sites leverage economies of scale to promote future projects. Island-wide optimization would be an extremely significant accomplishment and would continue an effort to reduce diesel consumption elsewhere on the island that has already displaced nearly 9,000,000 gallons of imported fuel since 2009 (Kodiak Electric Association, 2015). Connecting to Kodiak's electrical grid would be nearly impossible given the 110 miles of transmission lines required to be installed through mountainous terrain and the Kodiak National Wildlife Refuge.

Figure 2. Aerial photo of the village of Akhiok. A scale is provided to give context to the relative proximity of Akhiok's households. The school is in the lower left, the airport's runway begins in the lower right. The building in the lower right is the village's powerplant. Data Source: Google Earth

Infrastructure on Akhiok is more akin to one found in a third-world country than a country as advanced as the United States. The town recently requested help from the Department of Energy (DOE) to better understand the failures they were experiencing in their energy infrastructure (DOE, Office of Indian Energy, 2016). In the case of the city's water supply, the mayor, Dan McCoy said "Many families fly in bottled water because they never know how safe the water really is" (Gibbs, 2011). The energy costs in Akhiok are extremely high; residents pay $.80 per KWh for power generated by burning 80 gallons of diesel per day. This is roughly 6 times more expensive than the cost of electricity in the lower-48 states (Bazilian et al., 2013), and when combined with the median income of $25,417 for males and $6,250 for females, electricity absorbs an inordinate share of income (U.S. Census, 2010). According to Akhiok Mayor Dan McCoy, the residents of Akhiok earn their income mainly through dividend disbursements from the Akhiok-Kaguyak Native Corporation, as well as subsistence and commercial fishing activities (personal communication, August 4, 2017). These sources of income are seasonal, variable, non-reliable, or all of the above and are based on the balance sheet of the native corporation's real estate holdings or the fishing yield of local waters.

The consumer price of delivered goods is extremely high, as everything not directly farmed or harvested within the village must be brought in by airplane or irregular barge service from hundreds or thousands of miles away. According to long-time island resident Ken Reinke, travel to and from the village is very expensive and represents another significant pressure on the villagers, costing those who choose to or have to travel thousands of dollars per year (personal communication, June 8, 2017).

Energy Production and Storage for Rural Alaskan Villages

Wind, wave, solar, and tidal energy are used prevalently throughout Alaska and are the resources evaluated within this study. While moving to 100% renewable is a noble goal, there are still many benefits to efficient fossil fuel powered generators and their continued incorporation is evaluated. Identifying the correct configuration of systems that harness these forms will require better understanding of the current state-of-the-art in each of the relevant technologies. A comprehensive study of all methods of production and storage would be extraneous to the aims of this project, so the review below focuses on technologies that are employed in small municipalities within Alaska; other, niche technologies such as flywheel storage are not included as their utility is often limited to very narrow usages.

Energy Production

Wind. With the abundant wind energy available in Akhiok, installing turbines is a logical choice for power generation and is becoming a potent force for renewable penetration throughout Alaska. Wind power utilization, however, can prove somewhat problematic in small-town Alaska due to the isolation from maintainers, the cold weather that can sometimes cause turbine efficiency to drop, and the size of the turbines. According to Allen et al. (2016), "small communities struggle because their utilities do not enjoy the "scale economies" of larger utilities—in other words, the cost advantage of being larger that results in lower cost per kWh of electricity produced" (p. 7). The turbines themselves generate less costly energy as their size increases, owing to the exponential gains made via economies of scale of large blade sweep area, harnessing more and more of the wind as size increases.

Historical wind data were used to inform the modeling process and optimize the turbine selection in this research. Work has been done to identify long-term climactic shifts that might cause wind availability to change (Mölders, Khordakova, Dlugi, & Kramm, 2016), but suggests that while the seasonal variability could be an issue, the total amount of annual wind should remain constant. Wind installations can also prove to be polarizing to the communities where they are deployed and must be executed with maximum buy-in (Fergen & Jacquet, 2016)

Wave/Tidal/In-River. With abundant coastline and often-turbulent seas, the option of wave energy is promising for many communities. Harnessing the rise and fall of the waves to either drive pistons that produce electricity hydraulically or by compressed air can contribute to the grid, but carries higher cost and relatively less reliability. Cost for installed wave capacity can be estimated from a project in the UK, which produces electricity at approximately $.075 per kWh (Ocean Energy Council, 2014). This type of installation might work for large-scale utilities but the capital costs can be very high for small, community level usage. Energy from the changing tides can be harnessed but it is an expensive undertaking often reserved for larger and more remote communities, and typically comes heavily subsidized by research and industry (Ocean Energy Council, 2014). There are no sufficiently sizable rivers close enough to harness for an in-river system, however, many individual homes in Alaska use such systems to generate their own power.

Cogeneration. A very promising form of electrical and thermal energy derivation is by cogeneration, wherein the waste heat of a generator is harnessed to provide heat or cooling, a process that avoids losing much of the generation by-product heat. In fact, according to a 2008 DOE report, “The energy lost in the United States from wasted heat in the utility sector is greater than the total energy use of Japan” (p. 5). Combined Heat and Power (CHP) systems are installed in 4,400 facilities nationwide and achieves efficiencies of >80% versus the 31.6% for conventional, petroleum based generation systems (EPA, 2017).

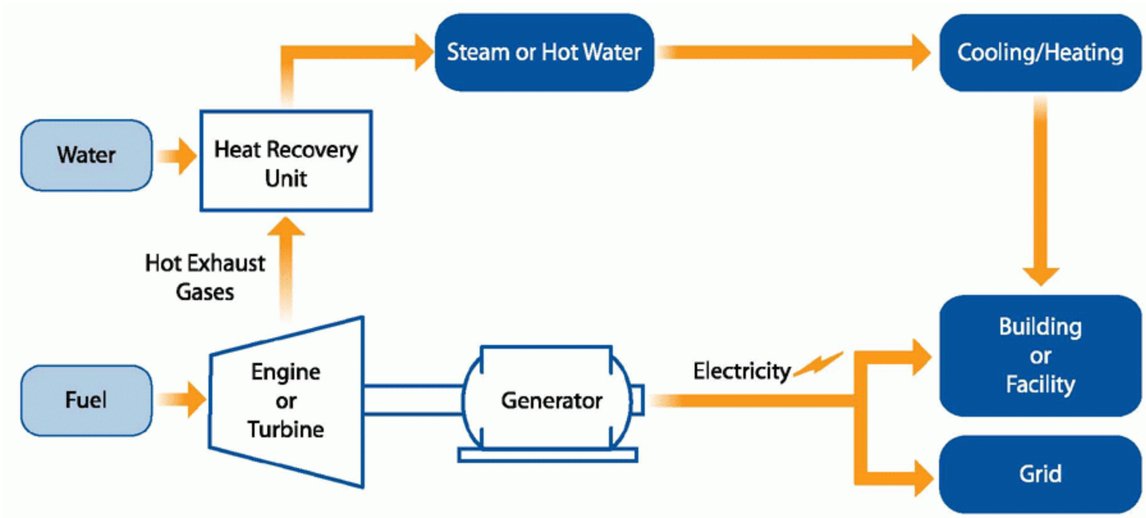

Figure 3. Block diagram of Combined Heat and Power system. Heat is carried from the engine to a heat transfer system and delivered to where it is needed. Data Source: EPA

Cogeneration is usually accomplished with a fossil fuel powered generator, but it can also be powered by a renewable energy source, such as solar in places with abundant sun such as South Africa (Prinsloo, Mammoli, & Dobson, 2016). Cogeneration does carry with it many trade-offs, and an optimal run schedule must be found to be able to efficiently utilize one or both of the forms of energy. According to Bischi, et al. (2014), "Due to the large number of decision variables and the necessity of determining trade-off solutions, the operation planning of CHP plants requires the development of specific optimization tools" (p. 13). Care must be taken to effectively store the thermal energy if it is not needed at the same time the electrical energy is.

Energy Storage

Pumped-hydro and electrochemical (battery) energy storage are the major current methods of utility level power storage (Center for Sustainable Systems, 2016). Comparing various storage options will yield various levelized costs, and sometimes the best option is a mix of the various methods (Ma, Yang, & Lu, 2014). It is worth noting that of the four main storage methods, the City of Kodiak currently utilizes flywheel, pumped hydro, and battery storage.

Important to selecting the appropriate method of storage is determining the required system size and discharge rate for the application. There are many methods for energy storage. The ones most applicable to Akhiok intersect the 100kw system size and allow for discharge between the minutes and hours on the vertical-temporal axis of Figure 4.

Pumped Hydroelectric Storage (PHS). (PHS) utilizes excess energy to pump water to a higher elevation from where it is metered out, utilizing gravity to power turbines. It is capital intensive and site-specific but able to generate the most power and it also demonstrates the longest period of energy discharge. PHS is among the most efficient commonly used storage method, realizing 76-85% efficiency (U.S. DOE, 2013). Due to its massive grid-level potential, as of 2016, 95% of U.S. energy storage is from PHS, equating to 20.4 GW (U.S. DOE, 2016). In the Canary Islands there are 411 MW of installed wind power that when combined with PHS yields 99.66% of the wind energy being used, a 40% increase over the system lacking PHS (Padrón, Medina, & Rodríguez, 2011). According to Ma, et al, in Hong Kong, the use of a pure PHS system was around 30% of the levelized cost of a battery option (2014).

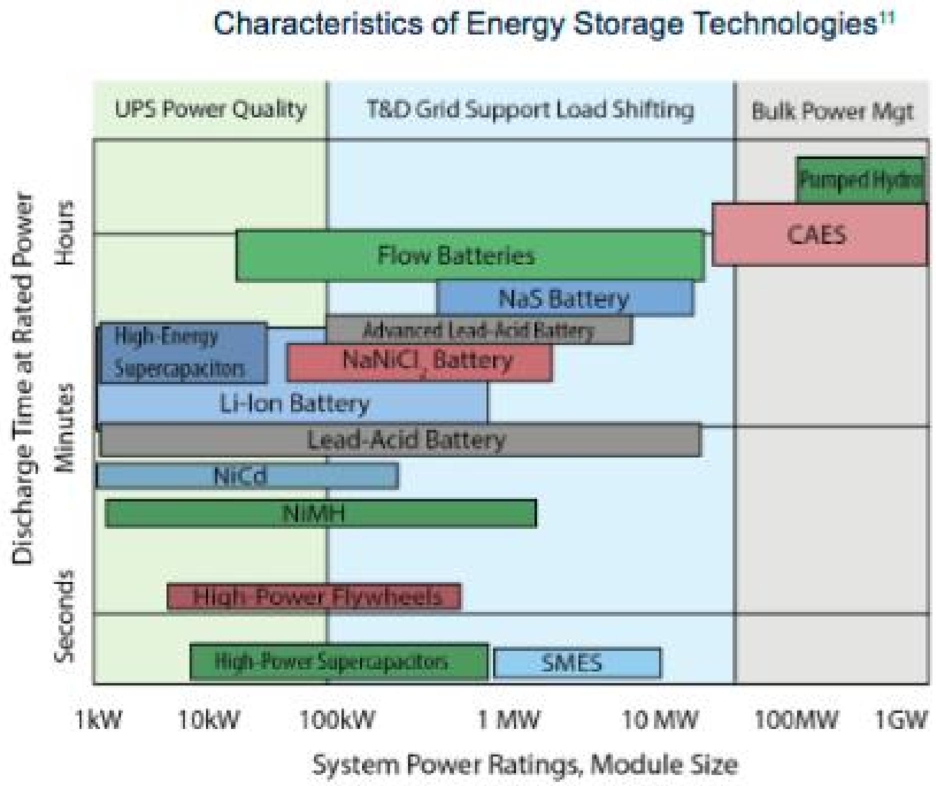

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Figure 4. Comparing storage solutions in terms of size and discharge. The various forms of electricity storage are arranged by size and discharge time, and categorized by their use. Data Source: Department of Energy

Batteries. "A battery is a device that is able to store electrical energy in the form of chemical energy, and convert that energy into electricity," (MIT, 2012). As of 2016, the U.S. has 360 MW of installed lead-acid, lithium-ion, nickel-based, sodium-based, and flow batteries (U.S. DOE, 2016).

Various systems allow energy to be stored in the form of heat (or cold) in periods of excess production and then later withdrawn when the need arises. One promising technology uses silicone to store energy at a density of approximately 1MWhr per cubic meter (Datas, Ramos, Martí, del Cañizo, & Luque, 2016).

Research Questions, Hypotheses and Specific Aims

To develop an alternative energy plan for Akhiok, I examined five research questions:

1. What is the ideal renewable energy solution to address Akhiok's electricity need? While this may not produce a definitive answer, teasing out the data from the potential options will better inform the villagers, so their priorities and budgetary constraints may guide their choices.
2. How can the thermal load be met most efficiently?
3. How can the needs of the town be met by using heat generation and distribution that maximizes available resources to the maximum extent possible, and drives down costs by reducing wasted heat and excess electricity?
4. How would the village residents react to the proposed overhaul?
5. Given the data produced from this study, how might the villagers be able to begin to plan and install the recommended solution?

The main hypotheses relevant to these research questions included:

- An energy solution for Akhiok comprised of a wind turbine, photovoltaics, battery storage, and a fossil fuel powered generator would be the most efficient mix, especially if previously wasted heat can be captured.
- A cogeneration plant using CHP, thermal storage, and a district distribution system provides heat with the lowest carbon footprint/LCOE possible.

- If the project is cost effective with limited upfront cost, and a third party handles the funding and operation of the micro-grid, the townspeople will support the endeavor.

Specific Aims

The above hypotheses generated the following aims that required addressing to complete the research:

1. Analyze the current energy use to determine consumption and fully burdened cost.
2. Utilize modeling software to rank the various system configurations and financially quantify their net-present value, demonstrating which configuration best meets the energy requirements in terms of cost and reliability.
3. Combine the model output with potential funding sources to inform the village in determining the most effective course of action.

Chapter II

Methods

Surveys were conducted to ascertain energy use and renewable penetration potential and used as inputs for the modeling software. To gauge the current efficiency of Akhiok's energy system, multiple telephone interviews were conducted with the village's mayor and manager, Dan McCoy, who is charged with the installation and maintenance of the town's energy production and is the local subject matter expert. Using the information gleaned from these conversations, a better understanding of the current grid configuration was derived to create a more targeted survey for the residents of the town. Twenty-six copies of the survey were sent to Dan McCoy, who distributed them to all the town's residents. Responses from roughly 1/3 of households were received, allowing inputs to accurately model the community's current distributed energy profile, their thermal load and supply at the single-home level, and to better understand how new grid configurations might interplay with this energy usage reality.

Modeling Methods

To model an optimal renewable energy microgrid configuration, I utilized the industry standard HOMER (Hybrid Optimization Modeling Software) to simulate thousands of potential grids and run them through 20 years of usage on site. HOMER was originally developed by the National Renewable Energy Laboratory, within the Department of Energy, to assist the development of effective micro-grids with powerful computational modeling (Givler & Lilienthal, 2005). HOMER utilizes time series data about local temperature, available wind and solar, along with native and inputted component performance data to run thousands of possible component combinations through years of simulations to come up with the best options. The various grid options are then ranked by the user's selected priority, and the default is by Net Present Cost (NPC). NPC is the total future cost, in this case of a grid or component, reduced by the discount rate of the capital expenditure. Levelized Cost of Energy (LCOE) is also generated and is helpful to compare potential configurations with the status quo to determine whether a switch in energy systems should be made. LCOE is the energy cost per unit (total production divided by NPC). Running each model through hourly simulations based on real world observations provides a much better depiction of actual performance than using less granular data such as monthly averages (Givler & Lilienthal, 2005). Over 14,000 model iterations were simulated in the analysis and the most optimal systems were ranked in order of their NPC.

To produce applicable real-world cost estimates, initial runs of the HOMER software were executed to generate the financial realities currently faced by the village. "Reverse Engineering" the current grid allowed follow-on assumptions to be inputted and combined with rough cost estimates for various components. The complexity of the system configuration was increased as components were added. Component costing was determined by gathering information gained from direct contact with the manufacturers and installers of the actual products utilized and combining it with a local price premium for the remote Alaskan installation. This led to a final set of models that used observed and detected natural resource availability data (wind, solar, temperature, etc.), current fossil-fuel prices, and capital expenses from purchase through operations and maintenance to recapitalization, all incorporated into the simulations to inform the village of their choices.

Modeling Assumptions

Data were gathered by the local mayor via survey, interviews, and from energy resource catalogs. Key modeling assumptions and input variables are outlined below.

Existing Infrastructure

According to Dan McCoy and a case study conducted by NREL for the village (NREL, 2015), the Akhiok power plant houses three generator sets, including one 75 kW, a 70 kW (currently not operational), and a 117 kW generator. The only batteries involved in the system are used to start the generators, which are housed in a Conex box approximately 2,000 feet from the village. The 12.47kV distribution provides power to the 71 people, 26 homes, power plant, school, water treatment plant, and health clinic via 4 junction boxes and 12 transformers. According to NREL (2015), All the lines are direct-bury, were installed 36 years ago, are subject to many freeze/thaw cycles, interact with rocks, suffer water intrusion, and are the cause of many service instability issues that are becoming more and more prevalent. Many of the junction boxes are unsecure and potentially unsafe due to many children playing nearby. To model the current conditions in Akhiok, the closest generator sizes within HOMER (Kohler 89kw and 105kw) were used and produced very accurate outcomes that matched the real-world costs as reported by the energy surveys, Dan McCoy, and the annual generation figures reported to the state.

Load

The electrical load for the town was computed from the usage survey findings, corroborated by reported electrical generation from a statewide survey. Dividing the 42,966 gallons of fuel brought into the village for power and heat by 71 residents yields an average of 605 gallons of fuel for each Akhiok resident. The city generates a total of 202MWh of electricity from the combustion of 24,000 gallons of diesel fuel per year (ISERUA, 2003). This works out to 8.41 kWh per gallon of diesel and equates to slightly less than 25% efficiency. By comparison, a more modern generator at peak efficiency will produce power closer to 30-35% (Diesel, 2018). The retail price to consumer of electricity in Akhiok is $.80/KWh and its distribution is as follows:

Table 1. Annual electrical load of Akhiok by usage type.

Type	MWh
Residential	60
Commercial	59
Community	53
Transmission Loss	30
Total	202

The thermal load for the town is estimated from the heating cost portion of the survey, the known relationship between residential energy use and commercial use, and the amount of fuel used to heat the school, gathered from Dan McCoy (Table 2).

Table 2. Annual gallons of fuel used to produce thermal load service.

Type	Gallons of fuel oil	BTUs (millions)
Residential	10,535	1,459
Commercial	2,431	336
Community	6,000	831
Total	18,966	2,626

Wind and Solar Resource

Akhiok is situated in an area of Class-7 winds, greatly favoring the incorporation of a wind turbine (Figure 5).

The solar resource was derived from a 22-year period from July 1983-June 2005 and downloaded from the NASA Surface Meteorology and Solar Energy web site for Akhiok, Alaska. The annual average solar radiation for this area is 2.91 kWh/m2/d. This is considered to be poor for PV, but places such as Germany have been able to capitalize on similar resources.

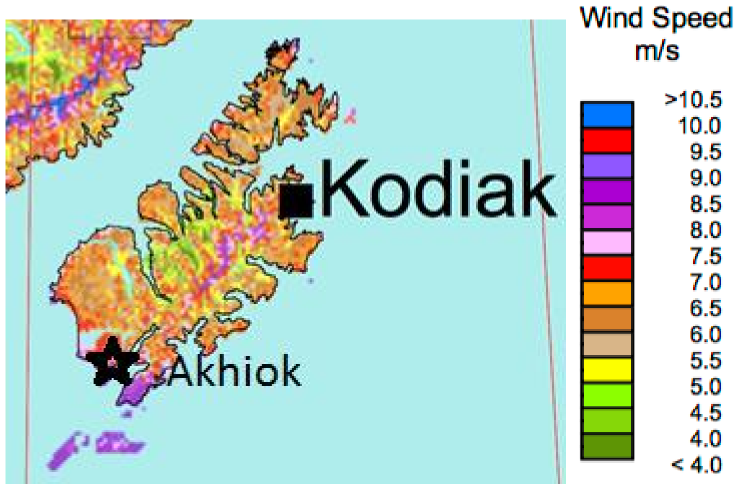


Figure 5. Wind speed chart of Kodiak Island. Akhiok is situated in a purple shaded area denoting >8 m/s windspeed, corresponding to a Class-7 wind resource. Data Source: NREL

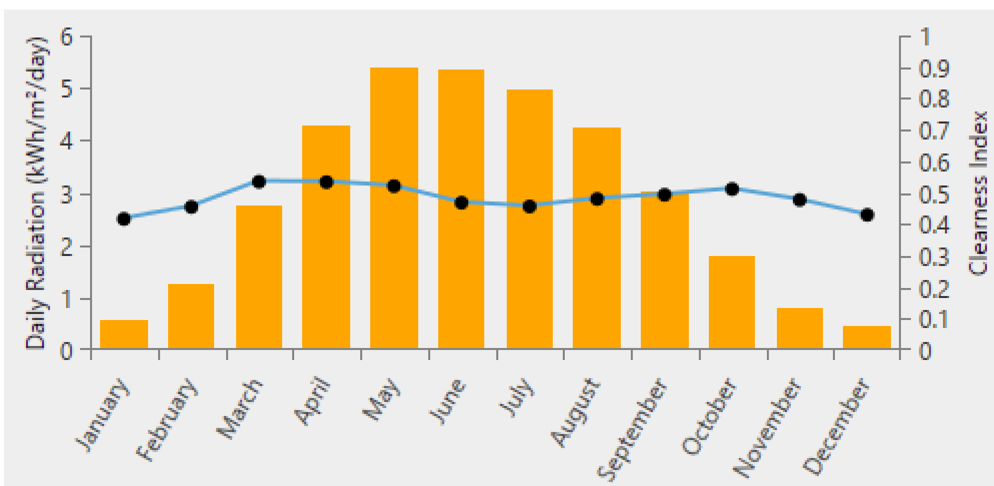


Figure 6. Available solar resource at Akhiok, Alaska.. Data Source: NASA

Economics

HOMER uses a real annual interest rate, which takes the current nominal rate and deducts inflation. This value factors into the NPC of the project, calculating cumulative future costs, including opportunity costs, to be factored into the decision making that surrounds determining grid construction. According to a similar study by Givler and Lilienthal (2005), “HOMER converted the capital cost of each component to an annualized cost by amortizing it over its component lifetime using the real discount rate” (p. 3).

The most recent cost per gallon of diesel fuel to the village was $4.55. That price did not include a delivery charge of $46,000 for the order from Homer, Alaska to Akhiok. Including delivery into the retail cost to the village brings the per gallon cost to $6.47 and $1.70 per liter (unit of measure used within HOMER).

The costs of components tor this study come directly from the manufacturer or installer as close as possible to the site. Photovoltaic panels are based on commodity pricing adjusted at a rate derived from Schwabe (2016), whose 2015 Alaska PV analysis assumed “…a flat $3/W pricing as the lower 48 base level price, which is then increased to account for higher costs for nearly all goods and services in remote Alaskan communities. This analysis multiplies the lower 48 base level price by 2, 3, or 4 times to get a range of estimates for remote village pricing” (p.15). According to an interview with Kirk Garroutte, a local renewable power installer, installation costs are typically at the lower end of Schwabe’s findings, at around an 80% cost increase over lower-48 pricing (personal communication, December 28, 2017). A slightly more conservative, simple doubling of the lower-48 PV prices are used for capital and operation/maintenance costs.

Chapter III

Results

Model results were generated first from recreating the current realities of Akhiok's grid within HOMER and subsequently substituting or adding components to inform the optimal grid configuration, depending on the energy priorities and budgetary constraints of the village. Once the electrical grid had been mapped out with storage capability and renewable generation sources, the thermal load was addressed. Excess electricity is fed into a thermal storage system, and eventually a CHP system is included for district heating. All model output was generated by HOMER X64 v.3.10.3 between October 2017 and January 2018.

Model 1: Current Composition – One Continuous and One Standby Generator

With approximate generator sizes of 89kw and 105kw, the model produced very accurate fuel use and production figures for the 75kw and 117kw generators on-site in Akhiok. Annual fuel use for the generators in the simulation equaled 25,000 gallons, within 4% of the actual amount used in 2016. Overall annual electrical production was 246kWh, matching the reported figures from Akhiok before reducing for transmission and other losses (Figure 7). LCOE matches the cost realities of Akhiok at $0.80, and NPC without upgrades were $2,080,645 for 25-years (Figure 8). This is a stunningly high cost for so few people to pay for energy, but its alignment with reality provides a solid baseline from which to model future grids.

Production	kWh/yr	%
Kohler 89kW Continuous	112,120	45.4
Kohler 105kW Standby	134,732	54.6
Total	246,852	100

Consumption	kWh/yr	%
AC Primary Load	201,845	100
DC Primary Load	0	0
Total	201,845	100

Quantity	kWh/yr	%
Excess Electricity	45,007	18.2
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	0
Max. Renew. Penetration	0

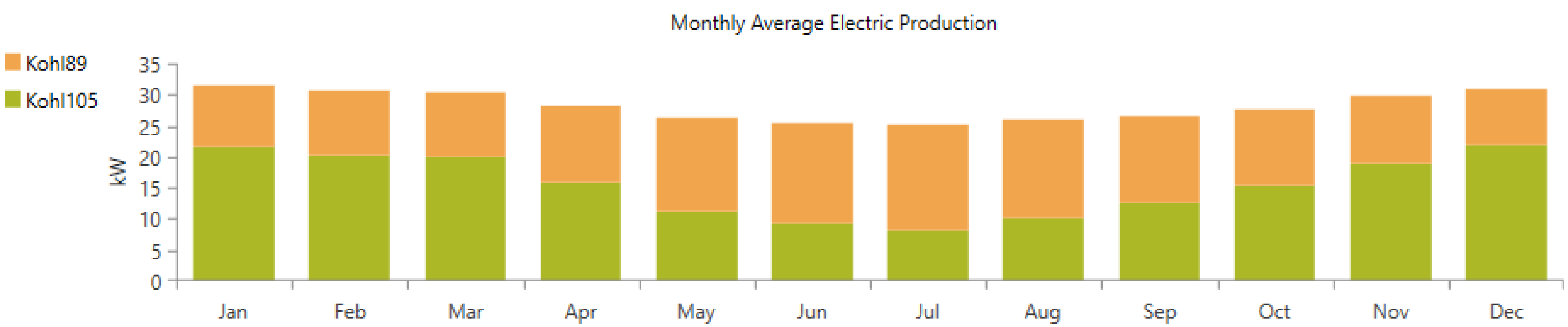
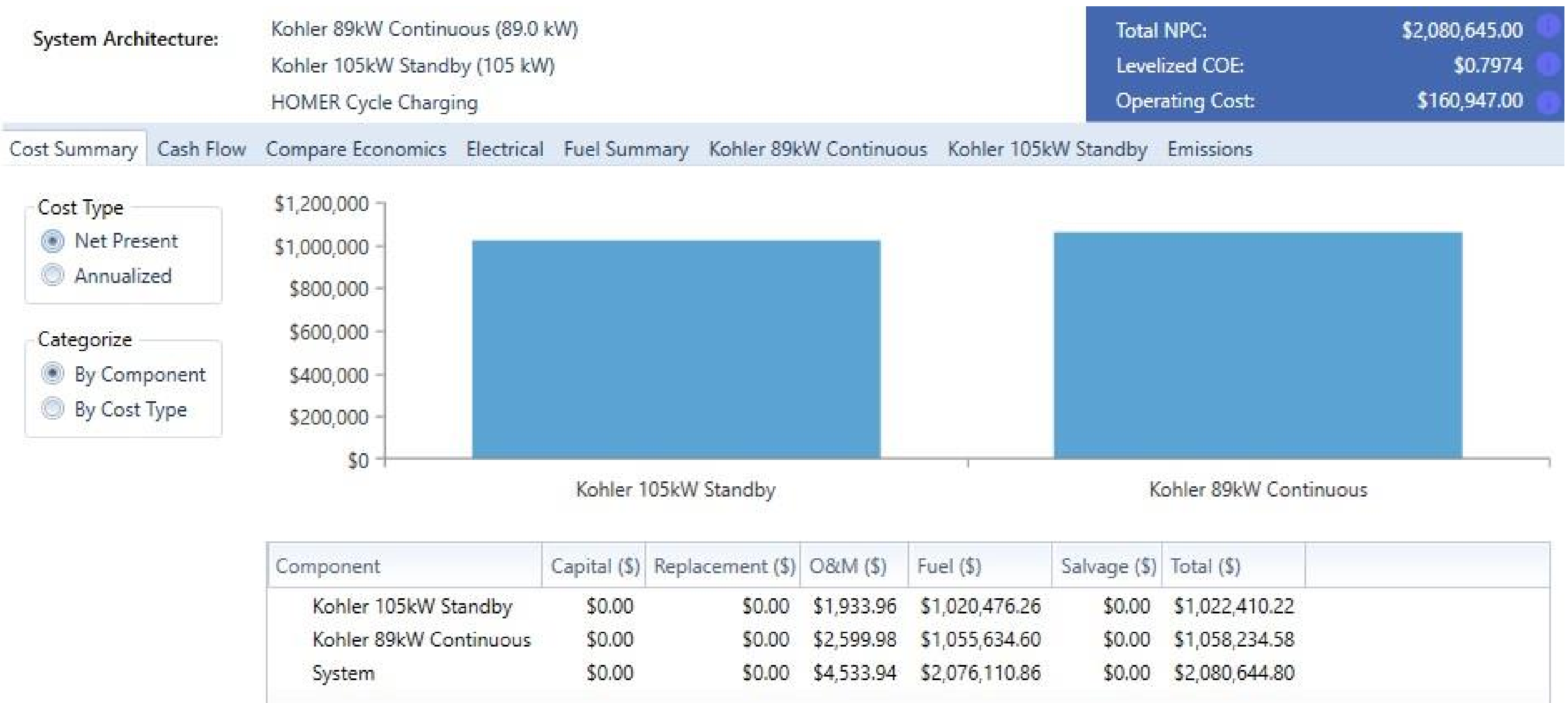


Figure 7. Annual electrical production of the current generation regime. HOMER switches between generators to equalize the run time of each generator. Seasonal load variability is evident in the monthly graphs. Data Source: HOMER

Of note, at the bottom of Figure 7 and in subsequent figures, “Monthly Average Electric Production” depicts the amount of electricity generated from each source. This will become more relevant as renewable power sources are added, as this graph depicts the seasonal variation in energy production attributed to each of the resources and usage by the utility customers. One of the obvious factors driving the need for grid upgrade is the amount of electricity that is produced and wasted by transmission loss. The energy is derived solely from fossil fuel and there is no apparent or reported subsidy given to the consumer. Proving this point, it was observed that the costs of the fossil fuel being consumed and the price of electricity per kWh line up almost exactly with the annual costs reported from the village at $160,947 per year (Figure 8). There is no long-term contract in place to modulate the price in any way and pricing is determined each time a delivery of diesel fuel is delivered to the city, based on the delivered price and any repair costs to the generators.

Model 2: Existing Generators Plus Tesla Powerwall 2

When given the option, HOMER optimized the grid to include seven “Tesla Powerwall 2” batteries. These are lithium-ion batteries, each with 14kWh of storage and a built-in inverter. The addition of these batteries is a necessary precursor to the integration of renewable power, as it overcomes the challenge of aligning the usage cycle with the resource availability cycle (Figure 9).



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Kohler 105kW Standby	$0.00	$0.00	$1,933.96	$1,020,476.26	$0.00	$1,022,410.22
Kohler 89kW Continuous	$0.00	$0.00	$2,599.98	$1,055,634.60	$0.00	$1,058,234.58
System	$0.00	$0.00	$4,533.94	$2,076,110.86	$0.00	$2,080,644.80

Figure 8. Costs associated with the status quo system. LCOE and fuel usage are depicted for the two existing generators over the 25-year output period. Data Source: HOMER

Production	kWh/yr	%
Kohler 105kW Standby	218,768	100
Total	218,768	100

Consumption	kWh/yr	%
AC Primary Load	201,845	100
DC Primary Load	0	0
Total	201,845	100

Quantity	kWh/yr	%
Excess Electricity	740	0.338
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	0
Max. Renew. Penetration	0

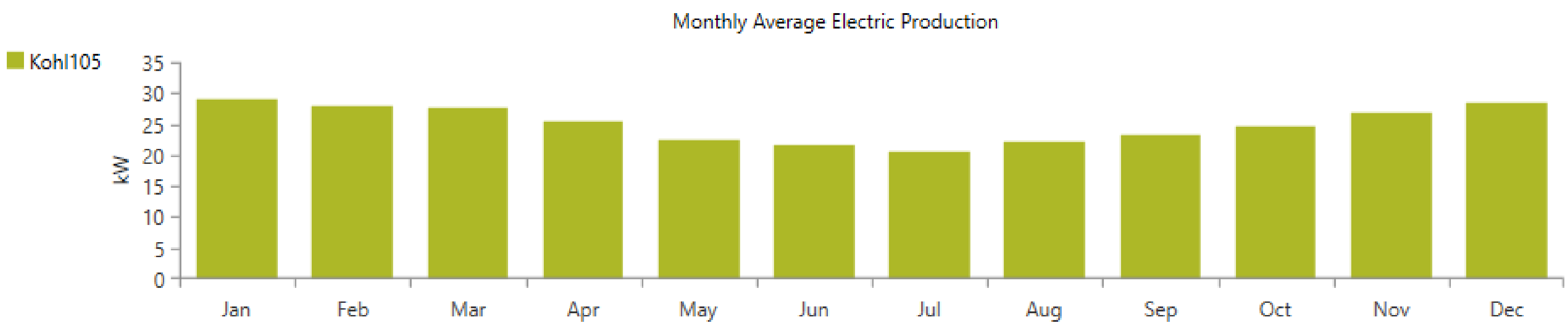
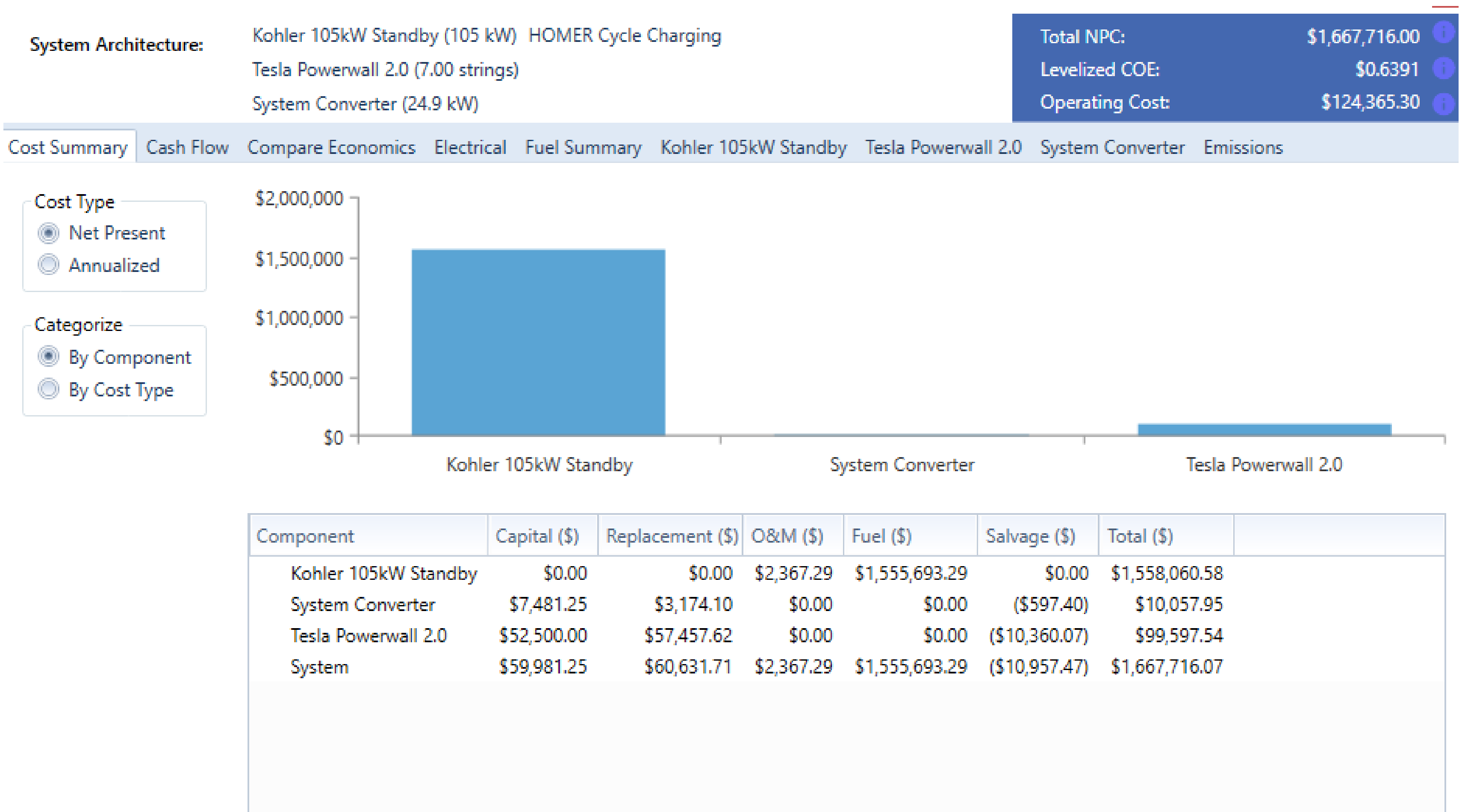


Figure 9. Annual electrical production with 7-Tesla Powerwall 2 batteries. The main benefit is the reduction in excess electricity being produced. Data Source: HOMER

By simply adding a conduit for storage, the generator no longer must run constantly and the amount of excess electricity generated drops from 45,007 kW/h to 740 kWh/yr; a vast leap in streamlining the grid's energy flows (Figure 9). The HOMER screenshot shows that power customers of Akhiok would see a reduction in the LCOE from the current rate of $0.80 to $0.64 (Figure 10).

This additional capability reduces annual fuel consumption from roughly 25,000 gallons to 18,700 – reducing net present fuel costs by $520,417 over 25 years. While this grid modification eliminates the "need" for a standby generator, saving capital replacement and O+M costs, the village could consider keeping the backup to alleviate long-term power loss from the failure of the single generator. Utilizing the model-produced charge and discharge cycles, the batteries are estimated to need replacement around the 8-year mark. While this adds to the net present capital costs of the system, the deferred fuel and second generator maintenance costs still make it a much less expensive option compared with the status quo. The batteries would be installed closest to the end consumer, and several would be clustered in the school where there is a large off-peak demand. This proximity to the end user boosts power availability by reducing the chance of intermediate disconnection and also allows for the addition of customer purchased photovoltaic panels. Giving household members the ability to store their own energy would allow them to charge the batteries and potentially open the gate for net metering, whereby the households can be paid for the excess power they produce. Siting the batteries within the households would also put the cells squarely within their optimal temperature range of 40-80 degrees Fahrenheit.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Kohler 105kW Standby	$0.00	$0.00	$2,367.29	$1,555,693.29	$0.00	$1,558,060.58
System Converter	$7,481.25	$3,174.10	$0.00	$0.00	($597.40)	$10,057.95
Tesla Powerwall 2.0	$52,500.00	$57,457.62	$0.00	$0.00	($10,360.07)	$99,597.54
System	$59,981.25	$60,631.71	$2,367.29	$1,555,693.29	($10,957.47)	$1,667,716.07

Figure 10. Costs associated with the addition of seven Tesla Powerwall 2 batteries. The reduction in fuel usage lowers LCOE. Data Source: HOMER

Model 3: Existing Generators, Tesla Powerwall, and PV

Adding solar panels to the simulation resulted in a HOMER recommendation of a 42.5kW photovoltaic array (Figure 11) at an upfront cost of $255,204 (Figure 12). The addition only reduces LCOE by less than $0.01/kWh, but reduces annual fuel use by 3,896 gallons (Figure 11). It also boosts the renewable fraction from 0% to 9.77% (Figure 11), and reduces generator run time from 4,518 hours to 2,873. The reduction in generator run time is also sure to have positive externalities related to a reduction in local air pollution, the assessment of which is outside the scope of this study.

The minimal cost saving is due to the expense of purchasing and installing PV (at double the price of the lower-48 states), and adding two more Tesla Powerwall batteries to allow for storage of excess power during peak solar insolation.

The goal of deferring fuel usage is achieved with this addition; however, the installed cost of PV absorbs most of the savings. The advantage of having an additional source of electricity does add to the system resiliency. This represents an advantage that is hard to quantify in terms of dollar value, but one that would come in handy in case of a generator interruption from mechanical failure or a fuel delivery disruption. Due to the relatively poor solar resource availability, the generator’s failure would have to come at a good time to be able to be offset by PV.

Production	kWh/yr	%
Generic flat plate PV	41,960	18.7
Kohler 105kW Standby	182,117	81.3
Total	224,077	100

Consumption	kWh/yr	%
AC Primary Load	201,845	100
DC Primary Load	0	0
Total	201,845	100

Quantity	kWh/yr	%
Excess Electricity	1,011	0.451
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	9.80
Max. Renew. Penetration	483

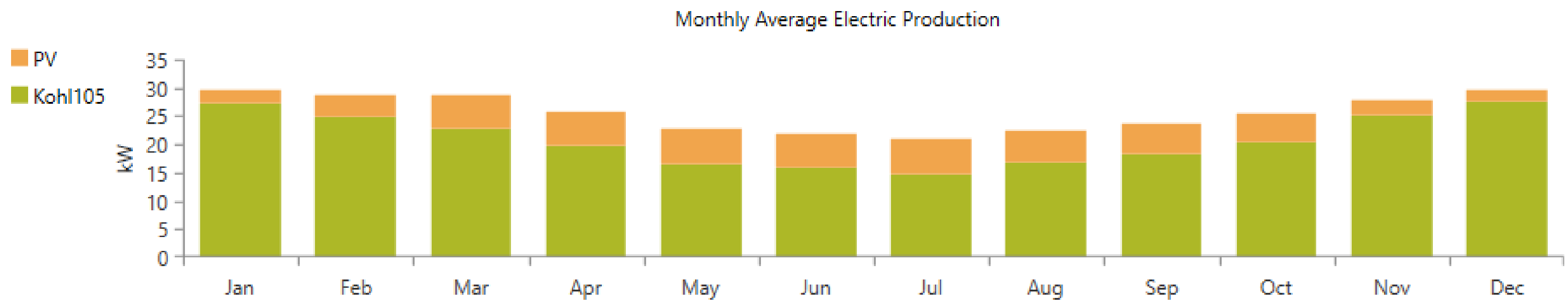


Figure 11. Annual electrical production with PV incorporated. The PV does relatively well in the summer months, but provides little additional power in the darker months. Data Source: HOMER

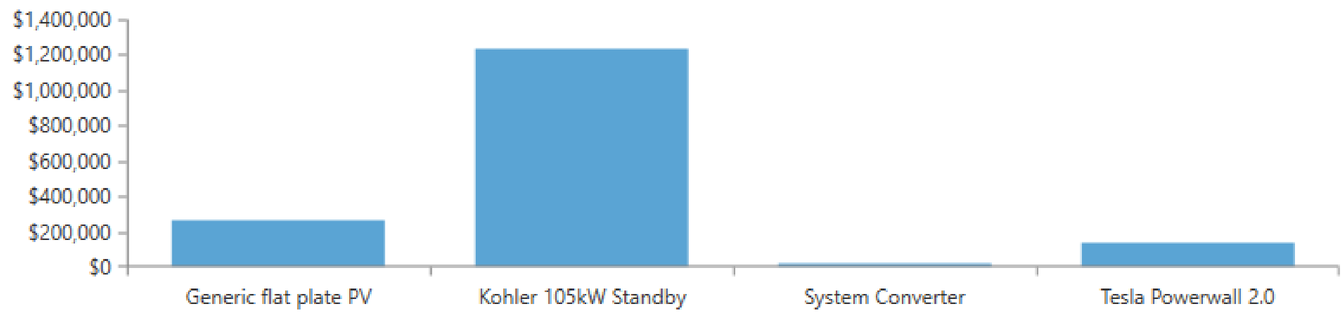
System Architecture: Generic flat plate PV (42.5 kW) System Converter (45.5 kW)
Kohler 105kW Standby (105 kW) HOMER Cycle Charging
Tesla Powerwall 2.0 (9.00 strings)

Total NPC:	$1,648,041.00
Levelized COE:	$0.6316
Operating Cost:	$101,464.90

System Converter Emissions
Cost Summary Cash Flow Compare Economics Electrical Fuel Summary Kohler 105kW Standby Renewable Penetration Tesla Powerwall 2.0 Generic flat plate PV

Cost Type
Net Present
Annualized

Categorize
By Component
By Cost Type



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic flat plate PV	$255,204.23	$0.00	$5,498.59	$0.00	$0.00	$260,702.83
Kohler 105kW Standby	$0.00	$0.00	$1,485.63	$1,231,506.09	$0.00	$1,232,991.72
System Converter	$13,647.49	$5,790.27	$0.00	$0.00	($1,089.79)	$18,347.98
Tesla Powerwall 2.0	$67,500.00	$84,443.23	$0.00	$0.00	($15,944.48)	$135,998.75
System	$336,351.73	$90,233.50	$6,984.23	$1,231,506.09	($17,034.27)	$1,648,041.28

Figure 12. Cost summary with PV incorporated. Some savings are yielded from a reduction in fuel but are nearly fully absorbed by the capital costs of adding PV. Data Source: HOMER

Model 4: Wind Turbine, Tesla Powerwall, and PV

Adding Eocycle's EO25 wind turbine at an installed cost of $175,000 results in a seismic shift in electrical cost for Akhiok. LCOE drops from $0.63 with PV and battery storage down to $0.38. Fuel usage plummets to 7,767 gallons, a reduction of over 17,000 gallons from the current paradigm (Figure 14). According to Eocycle's VP of sales, the turbine is "designed to be installed in remote areas that don't allow consistent maintenance" (pers. comm., October 20, 2017). The assemblies in the turbine are simple, the electronics are solid state, and the assembly itself would be fitted with a cold weather package that allows the turbine to operate reliably in the cold and wet condition of Akhiok. The same turbine was installed in Kotzebue, approximately 600 nautical miles to the northwest of Akhiok, and it has been operating without disruption for the past four years.

The addition of the wind turbine increases the renewable fraction from <10% to >50%, and still produces around 12,555 kWh of excess electricity, a non-trivial amount that can be used to heat water for a community building or to charge electric vehicles (Figure 13). The community has less than a dozen vehicles consisting of pickup trucks and a few all-terrain vehicles. If electricity can be generated more affordably, the market may steer vehicle purchases towards electrics. This shift holds similar supply-chain deferral benefits to the ones realized by power grid savings. Adding the wind turbine reduces the amount of PV recommended to 6.29kw, reducing capital attributed to PV by $222,143 to $37,746 (Figure 14).

Production	kWh/yr	%
Generic flat plate PV	6,206	2.71
Kohler 105kW Standby	94,573	41.2
Eocycle EO25 Class III	128,546	56.1
Total	229,325	100

Consumption	kWh/yr	%
AC Primary Load	201,845	100
DC Primary Load	0	0
Total	201,845	100

Quantity	kWh/yr	%
Excess Electricity	12,555	5.47
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	53.1
Max. Renew. Penetration	1,321

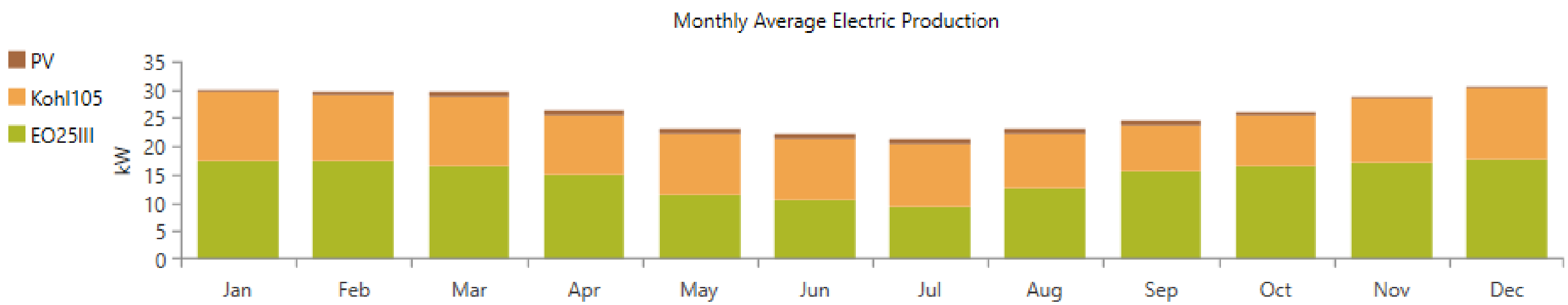
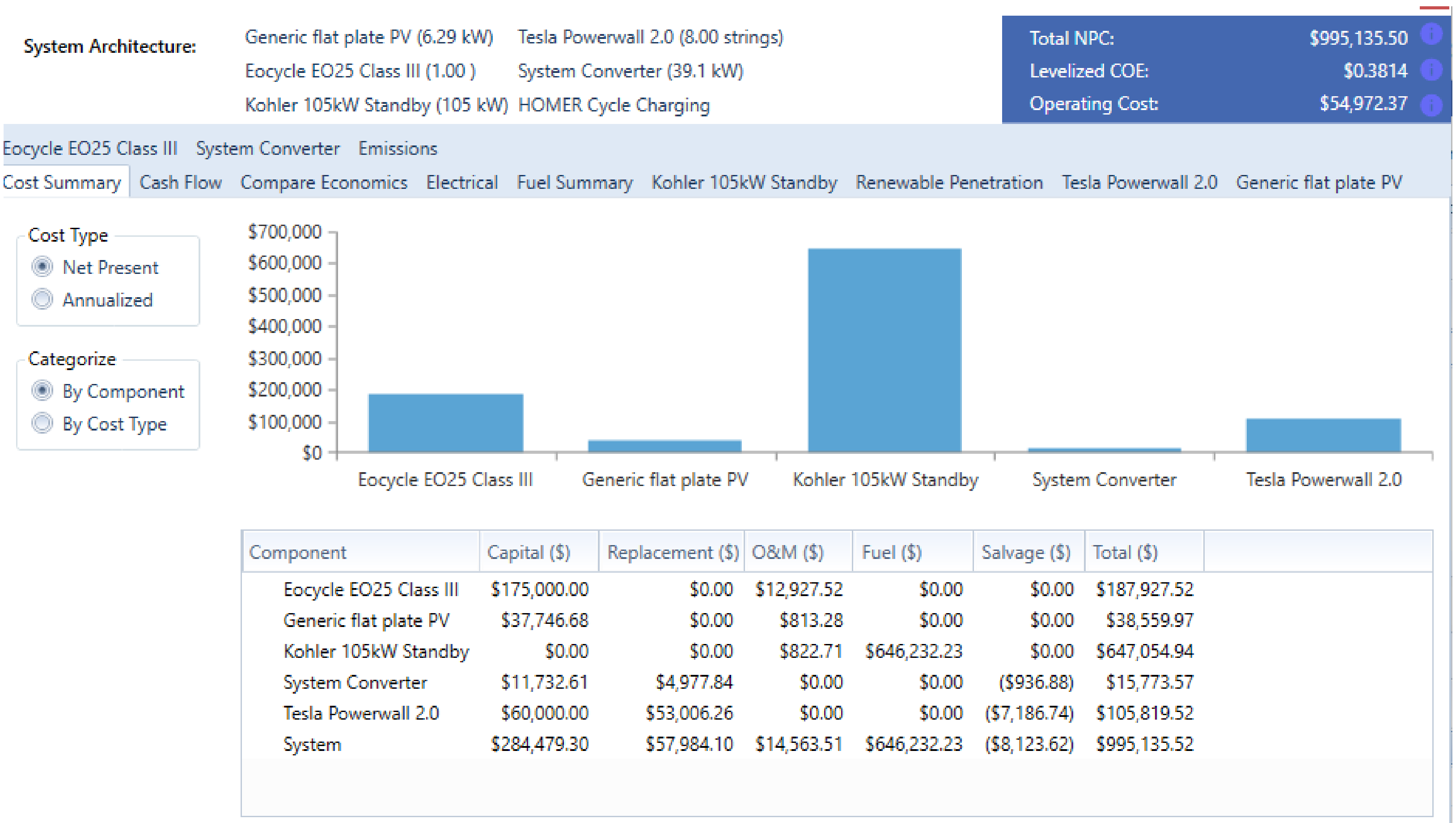


Figure 13. Annual electrical production with Eocycle 25 kw wind turbine. The wind turbine overtakes the fuel powered generator to become the primary electrical source for the village. Data Source: HOMER



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Eocycle EO25 Class III	$175,000.00	$0.00	$12,927.52	$0.00	$0.00	$187,927.52
Generic flat plate PV	$37,746.68	$0.00	$813.28	$0.00	$0.00	$38,559.97
Kohler 105kW Standby	$0.00	$0.00	$822.71	$646,232.23	$0.00	$647,054.94
System Converter	$11,732.61	$4,977.84	$0.00	$0.00	($936.88)	$15,773.57
Tesla Powerwall 2.0	$60,000.00	$53,006.26	$0.00	$0.00	($7,186.74)	$105,819.52
System	$284,479.30	$57,984.10	$14,563.51	$646,232.23	($8,123.62)	$995,135.52

Figure 14. Cost summary with Eocycle 25kw wind turbine added. LCOE is cut by a large margin. Data Source: HOMER

Model 5: Tesla Powerwall, Wind Turbine, and CHP

The thermal load for Akhiok is substantial, requiring 79% as much fuel for heat as is required for electrical production. Up until this point the installation of costly fossil fuel generators has been avoided in the simulations and LCOE has fallen. Addressing the thermal load requires an analysis of an optimized system with CHP to see if a drop in kWh pricing occurs while producing thermal energy to heat the community's largest building, the village school. The addition of CHP does present some issues stemming from the complexity of the system and the potential downtime that would result from a malfunction. Though extremely reliable, the technical expertise required to fix such a system isn't found locally, and so the trade-offs must be carefully weighed, and suitable backup generation should be in place. While CHP does offer the potential for district heating, the infrastructure required to carry heat throughout the village would be costly and susceptible to the harsh climactic variations.

The strategy of housing the CHP turbine in the school would minimize the costs and hazards inherent to a more widely distributed system. The school currently uses a boiler and 6,000 gallons of heating oil to provide heat to its 5,000 square feet of space. Adding the thermal load requirement of the school to HOMER and electing for CHP gives us the following thermal production (Figure 15). LCOE drops over $0.05/kWh with the addition of a Capstone C65 ICHP turbine, rated at 65kw (Figure 16). The addition of this CHP system brings energy cost and fuel use down by harnessing the heat from power production that would otherwise be wasted. It is also a better-sized generator given the addition of the renewable sources, as compared with keeping the existing generators in place. Though this turbine is considered somewhat novel as compared to the

Production	kWh/yr	%
Generic Gas Microturbine with CHP (size-your-own)	108,123	45.5
Generic Boiler	110,514	46.5
Excess Electricity	18,845	7.94
Total	237,482	100

Consumption	kWh/yr	%
Thermal Load	219,000	100
Total	219,000	100

Quantity	kWh/yr	%
Excess thermal	18,482	8.44

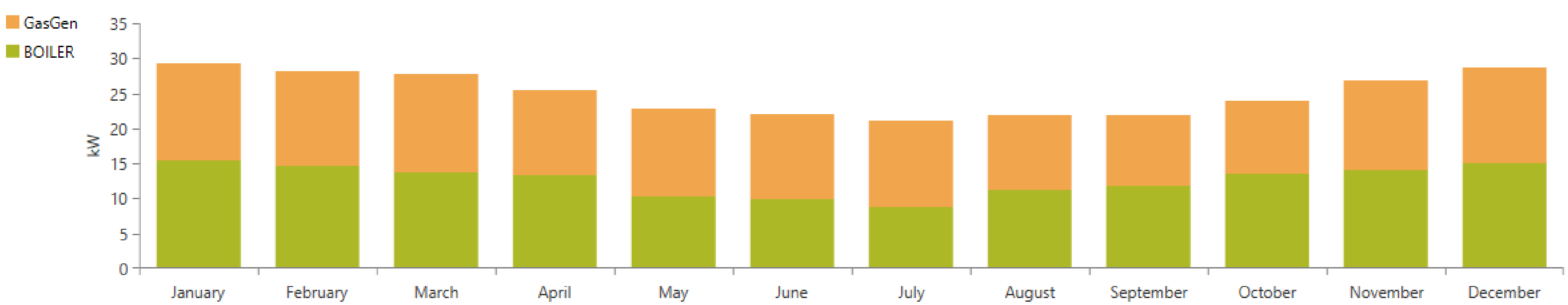
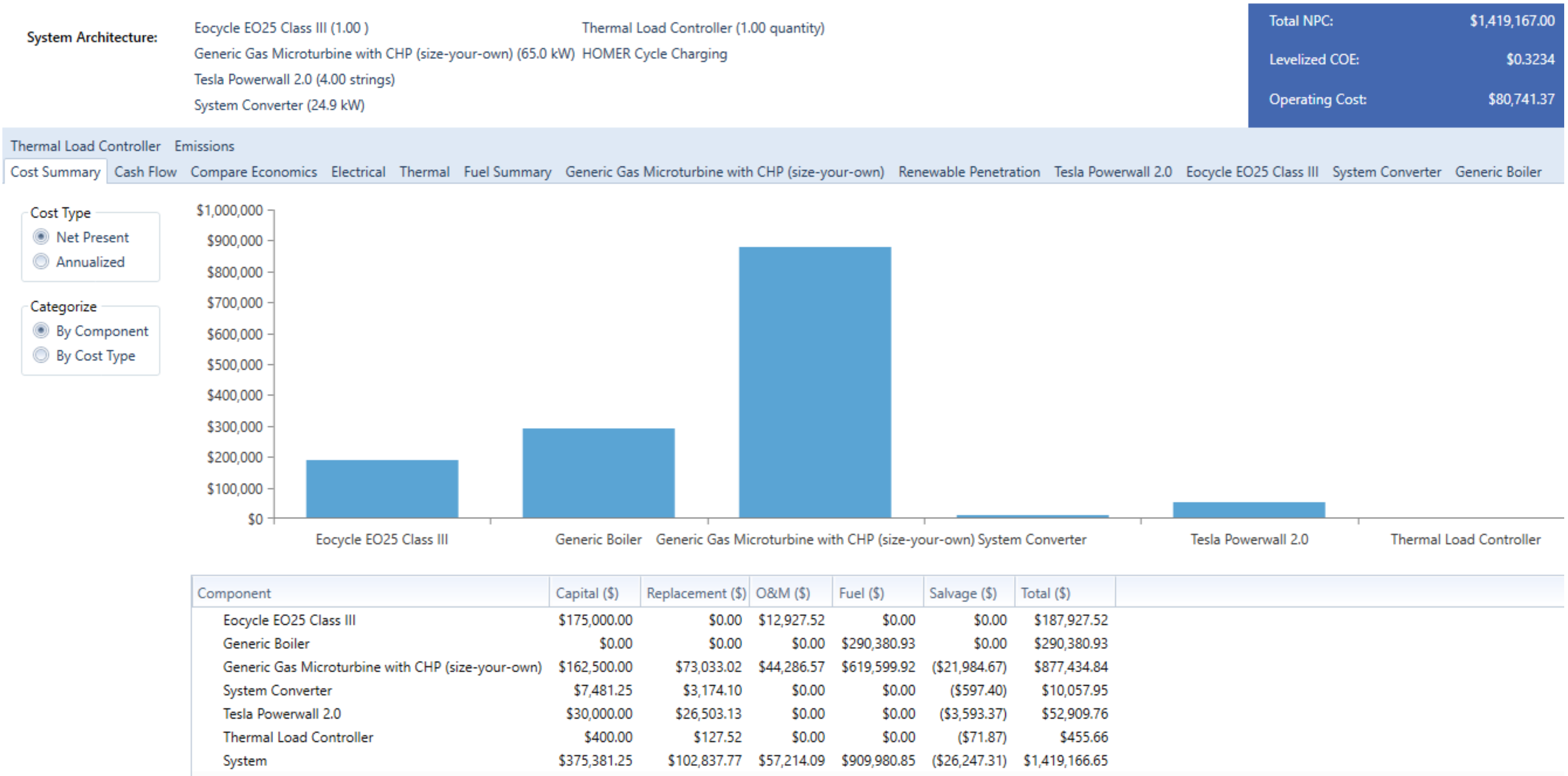


Figure 15. Annual thermal production with CHP. The CHP system combines with the existing boiler or a resized one to heat the school, realizing cost savings. Data Source: HOMER



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Eocycle EO25 Class III	$175,000.00	$0.00	$12,927.52	$0.00	$0.00	$187,927.52
Generic Boiler	$0.00	$0.00	$0.00	$290,380.93	$0.00	$290,380.93
Generic Gas Microturbine with CHP (size-your-own)	$162,500.00	$73,033.02	$44,286.57	$619,599.92	($21,984.67)	$877,434.84
System Converter	$7,481.25	$3,174.10	$0.00	$0.00	($597.40)	$10,057.95
Tesla Powerwall 2.0	$30,000.00	$26,503.13	$0.00	$0.00	($3,593.37)	$52,909.76
Thermal Load Controller	$400.00	$127.52	$0.00	$0.00	($71.87)	$455.66
System	$375,381.25	$102,837.77	$57,214.09	$909,980.85	($26,247.31)	$1,419,166.65

Figure 16. Cost Summary with CHP. Adding CHP does reduce the heating cost of the fuel. The complexity of CHP may not be worth the cost savings. Data Source: HOMER

more ubiquitous reciprocating generators, it is being used successfully in Alaska with infrequent maintenance issues. When CHP is added, the annual heating cost of the school is reduced from the base case at $38,820 per year to $22,580, with a total annual reduction in fuel use of 2830 gallons (Figure 16). The reduction in thermal load for the school could also allow a newer, more efficient boiler to be installed that could further reduce costs.

Chapter IV

Discussion

The output of HOMER gives us insights into the trade-offs associated with the varying options for Akhiok. However, further discussion is required to ascertain the feasibility of each option. Basic upgrades must be made to the town’s infrastructure before any additional resources are incorporated. Mechanisms such as grants, leases, and Power Purchase Agreements (PPAs) to fund the chosen option exist, and have been used throughout the state.

Grid Repair

The electrical infrastructure of the village is outdated, fragile, and in many areas throughout the town, dangerous. The NREL assessment conducted in October of 2015 highlighted numerous specific deficiencies in the grid that must be resolved before modernization begins. According to NREL, the housing stock was mainly built in 1978, with some other units added in 1987. The original electrical wiring from that time period is still being used. Failure events are occurring with increasing frequency, and in November of 2017 Dan McCoy reported “I've had four dead shorts in the ground in the last four months and one of them put the school out of power for three weeks. I had to run back up genset and used up a lot of the school's heating fuel for the winter. Our in-ground electric grid is in such bad shape it's getting dangerous and the concentric ground on the primary transmission lines is gone, rotted away, so it offers no protection” (McCoy, 2017). Similarly, within the NREL report it was found that “utility personnel noted that the concentric neutrals on the buried cables are badly corroded. This limits both return and fault currents” (NREL, 2015). The many weaknesses of Akhiok’s grid are not solely limited to the subterranean realm. Junction boxes are rusted and some fail to close, posing an enormous liability to the children of the village who were witnessed playing close to boxes like the one in Figure 17.

Figure 17. Open Junction box in Akhiok. This type of disrepair is prevalent throughout the village and poses a significant safety hazard and power-resiliency risk (photo: NREL, 2015).

The executive summary of the NREL assessment stated a very succinct conclusion: “The next step will be to use this report to request funding for $1.3M and to provide a roadmap for improving safety, efficiency and replace the aging and failing Akhiok electrical distribution system” (NREL, 2015). Unfortunately, in the more than two years since this NREL assessment was conducted, the recommended course of action has not yet been undertaken. Additionally, the $1.3M cost figure excluded escalation, RFP and contracting costs, engineering, and the transportation of workers, tools, construction equipment, and other materials to Akhiok (NREL, 2015).

Financing Options

The state of Alaska and the Federal government offer many different grant options to help local governments modernize their energy infrastructures. These grants require extensive documentation for awarding, and accountability post-delivery, but they would provide much needed money for the repair of the existing infrastructure and procurement of the chosen renewable options. The Department of Energy lists several options (Table 3).

As the village looks at the particular avenues presented in this study, they may elect to pursue financing for the installed cost of the equipment, and/or to enter into a PPA that allows more comprehensive control to be handed over to a third-party. This type of Third Party Ownership (TPO) is commonplace, from small-scale grids like Akhiok's, to large, recently deregulated nations such as India where investment is sorely needed yet public money is often lacking (Jenkins & Lim, 1999). All of the manufacturers affiliated with this analysis offer financing options and adding the loan rates to the models would accordingly affect the NPC and LCOE.

The town could seek to utilize a PPA that would use a third party who manages the selection, planning, installation, and operation of the revamped grid and handle the provision of power to the village. Funding within such a PPA could come from a mixture of various sources such as private equity, public and private loans, grants, and an Independent Power Producer (IPP) would be formed to sell power to the village. Further

Table 3. Available grant options for modernizing energy infrastructure.

DOE Office of Energy Efficiency and Renewable Energy Financial Opportunities	Provides competitively awarded financial assistance to U.S. states and territories to advance policies, programs, and market strategies that accelerate job creation and reduce energy bills while achieving energy and climate security for the nation.
State Energy Program Competitive Financial Assistance Program	Find funding opportunities available for businesses, industry, universities, and others.
Environmental Protection Agency Local Climate and Energy Program	Provides local governments with peer exchange training opportunities and competitive grant funding along with planning, policy, technical, and analytical information to advance their climate change mitigation and clean energy goals.
The Alaska Renewable Energy Fund (REF)	Provides benefits to Alaskans by assisting communities across the state to reduce and stabilize the cost of energy. The program is designed to produce cost-effective renewable energy for heat and power to benefit Alaskans statewide. The program also creates jobs, uses local energy resources, and keeps money in local economies.

analysis would be conducted to determine risks and sensitivities in order to inform the IPP of the financial feasibility of entering into an agreement. Terms would be laid out between the IPP and village, spelling out how the IPP is to be paid for energy produced. Often times an IPP will include an escalator clause that allows rates to rise in order to offset the depreciation of assets that inevitably occurs. A fixed rate of return type contract would give the investors a clearer picture of the agreement terms as a whole and would allow the village a more stable energy price going forward. According to Jenkins & Lim

(1999), perhaps the most important part of the PPA is the Fixed Charge Payment, encompassing “(1) Interest on Debt, (2) Depreciation Payment, (3) Return on Equity, (4) Interest on Working Capital, (5) O&M and Insurance Expenses, (6) Taxes on Income, (7) Special Appropriation,” (p.5). A PPA is a powerful tool that could speed up shovel ready projects, versus relying on scant home-grown funding, expensive financing, or often elusive grant money.

Going forward with the full complement of the recommendations made in Model 5 could be too big of a hurdle for Akhiok, even with a PPA. The relatively low cost of the wind and battery option might be the best option given the rapid reduction in LCOE per unit of initial capital, assuming the infrastructure issue is resolved.

Selecting a Course of Action (COA)

Exploring partnerships for a PPA will be critical to understanding and weighing the financial path to revitalizing Akhiok’s power system, and partnerships should be scoped to begin this process. Whether or not the highest level of a hybrid grid is eventually selected, choosing the appropriate path forward will require extensive discussions with the village to determine their fiscal priorities and discount rate. Along with exploring a PPA, the most obvious and immediate goal of the village - improving the safety and reliability of the current electricity regime - should be undertaken. To accomplish this, the village should apply for grants totaling at least the $1,300,000 specified within the NREL document. Attracting this money could most easily be accomplished by touting the safety improvements to potential grantors. Much of the specifics involved in choosing the optimized configuration will have to wait until an accurate assessment of how much “free-money” will flow towards the project. Once this amount is known the PPA can begin to take shape and the COAs can be laid out with all the costs available for comparison.

Assuming the infrastructure repair can be accomplished with outside money, the component selection can be made with an informed discussion on the trade-offs between each specific model. Subordinate to the main goal of improving safety and reliability is the reduction in cost to consumer. This reduction in LCOE is accomplished by spending increasingly on capital goods. The following chart (Figure 18) depicts the rate of initial capital increase that will be needed for the associated drops in levelized costs.

If the village finds difficulty in funding the purchases above a certain level, the choice might be made for them. Pursuing Model 1 by adding battery storage is an obvious first move for an initial upgrade, and owing to its relatively low cost of $59,981, it is one that should be accomplished even if there are no funding avenues that facilitate higher levels of grid development (Table 4). The addition of batteries would offset the need for two generators, reduce related life-cycle O+M and replacement costs nearly in half, and eliminate $520,417 in fuel costs over 25 years. This relatively simple upgrade pays for itself in the first 3.6 years.

Table 4. Financial assumptions for each model.

	Status Quo	+Battery	+Battery, PV	+Battery, PV, Wind	+Battery, PV, Wind, CHP
Initial Capital	0	59,981.25	336,351	284,479	375,381
Operation and Maintenance	4,533	2,367.29	6,984	14,563	57,214
Replacement	-------	60,631.71	90,233	57,984	102,837
Total	4,533	122,980	433,568	357,026	535,432

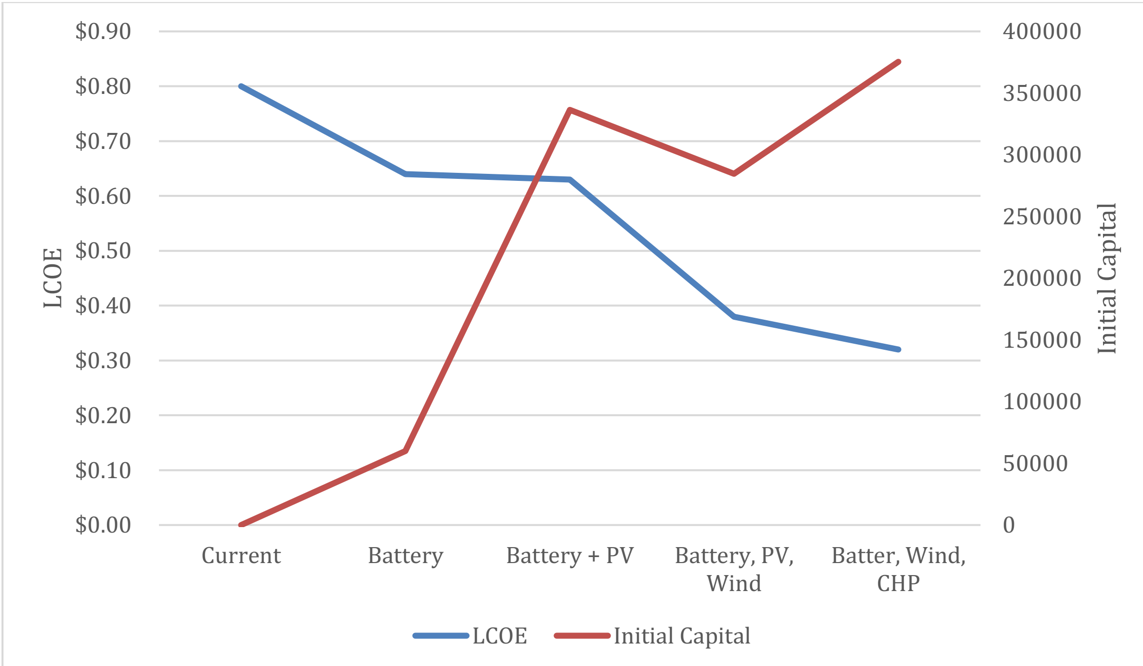


Figure 18: Comparison of initial capital cost and LCOE. As the grid mix increases in complexity the capital cost and LCOE reacts in varying degrees. For example, adding PV requires a significant amount of capital, but barely reduces LCOE. Data Source: HOMER

The addition of PV, at the recommended scale of Model 2, comes at a high initial capital cost of $255,204 and only reduces NPC by $19,675 (Figure 12, Table 4). This would be a hard pill to swallow for the villagers if it were in the form of an upgrade paid for only by them. This COA may only appeal to an outside funding organization that aims to reduce fossil fuel usage as part of either a grant or loan. Though unlikely to be adopted, this step on the stairway towards greater renewable fraction is useful for examination as it showcases that it is possible to "miss the forest for the trees" when optimizing a microgid. Adding solar does a lot for the greater goal of reducing the carbon footprint of Akhiok, but it is not one that makes great financial sense.

Implementing Model 4, wind generation with a 25kw turbine, requires initial capital expenditure of at least $175,000 (Figure 14). The reduction in LCOE and NPC is dramatic and produces excess electricity that the village could use to store thermal energy. The city of Concord, Massachusetts, for instance, allows its residents to purchase off-peak electricity at $0.064/ kWh (Town of Concord, 2018), when the resident has signed a contract to specifically use that electricity to convert for thermal storage. This cheaper, and most likely previously unused power flows from 10pm to 6am, heating the houses of Concord well into the morning and afternoon. Capitalizing on windy nights in this way would be akin to providing nearly free energy and would reduce reliance on heating fuel. Many PPAs even incorporate a production cap above which the electricity is given to the utility for free.

Adding a CHP system in Akhiok would be expensive, and as discussed, could expose the village to costly downtimes if a failure occurred. The primary benefits of CHP within the context of Akhiok are that it would allow previously wasted heat to be used, and a better-scaled generator would be inherently more efficient. Another way to realize benefits from these two areas would be to purchase a new, more efficient, and better scaled generator and to utilize add-on heat recapture features for thermal capture. A simple heat exchanger attached to the generator lubrication and exhaust system would not be as efficient as a larger purpose-built genset, but it would allow for thermal capture that would otherwise be impossible owing to the lack of an affordable, reciprocating CHP options in the size-class recommended.

Conclusions

Akhiok presents the same kind of challenges that many isolated communities face when selecting ways to produce cheaper and cleaner power. The logistical challenges of employing any of the recommended options are put into perspective when the yearly cost of merely delivering the required fuel is taken into account. A village like Akhiok, with limited financial resources, is squandering its meager income on already high fuel costs and the associated, and extremely variable, $46,000 shipping cost. Deciding on the most appropriate option for the village will be an iterative process requiring a systems-oriented approach. Clearly identifying priorities and matching the correct equipment to them will ensure that the system installed will be the one best able to meet the extreme demands of the townspeople.

Adding a vehicle for energy storage to a grid without any ability to respond to demand peaking, would be an obvious first step. Model 2 added seven Tesla Powerwall batteries, at a total cost of around $100,000, would save the village $520,417 over 25 years. This addition would eschew over 6,000 gallons of fuel and the associated carbon footprint and transportation cost. Model 3 included the installation of 42.5kW of PV cells. This upgrade is not only not intuitive given the latitude of Akhiok, but the data show a very marginal reduction on LCOE of one penny per kWh. The minimal cost savings comes from the expensive upfront cost of the panels and installation. Adding solar would reduce fuel usage by around 3,896 gallons and would be a wise move if offsetting fuel was the priority, rather than lowering cost. The addition of a 25kW wind turbine results in a large shift in the cost of producing power in Akhiok. This configuration reduces the cost of energy by more than half from the status quo, utilizing the abundance of available wind energy. The excess power produced can be shunted to thermal storage and utilized when needed. The share of energy from renewable energy jumps from the present day 0% to 53%, ensuring a cleaner village. The final model adds CHP to the mix, using once wasted energy to heat the school. The cost to heat the school is reduced by $16,240 per year, a savings that should offset the additional complexity resulting from such a state-of-the-art system.

Regardless of the system the village chooses, the applications necessary for state and federal assistance should be a priority. A Request For Offer (RFO) for a PPA should be drafted to begin the process of receiving bids from as many providers as possible to ensure a competitive process. The easiest choice is to install the batteries to begin eschewing fossil fuel purchases while at the same time pursuing PPAs to modernize the infrastructure and purchase the wind turbine and associated equipment. Once the funding structure and equipment is finally in place and the cost savings are realized, the village can focus on other priorities of great import to their health, safety, and economic well-being.

Appendix

Survey: Energy Usage and Cost Profile

Community Survey

List of Community/Commercial Buildings

Name and description of use	Size	Age
1.		
2,		
3,		
4,		
5,		
6,		
7,		
8.		
9.		
10.		

Any New Buildings Being Constructed or Planned

Annual Energy Use and Cost

Type of Energy	Quantity	Cost
Electricity		
Natural Gas		
Fuel Oil		
District Steam		
District Hot Water		

General

When was your home built?

About how many square feet is your home? Your best estimate is fine.

About how many windows does your home have?

1 1 or 2 windows
2 3 to 5 windows
3 6 to 9 windows
4 10 to 15 windows
5 16 to 19 windows
6 20 to 29 windows
7 30 or more windows
--4 Don't know

Which of these best describes the insulation level of your home?

1 Well insulated
2 Adequately insulated
3 Poorly insulated
4 Not insulated

Heating

What is the main type of heating equipment used to provide heat for your home?

About how old is your main heating equipment? Your best estimate is fine.

During the winter, what is the typical temperature when someone is home during the day?

What is the typical temperature when no one is inside your home during the day?

What is the typical temperature inside your home at night?

In addition to your main heating equipment, does your household also use any of the following as a second source for heating your home? If more than one, select the type most frequently used.

0 No other equipment used

1 Portable electric heater
2 Wood--burning stove
3 Natural gas fireplace
4 Wood--burning fireplace
9 Other (please specify equipment and fuel):

What fuel does your main water heater use?

1 Electricity
2 Propane (bottled gas)
3 Fuel oil
4 Other (please specify):

Electric Use

How many of the following are in your house?

Refrigerators
Stoves
Standalone Freezers
TVs
Dishwasher
Clothes Washer
Clothes Dryer
Stereo Systems

Approximately how many light bulbs are installed inside your home?

Of those, how many are:

Incandescent bulbs
CFL bulbs?
LED bulbs?

Cost

How much money do you spend per year on the following?

Electricity
Propane
Fuel oil
Wood or other solid fuel

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