Kokhanok Renewable Energy Retrofit Analysis

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Introduction / Overview

This presentation describes the results of an analysis of renewable energy retrofit options for the community of Kokhanok, Alaska. This small community (population ~150) has a typical Alaska diesel microgrid. The average electrical load (2015) is 48 kW, with a peak of 84 kW. In 2010, the community installed two 90-kW wind turbines, battery storage, converter, and equipment for integration. Due to a failure of the system controller, the turbines were switched off. The analysis was conducted to identify the lowest-cost (on a life-cycle cost basis) microgrid conceptual designs that reduce fuel consumption and reduce costs.

The analysis attempts to answer three interrelated questions.

- What is required to achieve a 50% reduction in power plant diesel fuel consumption in a diesel microgrid?
- What is required to achieve a 50% reduction in “total” (diesel + heating oil) consumption in a remote community?
- What is the potential impact and role of energy efficiency?

Researchers conducted the analysis and modeling using the HOMER and REopt software modeling packages.

This presentation is divided into three sections:

- Section 1 provides an overview of the community of Kokhanok.
- Section 2 delves into the assumptions that underpin the analysis. This section provides information and data on the following: energy consumption; fuel costs; power plant performance and costs; wind resource; cost and performance assumptions for wind turbines, batteries, and controllers; cost and potential extent of energy efficiency; and financial assumptions.
- Section 3 provides the analysis results.

Section 1
Community Overview

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Overview

Table 1. Kokhanok Community Overview

Population	152 (2016 Department of Labor Estimate) 170 (2010 Census) 174 (2000 Census) 152 (1990 Census)
Incorporation type	Unincorporated (Census Designated Place)
Borough	Lake & Peninsula Borough
School district	Lake & Peninsula Schools
Regional Native Corporation	Bristol Bay Native Corporation
Village Corporation	Alaska Peninsula Corporation
Latitude	N 59.4416
Longitude	W 154.7554
Elevation	25 m
Legal description	Sec. 32, T008S, R032W, Seward Meridian
Electric utility	Kokhanok Village Council

Source: State of Alaska Department of Commerce, Community, and Economic Development website, https://www.commerce.alaska.gov/dcra/DCRAExternal/community/Details/5a9a2965-3bce-4655-af6f-1861b119bebb

Figure 1

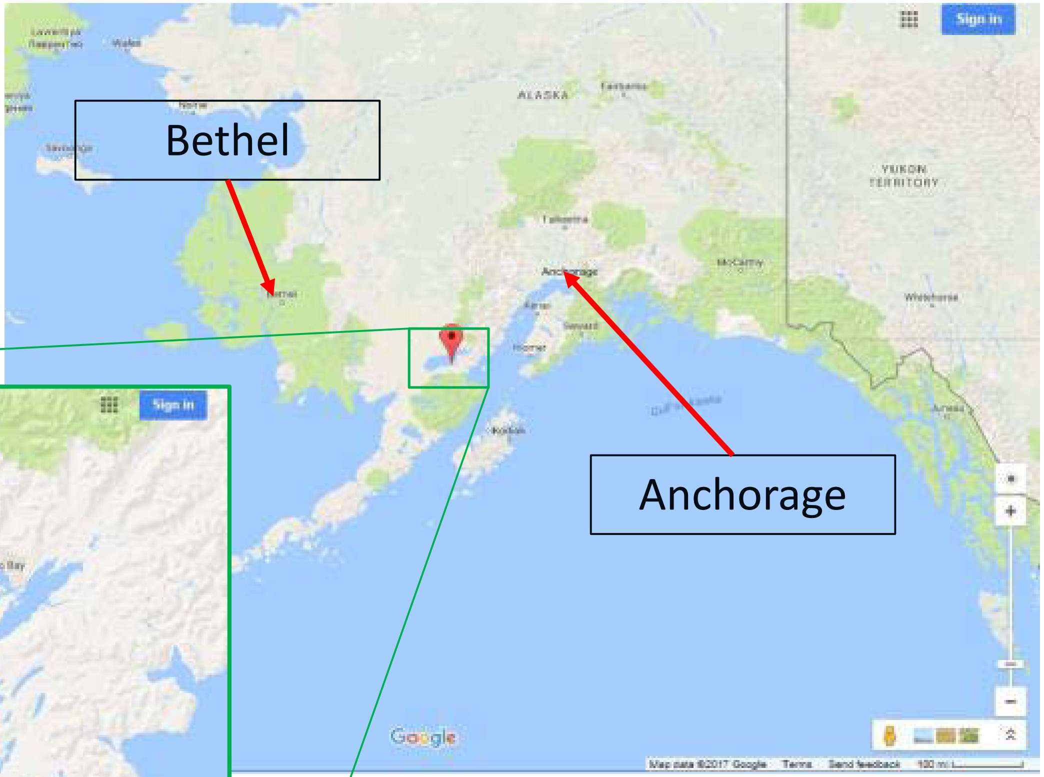

Figure 2

Overview: Maps (2 of 2)

Figure 3

Source: Google Maps

Community Overview

Location: Kokhanok is located on the south shore of Iliamna Lake, 22 miles south of Iliamna and 88 miles northeast of King Salmon. Kokhanok is located in the Iliamna Recording District.

Climate: Kokhanok lies in the transitional climatic zone. Average summer temperatures range from 40° to 64° F; winter temperatures average 3° to 30° F. The record high is 84° F; the record low -47° F. Precipitation averages 32 inches annually, including 89 inches of snowfall. Wind storms and ice fog are common during winter.

Culture: The village has a mixed Native population, primarily Alutiiq and Yupik. Subsistence activities are the focal point of the culture and lifestyle.

(State of Alaska Department of Commerce, Community, and Economic Development website: https://www.commerce.alaska.gov/dcra/DCRAExternal/community/Details/5a9a2965-3bce-4655-af6f-1861b119bebb)

Community Overview

Transportation: Kokhanok is accessible by air and water. A state-owned 2,920-feet-long by 60-feet-wide gravel airstrip and a sea-plane base serve scheduled and charter air services from Anchorage, Iliamna, and King Salmon. Supplies delivered by barge via the Kvichak River must be lightered to shore. There are no docking facilities. The community wants to develop a boat harbor and launch ramp. Skiffs, ATVs, and trucks are common forms of local transportation.

(Above information from State of Alaska Department of Commerce, Community, and Economic Development website: https://www.commerce.alaska.gov/dcra/DCRAExternal/community/Details/5a9a2965-3bce-4655-af6f-1861b119bebb)

Building Stock

Table 2

Community Buildings
Power Plant
Water Treatment Plant
Clinic
Tribal Office
KCC/Community Center
School
Store
VPSO Office
VPSO House
Water Tank

Source: Kokhanok START Round 3 Application

Table 3

Residential Units	
Total Housing Units	65
Occupied Housing (Households)	52
Vacant Housing	13
Vacant Due to Seasonal Use	10
Owner-Occupied Housing	35
Renter-Occupied Housing	17

Source: State of Alaska Department of Commerce, Community, and Economic Development website: https://www.commerce.alaska.gov/dcra/DCRAExternal/community/Details/5a9a2965-3bce-4655-af6f-1861b119bebb

Sources

State of Alaska Department of Commerce, Community, and Economic Development website: https://www.commerce.alaska.gov/dcra/DCRAExternal/community/Details/5a9a2965-3bce-4655-af6f-1861b119bebb
Alaska Energy Data Gateway: https://akenergygateway.alaska.edu/community-data-summary/1404333/#detail-sales Alaska Energy Data Gateway, developed by the Institute of Social and Economic Research, University of Alaska Anchorage, is supported by the U.S. Department of Energy Office of Science, Basic Energy Sciences, under EPSCoR Award # DE-SC0004903 (database and web application development) and by Alaska Energy Authority (Renewable Energy Fund data management and reporting). Database and web hosting provided by Arctic Region Supercomputing Center, University of Alaska Fairbanks
Kokhanok START Round 3 Application: "START_Alaska_Round 3_EnergyUsageSpreadsheet.xlsx"; Data supplied as part of a technical assistance request to the U.S. Department of Energy-funded Strategic Technical Assistance Response Team (START) program

Section 2
Energy Data

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Analysis Purpose and Overview

This analysis was conducted to answer three interrelated questions:

- What is required to achieve a 50% reduction in power plant diesel fuel consumption in a diesel microgrid?
- What is required to achieve a 50% reduction in “total” (diesel + heating oil) consumption in a remote community?
- What is the impact and role of energy efficiency?

The analysis was conducted by using the community of Kokhanok, Alaska, as a case study. This small community (population ~150) has a typical Alaska diesel microgrid. The average electrical load (2015) is 48 kW, with a peak of 84 kW. In 2010, the community installed two 90-kW wind turbines, battery storage, converter, and equipment for integration. Due to a failure of the system controller, the turbines were switched off. The analysis was conducted to provide the lowest cost (on a life-cycle cost basis) microgrid conceptual designs that reduce fuel consumption and reduce costs.

Researchers conducted the analysis and modeling using the HOMER and REopt software modeling packages.

Energy and Fuel Consumption Overview

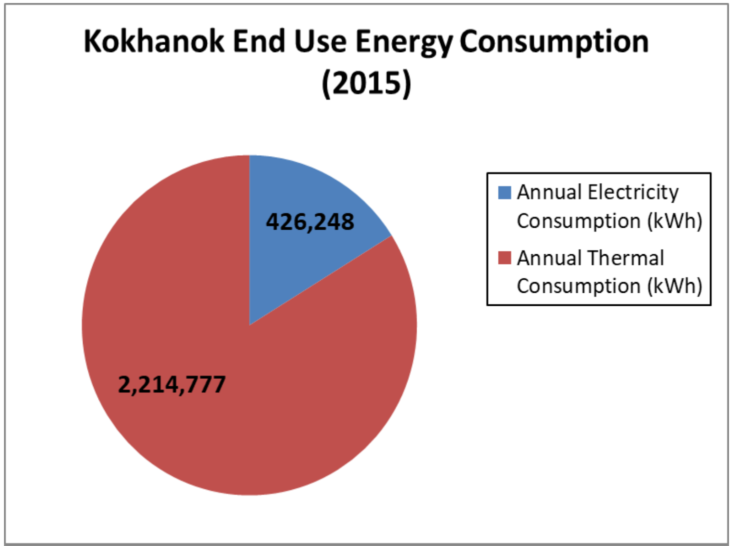
Heating is roughly 80% of total end use energy consumption, with the electrical load accounting for the remaining 20%. Due to the greater efficiency in converting diesel fuel to heat compared to converting diesel fuel to electricity, the fuel consumption between the two categories is more even, with a roughly 60%/40% split between fuel used for heat and fuel used to generate electricity.

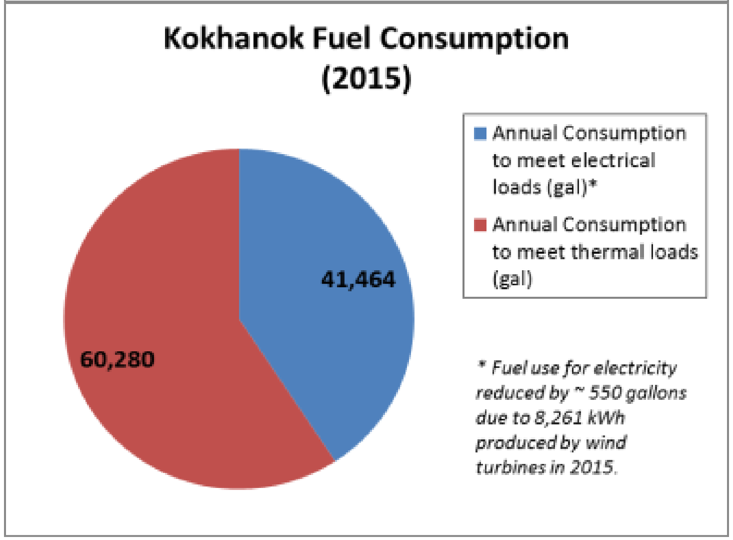
The third major energy category (in addition to heat and electricity), transportation, is excluded from this analysis due to a lack of data and a lack of current plausible alternatives to fossil fuel-powered engines. However, if electric vehicle technology becomes widespread, inclusion of the transportation sector should be revisited, as electric vehicles may contribute to grid balancing.

A key take-away is that any attempt to achieve 50%+ fuel reduction in imported energy will require addressing both electrical and thermal loads.

Sources:
http://www.akenergyauthority.org/Programs/PCE
“START_Alaska_Round 3_EnergyUsageSpreadsheet.xlsx”

Figure 4



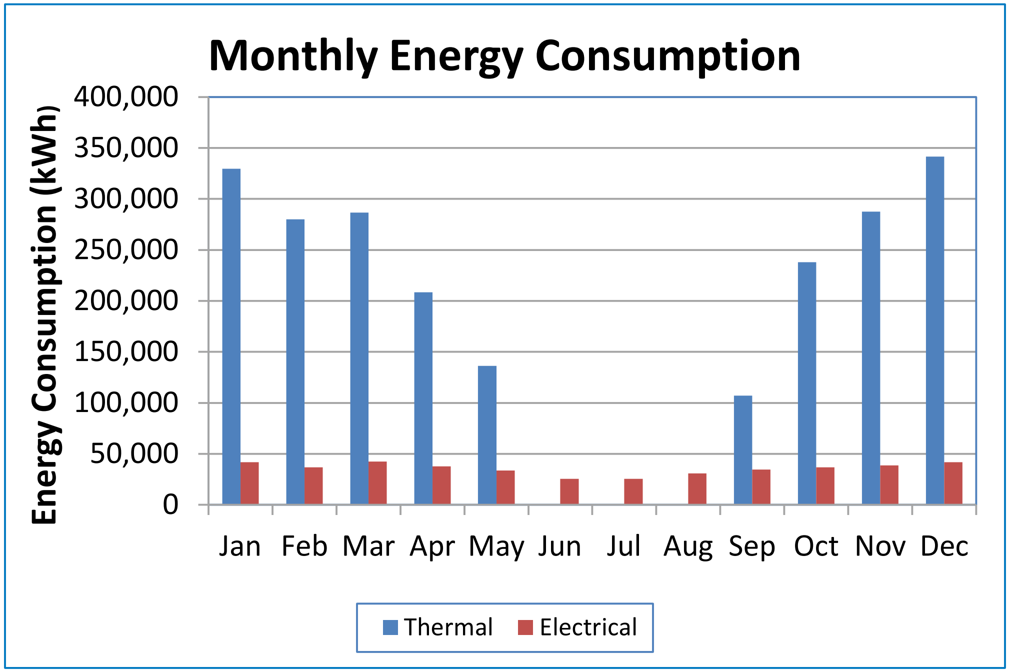


Monthly Energy Consumption (in Kilowatt-Hours)

Table 4

Month	Thermal (kWh)	Electrical (kWh)
Jan	329,665	41,905
Feb	279,970	36,687
Mar	286,551	42,460
Apr	208,338	37,697
May	136,234	33,773
Jun	0	25,517
Jul	0	25,580
Aug	0	30,737
Sep	107,041	34,583
Oct	237,993	36,681
Nov	287,569	38,830
Dec	341,417	41,799
TOTAL	2,214,777	426,248

Figure 5

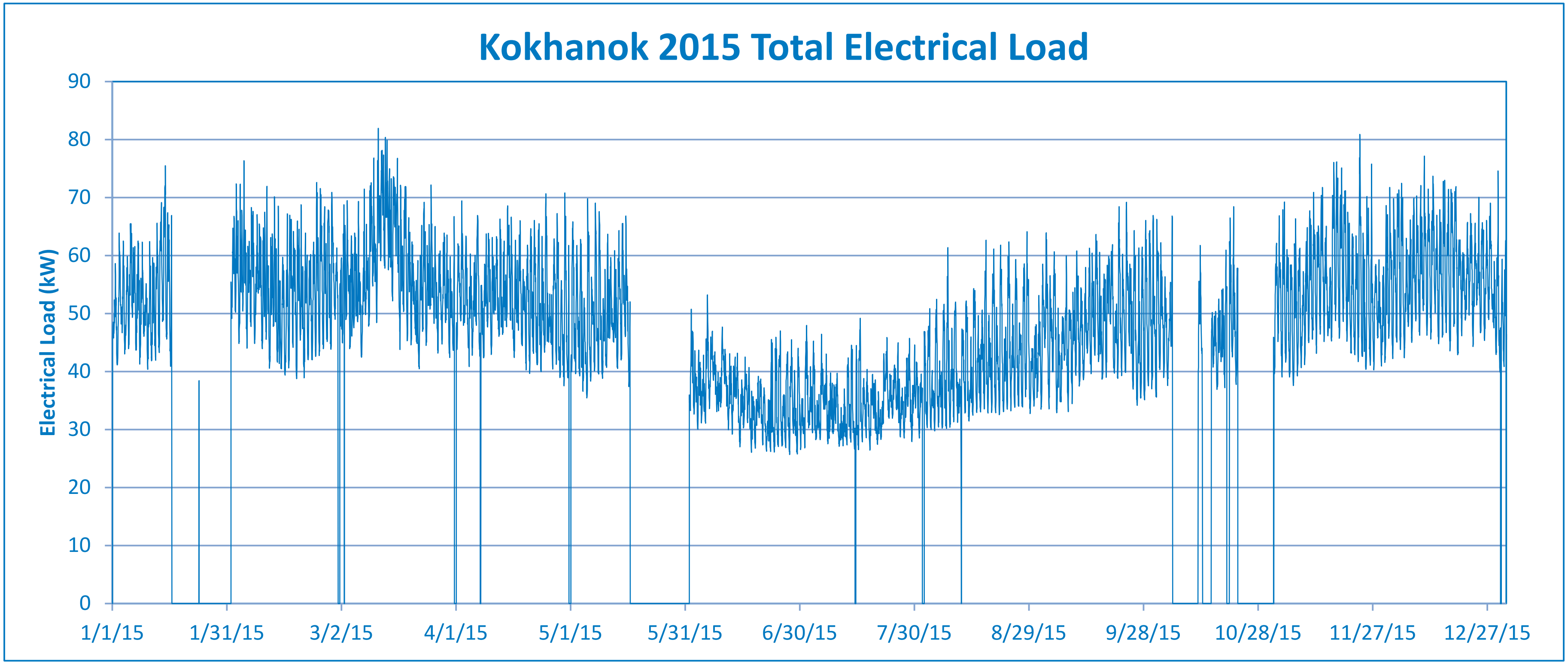


Note: The thermal load in the summer is not truly zero. The relatively small summer thermal load was shifted to other months to avoid over-valuing waste heat recovery and excess renewable energy-generated electricity.

Electrical Load

- Source: 2-second load data provided for 2015 by Alaska Center for Energy & Power
- Generated hourly profiles taking average total village load over each hour
- 1271 hours of load missing (15% of the year). Primary gaps: Jan 16-Feb 2, May 16-Jun 1, most of Oct 5-Oct 15, and Oct 22-Nov 1
  - Filled in 352 hours from generator output files (4%)
  - Filled in the balance by copying chunks of load from adjacent/representative days

Figure 6

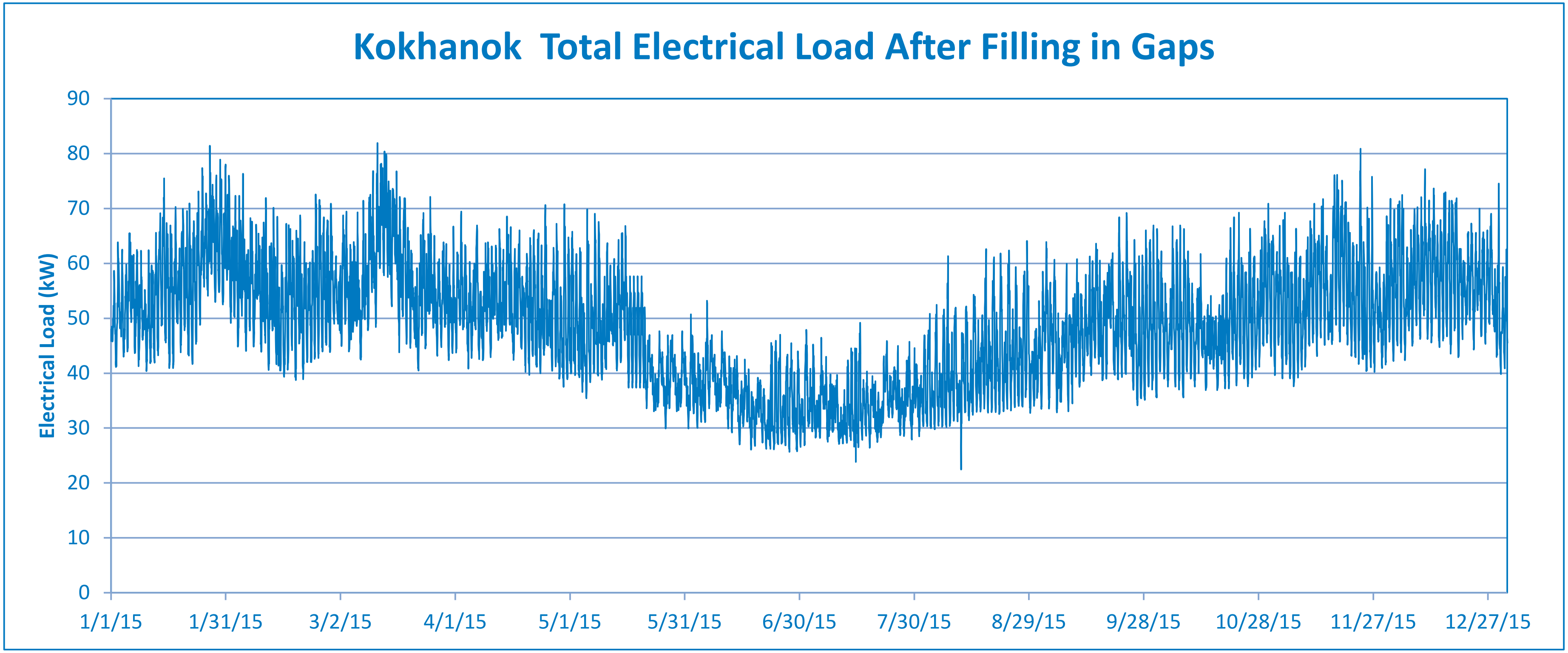


Electrical Load

Resultant load for model shown below

- Max 82 kW hourly average, 104 kW 2-second peak
- Average 48.7 kW
- Minimum 22 kW, after removing zeros
- Total 426,248 kWh

Figure 7

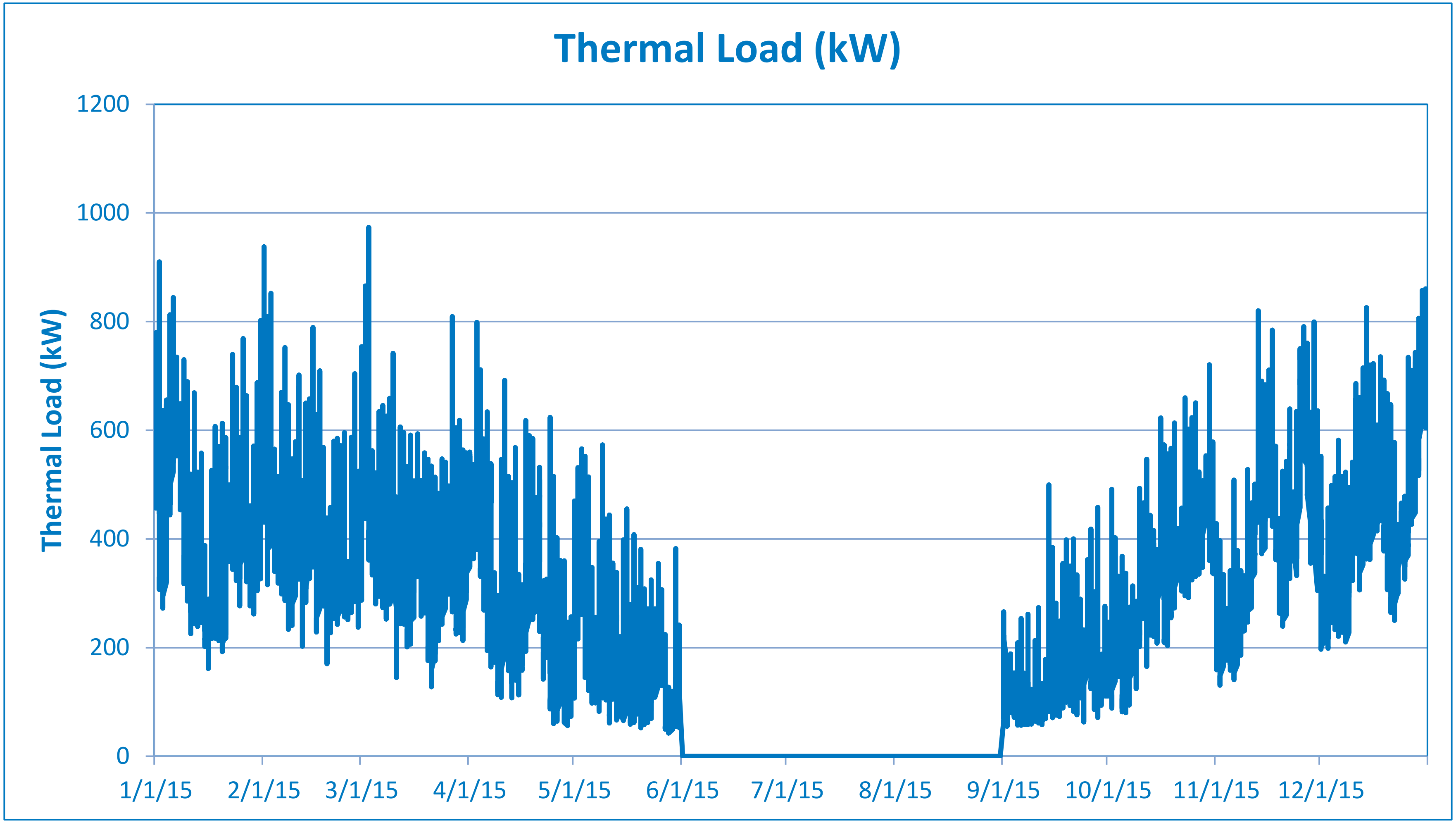


Heating Load

- General procedure:
  - Combine annual heating oil consumption with building models and TMY regional weather files to create an hourly time series thermal demand profile
  - Add in assumed heat provided to school from waste heat recovery (assume 30% recovery)
  - Shift the summer (June 1 – August 31) heat load to the remaining months
- Total annual heating oil consumption: 60,280 gallons (Reference: "START_Alaska_Round 3_EnergyUsageSpreadsheet.xlsx" These data were supplied by Kokhanok as part of a technical assistance request to the U.S. Department of Energy-funded Strategic Technical Assistance Response Team (START) program.)
- This is the assumed total village fuel usage for heating.
- Heating load profiles generated from this data ignore fraction of heat already served by wood stoves.
- Building models and regional weather files are used to shape heating fuels into an hourly consumption profile. The profile is a blend of retail, office, school, and residential loads.
- When converting from gallons of heating oil to kW, the analysis assumes typical stove/boiler efficiency of 80%.
- Shifting summer thermal loads to the remaining months results in a more conservative estimate of value of both excess wind for secondary loads and waste heat recovery.

Community Thermal Load Profile

Figure 8



Potential for Load Growth

Over the past 20 years, the community’s population has been stable or declining. Therefore, load growth due to population increase is not anticipated.

Power Plant Overview

The power plant at Kokhanok includes four diesel generators with a total rated power of 452 kW and two 90-kW wind turbines. The diesel plant was last renovated in January 2015. The wind turbines, a battery bank, converter, and control system were installed in 2010. Due to failures in the controllers that could not be repaired, the wind turbines have been off-line since 2015. The community is installing sufficient controls and system integration equipment to allow the turbines to be brought back online and to supplement the energy produced by the diesels. In the longer term, the community plans to install an energy storage system, along with the necessary controllers and converters, to allow diesel-off operation with energy stored from either unused wind or diesel generation.

Kokhanok currently has a heat recovery system that can also be supplemented with excess wind power via an existing secondary load boiler. This system supplies a portion of the heat needed by the school. It is not clear whether there is sufficient waste heat to supply heat to additional buildings in addition to the school. Expansion of the heat recovery/secondary load system to serve additional buildings is not considered in this model due to insufficient information on buildings/loads that could be served and cost estimates to connect them to the system.

Sources:

- Alaska Renewable Energy Fund application
- "START_Alaska_Round 3_EnergyUsageSpreadsheet.xlsx“

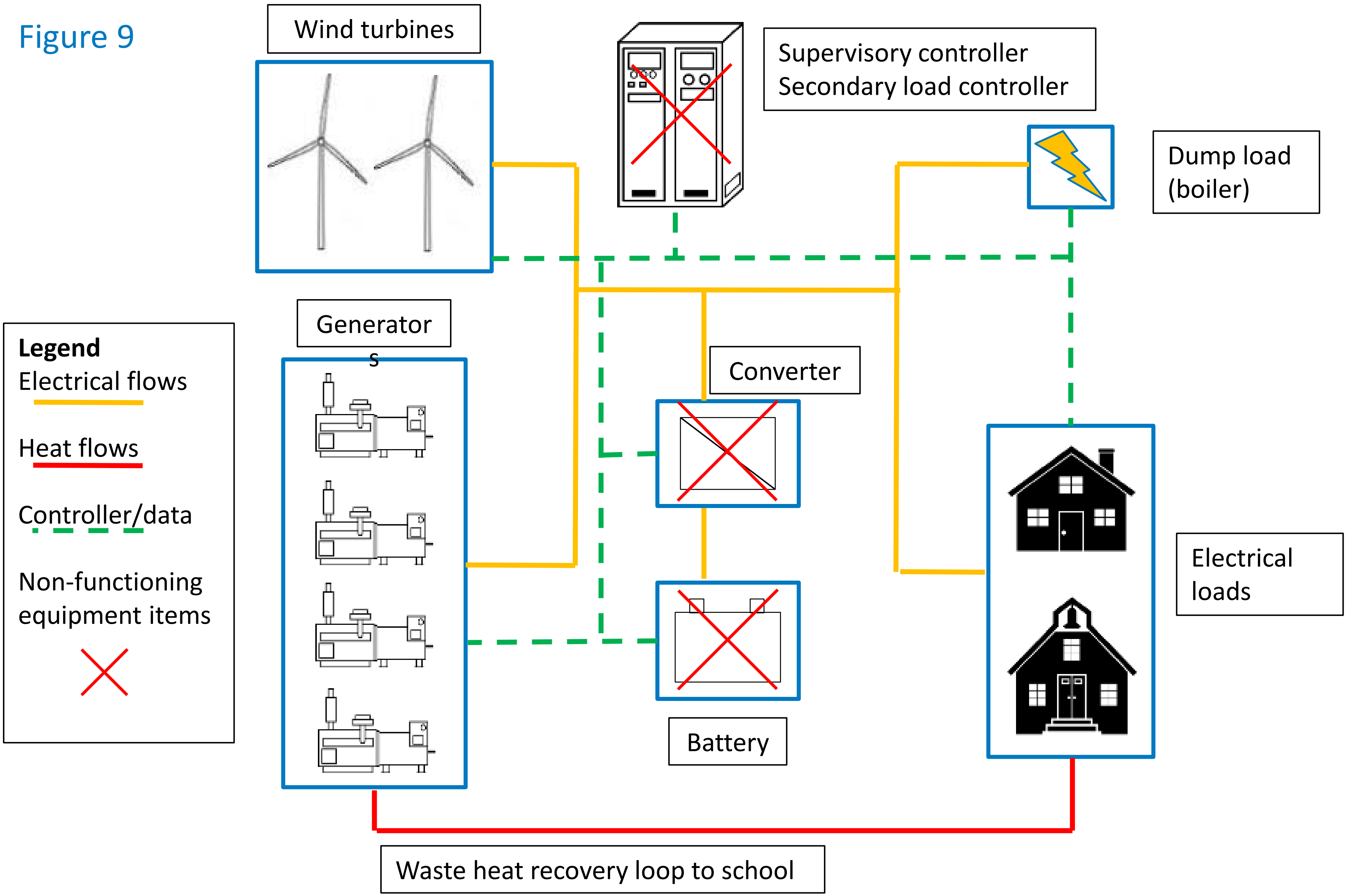
Power Plant Overview

Table 5

Component	Make/Model	Rated Power (kW) or Size (kWh)	Operating? (Y/N)	Notes
Generator #1	John Deere 4045	60 kW	Y	
Generator #2	John Deere 6068	115 kW	Y	
Generator #3	John Deere 6081	160 kW	Y	
Generator #4	John Deere 4045	117 kW	Y	
WTG #1	Vestas V17	90 kW	N	Not operating due to controller failures
WTG #2	Vestas V17	90 kW	N	Not operating due to controller failures
Battery Bank	Lead-acid	168 kWh	N	Presumed non-repairable
Controller (Supervisory)	custom		N	Presumed non-repairable
Controller (Secondary Load)	custom		N	Presumed non-repairable
Converter (Synchronous Condenser)			???	Presumed non-repairable
Converter (Load Following Inverter)			???	Presumed non-repairable

Power Plant Schematic

Figure 9



Diesel Generator Cost Data

- **References**
  - Alaska Renewable Energy Fund application
    - "START_Alaska_Round 3_EnergyUsageSpreadsheet.xlsx“
    - (Says date of last renovation was January 2015)
  - NetCDF data files from Alaska Center for Energy and Power have the following metadata:
    - Diesel Engine Generator 1 (58 kW)
      - Make: John Deere, Model 4045TF150
      - Year: 2012
    - Diesel Engine Generator 4 (117 kW)
      - Make: John Deere, Model 4045HF486 (SIC). Cannot find this model. URL included points to model 4045HF485 (engine only)
      - Year: 2012
- **O&M, nonfuel**
  - $0.10/kW nameplate/hr. of runtime estimated from Alaska Center for Energy and Power DRAFT diesel engine costs briefing and Alaska Village Electric Cooperative O&M data that show $0.09 to $0.18/kWh as a reasonable value for a plant of similar size. To convert to a cost per runtime, a 55% load factor is assumed, as described in Alaska Center for Energy and Power briefing
  - Generator replacement cost folded into hourly O&M

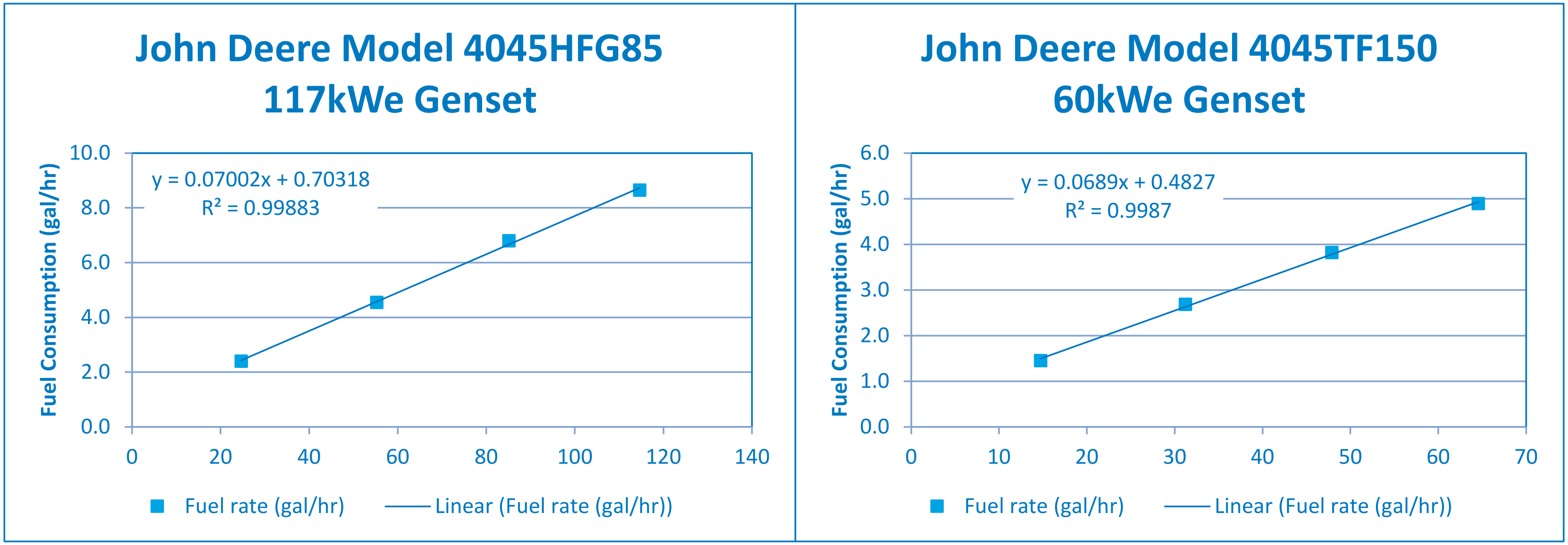
Table 6

	Make/Model	Rated Power (KW)	Operational (Y/N)	
Generator #1	John Deere 4045	60	Y	← Modeled
Generator #2	John Deere 6068	115	Y	
Generator #3	John Deere 6081	160	Y	
Generator #4	John Deere 4045	117	Y	← Modeled

Engine Generator Performance Specs

- Unable to find John Deere engine generator fuel usage versus electrical power output
- Use engine brake horsepower specs and 90% generator efficiency
- Impose 30% minimum load constraint

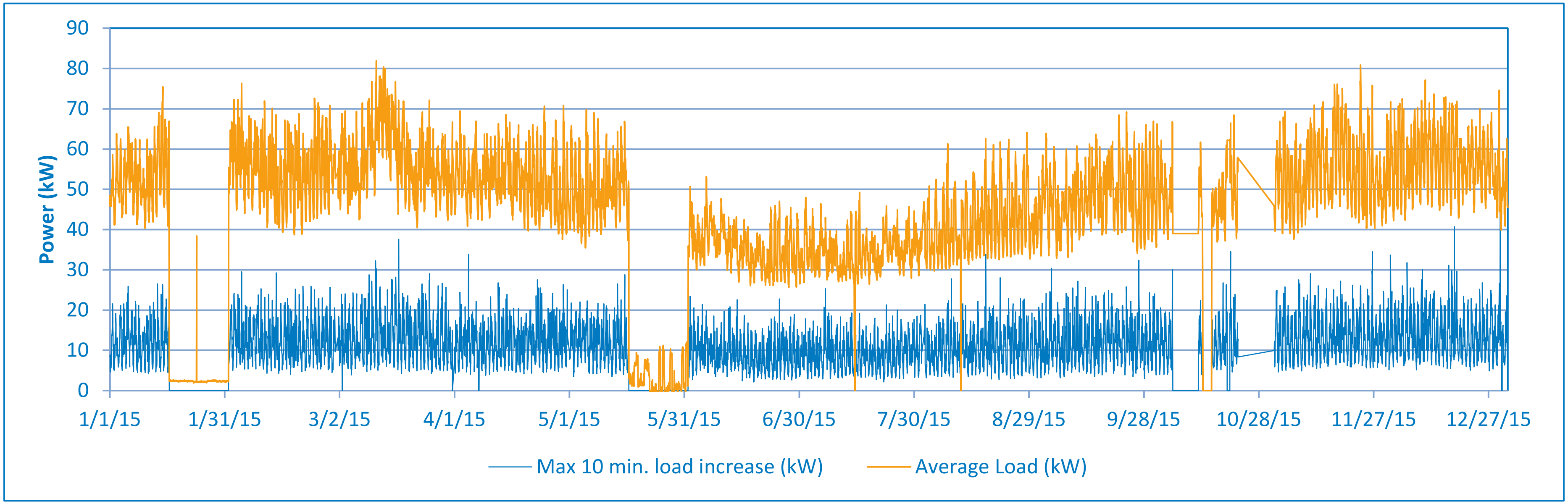
Figure 10



Assumed Reserve Requirements

- For up-ramps in load, assume 25 kW constant reserve needed every hour of the year based on analysis of 2-second load data provided. See figure below.
- For wind serving load, assume additional reserve requirement of 50% of wind power *going to load*

Figure 11



The average load in each hour is shown in gold. The blue trace is the maximum increase in load recorded in the 2-second data in a 10-minute rolling window. The maximum step increase for each hour of the year is plotted.

Power Plant Fuels Consumption and Costs

- $5.61/gallon (unsubsidized) (Power Cost Equalization reports at http://www.akenergyauthority.org/Programs/PCE)
- $2.59/gallon (with Power Cost Equalization subsidy) (Power Cost Equalization reports at http://www.akenergyauthority.org/Programs/PCE)
- $3.80/gal (2016) (unsubsidized?) Alaska Affordable Energy Model (http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/overview.html [accessed 2017 May 11])
- NOTE: Pre-Power Cost Equalization costs used in modeling
- Analysis conducted a sensitivity study on diesel fuel costs: $4.00/gal and $5.60/gal

Table 7

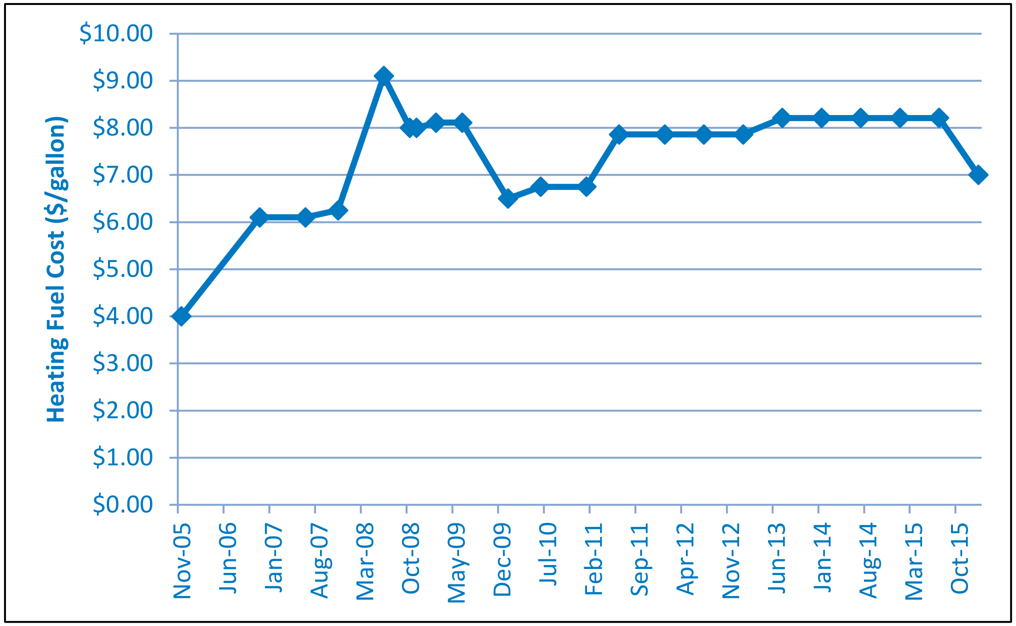
	Kokhanok			
	2013	**2014**	**2015**	**Average**
Total Fuel Used (gal)	33,184	39,466	41,364	38,005
Total Cost ($)	$198,878	$235,344	$204,955	213,059
Unit Cost Before PCE ($/gal)	$5.99	$5.96	$4.95	**$5.61**
PCE Rate	$0.59	$0.49	$0.41	$0.50
Energy Sold that is PCE Eligible (%)	56.9%	59.5%	58.7%	58.4%
Total Energy Sold (kWh)	428,518	372,327	354,821	385,222
Total PCE ($)	$143,858	$108,552	$85,395	$112,601
Fuel Cost Less PCE	$55,020	$126,792	$119,560	$100,458
Fraction of PCE Subsidy	72%	46%	42%	53%
Unit Fuel Cost with PCE ($/gal)	$1.66	$3.21	$2.89	**$2.59**
Fuel cost per kWh without PCE ($/kWh)	$0.46	$0.63	$0.58	$0.56
Fuel cost per kWh with PCE ($/kWh)	$0.13	$0.34	$0.34	$0.27
Total Energy Generated by Diesel (kWh)	362,826	406,000	408,000	392,275
Fuel efficiency (kWh/gallon)	10.9	10.3	9.9	10.4
Non-diesel Generation (kWh)	146,535	31,928	8,261	

Declining wind power production reported

Heating Fuel Costs

- Average of DCRA data from Jan. 2013 through Jan. 2016: $7.99/gallon (Alaska Department of Commerce, Community, and Economic Development, Division of Community and Regional Affairs surveys
- 2016 Cost: $5.08/gal (Alaska Affordable Energy Model: http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/overview.html [Accessed 2017 May 11])
- Analysis conducted a sensitivity study on heating oil costs: $6.00/gal and $8.00/gal

Figure 12



Energy Efficiency Opportunities (End Use)

In many instances, saving a unit of energy is less expensive than generating a unit of energy.

Energy efficiency efforts in Alaska have focused on weatherization to reduce building thermal loads. While there is a large spread in the data, various Alaska data sources indicate that thermal loads in the remote communities can be reduced by roughly one-third at a cost of roughly $1.50 per annual kWh_{th} reduction in load. The data more specific to Kokhanok show somewhat higher costs; $1.80/annual kWh_{th} is used in the analysis.

Residential electricity use in Kokhanok, and in Alaska's remote communities in general, is lower than the U.S. average. Due to the already relatively low electricity consumption in these communities, dramatic decreases in electricity demand are less likely than large decreases in thermal demand. This does not preclude continuing modest improvements due to activities such as replacement of older appliances with more energy efficient models and the conversion to LED lighting. Based on rather limited data, this analysis uses a value of $1.10 per annual kilowatt-hour saved.

Sources:

- "Alaska Regional Wx Stats.xls", provided by Neil McMahon (AEA). Based on data from the AK Retrofit Information System (ARIS)
- Alaska Affordable Energy Efficiency Strategy, Kokhanok (Residential EE) http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/residential_energy_efficiency.html
- Alaska Affordable Energy Efficiency Strategy, Kokhanok (Non-Residential EE) http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/non-residential_energy_efficiency.html
- AEA, "Remote Alaska Communities Energy Efficiency Competition-Chefornak," 2016 Aug 19

Energy Efficiency Opportunities

Electrical

- Reduce distribution system losses
- Replace infrastructure to increase efficiency
- Implement end use electrical energy efficiency projects

Thermal

- Implement waste heat recovery from the diesels (already done)
- Implement end use energy efficiency (weatherization)

Sources:

- Alaska Affordable Energy Efficiency Strategy; Kokhanok (Residential EE): http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/residential_energy_efficiency.html
- Alaska Affordable Energy Efficiency Strategy; Kokhanok (Non-Residential EE): http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/non-residential_energy_efficiency.html
- AEA, "Remote Alaska Communities Energy Efficiency Competition-Chefornak," 2016 Aug 19
- Residential weatherization cost and performance data from the Alaska Retrofit Information System (ARIS). Spreadsheet provided by Neil McMahon (AEA). "AK Regional Wx Stats.xls"

End Use Energy Efficiency Cost Effectiveness

Data from various Alaska sources were consulted to develop a high-level metric of the cost effectiveness of EE (both thermal and electric). From these sources, the following effectiveness benchmarks were developed:

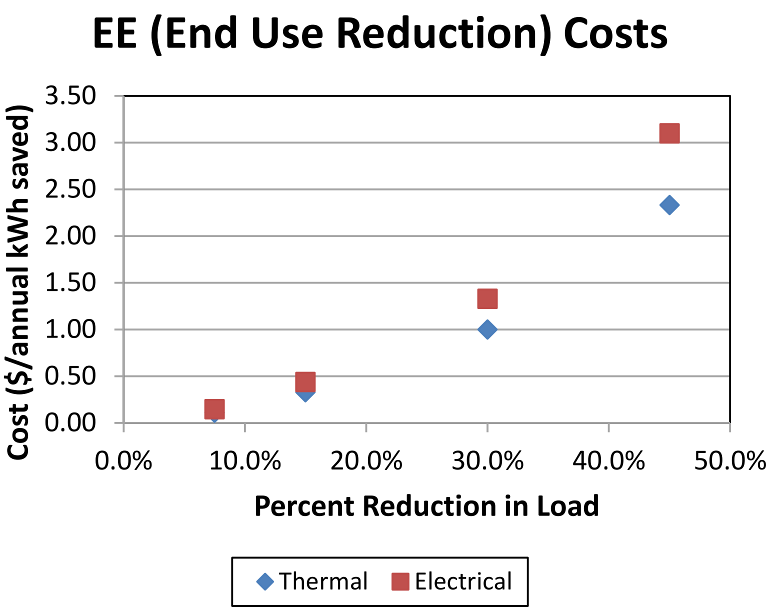
EE (thermal): 1 kWh/year/$ (to ~30% reduction)
EE (electrical): 0.75 kWh/year/$(to ~30% reduction)

In reality, the initial increment of use reduction is the lowest cost, with each successive increment costing progressively more. To capture this, the metrics were fit to a curve as shown in the accompanying table and graph. Alternately, use a linear fit, but cap the reduction in load to approximately 30%.

Table 8

	Cost ($/KWh/year saved)	
% Reduction	Thermal	Electrical
7.5%	0.11	0.15
15.0%	0.33	0.44
30.0%	1.00	1.33
45.0%	2.33	3.10

Figure 13



Sources:

- Alaska Affordable Energy Efficiency Strategy; Kokhanok (Residential EE): http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/residential_energy_efficiency.html
- Alaska Affordable Energy Efficiency Strategy; Kokhanok (Non-Residential EE): http://model-results.akenergyinventory.org/m0.24.6_d0.24.0/Kokhanok/non-residential_energy_efficiency.html
- AEA, "Remote Alaska Communities Energy Efficiency Competition-Chefornak," 2016 Aug 19
- Residential weatherization cost and performance data from Alaska Retrofit Information System. Spreadsheet provided by Neil McMahon (AEA). "AK Regional Wx Stats.xls"

Wind Resource

- Wind data collected using a 34-m meteorological tower installed on point extending into Iliamna Lake
  - Latitude 59.448°, longitude -157.764°
  - Data collected 12 August 2004 – 14 June 2006

Source: Douglas Vaught, P.E.; Kokhanok, Alaska Wind Resource Report; V3 Energy, LLC.

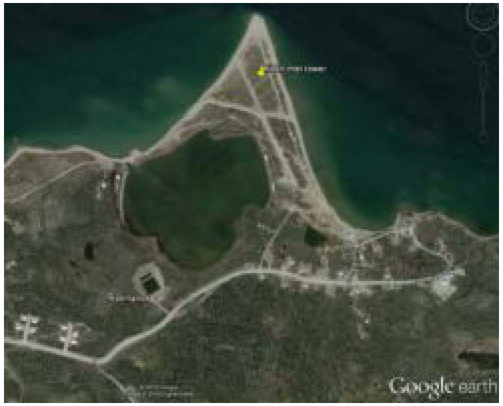


Figure 14

- Summary of Measured Data (for 29 m above ground level)
  - Annual average wind speed (measured): 7.84 m/s
  - Weibull k factor: 1.64
  - Turbulence intensity: 0.0986 (low)
  - Power Law Exponent: 0.0725
- Estimated long-term resource (26 m above ground level)
  - Estimated long-term average wind speed (based on TMY data): 6.9 m/s

Wind Power – Assumptions

- Wind can:
  - Serve electrical load directly
  - Charge a battery
  - Power electric heaters/boilers
  - Be diverted to serve a thermal load

- CAPEX
  - First two turbines: $0 (sunk costs) for the turbines + $200,000 fixed cost for integration
  - Each additional turbine: $700,000 per turbine
- O&M $80/kW-year
  - At 27% net capacity factor, this is equivalent to $0.034/kWh generated

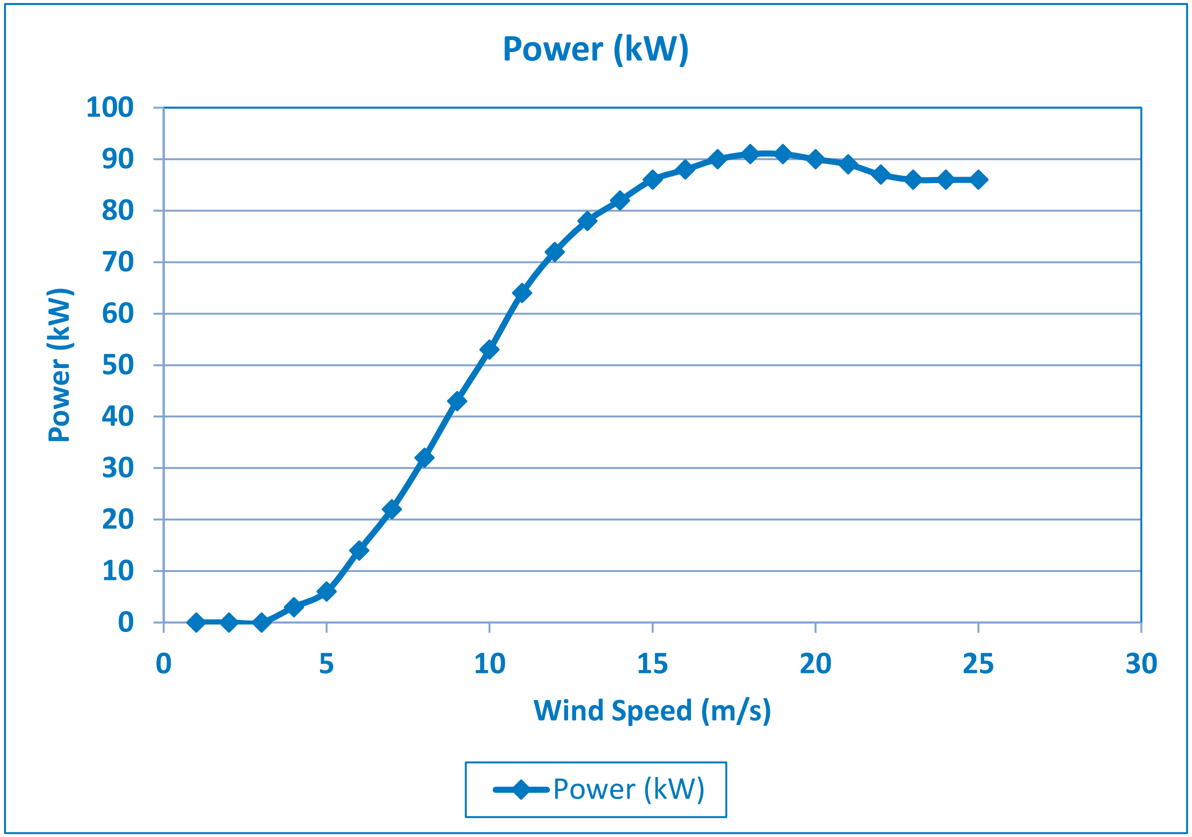
- Hub height: 85 feet (26 m)

Wind Power – V-17 Power Curve

Table 9

Wind Speed (m/s)	Power (kW)
1	0
2	0
3	0
4	3
5	6
6	14
7	22
8	32
9	43
10	53
11	64
12	72
13	78
14	82
15	86
16	88
17	90
18	91
19	91
20	90
21	89
22	87
23	86
24	86
25	86

Figure 15



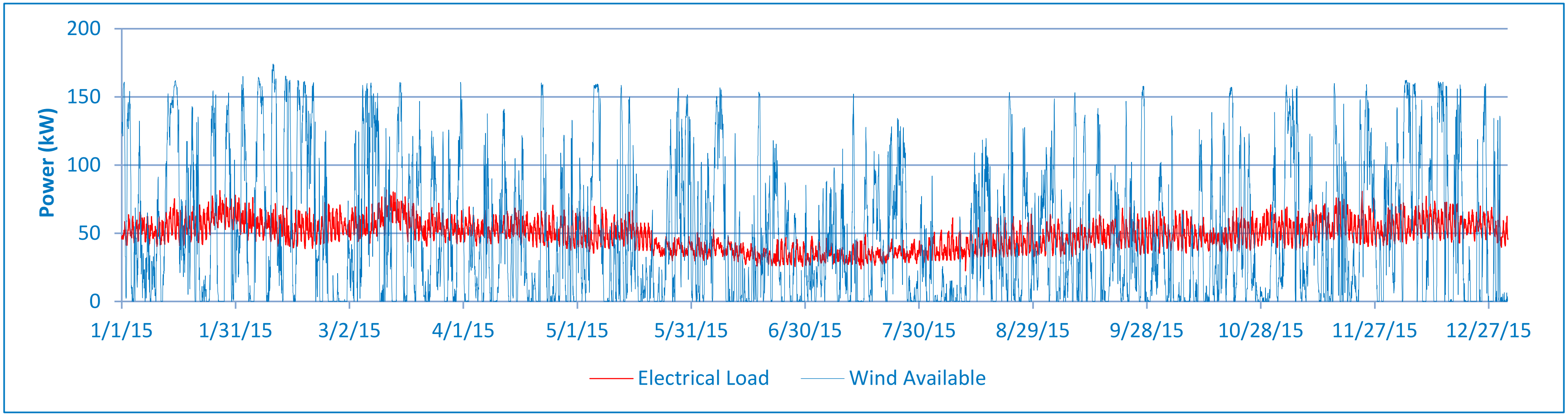
Wind Energy Production

- Production estimate assumes 15% losses
- On an annual basis, available wind energy production (from two turbines) is equal to 100% of community electricity consumption

Table 10

Turbine	Hub Height (m)	Average Wind Speed (m/s)	Annual Average Net Power (kW)	Net Annual Energy (kWh/yr)	Net Capacity Factor
(2) Vestas V-17	26	6.9	48.6	425,858	27%

Figure 16



Controller/Converter/Battery

- **Sources:**
  - "Energy Storage Technology Report (Draft)"; Alaska Center for Energy & Power
  - Anecdotal of Rough Order of Magnitude cost data points provided by installers
- **Controller/integration:**
  - Assume $300,000 fixed cost. Split between WTG ($200,000), converter ($50,000), and battery ($50,000)
- **Converter:**
  - $50,000 (allocated portion of fixed costs) + $875/kW (up to 160 kW) + $600/kW (> 160 kW)
- **Batteries (Li-Ion):**
  - $50,000 (allocated portion of fixed costs) + $700/kWh (up to 200 kWh) + $480/kWh (> 200 kWh)
- **Assumed efficiencies:**
  - Rectifier 96%, inverter 96%

Table 11

Converter Size (kW)	Battery Size (kWh)	Cost (Integration + Converter + Storage) ($)	Cost Curve (Integration + Converter + Storage) ($)	Marginal Converter Cost ($/kW)	Marginal Battery Cost ($/kWh)
0	0	$300,000	$300,000		
80	100	$440,000	$440,000	$875	$700
160	200	$580,000	$580,000	$875	$700
240	300	$675,000	$676,000	$600	$480
320	400	$770,000	$772,000	$600	$480

Heat Options

- Continue to use existing fuel oil heaters/boilers
- Wind power to distributed electric stoves with thermal storage

Wind-Powered Heater with Storage Module

- Heater is powered by wind. Heaters are only activated when excess wind energy is available.
- Capital cost:
  - $10,000 fixed cost (set up communications backbone)
  - $3,000 per unit
- Max heat delivery: 6 kW
- Thermal storage: 33 kWh
- Thermal storage decay rate: 15%/hour
- Max number of units: 104 (assume 2 per house, Kokhanok has 52 occupied houses)

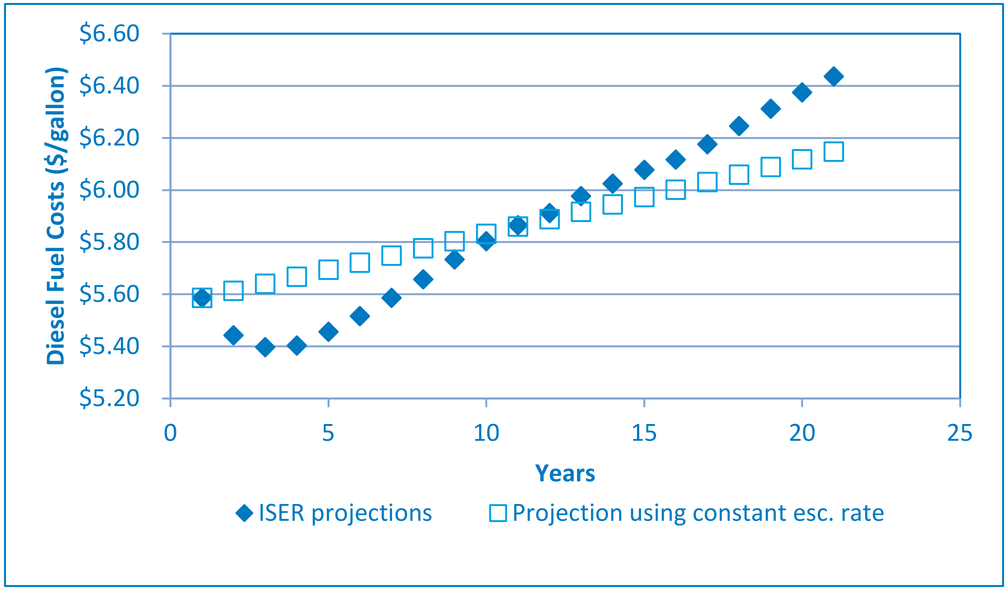
Figure 17

Electric thermal stove. *Source: Tony Jimenez*

Model Financial Inputs

- 20-year analysis
- 3% real discount rate
- 1% real diesel fuel cost annual escalation rate
  - 2015 EIA Annual Energy Outlook has 0.7%/year real from 2013 to 2040 (commercial, distillate)
  - 2016 EIA Outlook has 2.4%/year real, 2015-2040
  - University of Alaska Anchorage, Institute of Social and Economic Research, "Alaska Fuel Price Projections 2014-2040" spreadsheet has 0.5%/year real best fit to get same annual average cost
- Note: The analysis uses the unsubsidized fuel cost.

Figure 18



Model Assumptions

- Does not include additional parasitic loads of electric resistive heaters in the nacelles of the wind turbines
  - Estimated by Marsh Creek in their 2009 proposal to be constant 6 kW per turbine during the “colder 6 months”
- Wind can serve electrical load, go to heaters, or be diverted by dumping to existing secondary load, which can be used for useful heat or dissipated to atmosphere through engine radiators.

Section 3
Analysis Results and Conceptual Design

Section Overview

Main Presentation

- Analysis results
- Decision variables and sensitivities
- Listing of analysis cases and sensitivities
- Recommended conceptual designs
- Results discussion
- Cost breakdown

Detail Slides

- Listing of analysis inputs
- Model descriptions (REopt, HOMER)

Key Results (Kokhanok Specific)

- Achieving a 50% reduction in imported fuel requires a combination of energy efficiency and renewable energy (specifically wind energy in this case). With implementation of aggressive, but doable, energy efficiency measures, four turbines (including the two that are already onsite) are required to achieve a 50% reduction in total imported fuel. The four-turbine architecture (combined with energy efficiency) is not the lowest life-cycle cost option, but it does have a lower life-cycle cost than the current (no-energy efficiency, no-renewable energy) situation.
- Energy efficiency, particularly weatherization, is crucial to achieving high levels of imported fuel reduction. Achieving 50% imported fuel reduction without energy efficiency requires nine wind turbines. Even under the most favorable scenario (high fuel cost, low discount rate), the economics are unfavorable because as turbines are added, an increasing proportion of the turbine energy production is spilled.
- The lowest life-cycle cost option is a two-turbine architecture (with energy efficiency). This is not particularly surprising. Kokhanok has an excellent wind resource. The two turbines onsite are essentially “free” (a sunk cost), requiring only a relatively low-cost (compared to the turbine capital cost) repair or replacement of the system controls and integration equipment to allow the turbines to operate.
- The thermal electric stove capacity generally scales with the turbine capacity. As the number of turbines increases, an increasing proportion of the wind turbine energy goes toward meeting the thermal load.
- The converter size does not scale with the number of turbines. Since the wind turbines in this case are connected directly to the AC bus, the converter needs only to be large enough to facilitate needed energy draws to/from the battery.
- The battery storage does not scale with increasing number of turbines. The economically optimal battery size is 0.5 to 3 hours of autonomy (based on the average load). The main value of the battery bank and converter is that they allow diesel-off operation by providing spinning reserve to cover short-term lulls in the wind resource or spikes in electrical demand. Another driver of this non-scaling of the battery and converter is the existence of (inexpensive) thermal electric stoves that allow for the productive use of excess wind energy. It is less expensive to use excess wind energy to displace heating oil than to install a sufficiently large battery bank to store it.
- Dispatch strategy: The models indicate that cycle charging is the economically preferred strategy. For a two-turbine configuration, load following increases the life-cycle cost by roughly 4% compared to cycle charging.

Key Results (General Design Lessons)

Caveats/Limitations

- Results can be generalized to wind-diesel systems in communities with a large thermal load and a good wind resource. The results may not apply to the integration of other renewable energy technologies.
- References to “total energy” include electrical and thermal loads but exclude energy used for transportation.
- Due to its excellent wind resource and the presence of two wind turbines, the economics of wind energy are unusually favorable for this analysis.

General Design Lesson

- Achieving a 75% reduction in imported fuel is technically feasible but economically impractical.
- With a good wind resource and cost-effective wind turbines, achieving a 50% reduction in imported fuel may be economically feasible **with a combination of renewable energy retrofits and energy efficiency**. Achieving 50% imported fuel reduction with renewable energy alone is generally economically marginal at best.
- Energy efficiency is key to achieving greater imported fuel reduction. The data indicate that implementation of cost-effective energy efficiency measures alone (mostly weatherization in the case of remote Alaska communities) can reduce imported fuel by 20% or more.
- The main value of storage is to allow for more extended diesel-off operation by covering short-term lulls in wind energy production. This function requires only a modest amount of storage (assumed to be Li-ion batteries) and converter capacity. The required battery bank should be sized to meet 0.5 to 3 hours of average load. The converter rated power is somewhere between the average and the peak load (for situations in which the turbine is connected to the AC bus). Unlike for very small systems (e.g., a single house), where the storage supplies the load when there is no renewable energy production, the value of storage for community-size systems is to allow diesel-off operation when there is renewable energy production.
- Water and space heating are an excellent use for excess wind energy that would otherwise be spilled and can allow larger renewable energy systems and better economics. This use of excess wind energy for heating allows for the use of modest-size converters and battery banks. Economically, the use of excess wind energy for heat is needed to go beyond low-contribution wind systems.

Decision Variables

The decision variables are items for which the model selects the values.

Table 12

# of wind turbines (V-17s)
Converter capacity (kW)
Battery storage capacity (kWh)
Electric thermal stove capacity (kW)
Diesel dispatch strategy (load following or cycle charging)

Notes:

- V-17s are used because the community already has installed two of these turbines. At this community, each V-17 has the potential to produce 200,000 kWh/year, an amount equal to one-half the community's electrical consumption.
- Diesel dispatch strategy refers to how to operate a diesel when a system includes storage. Under load following, the diesel follows the (net) load and does not charge the batteries. Under cycle charging, the diesel will, in addition to meeting the load, also charge the batteries. Depending on the circumstances, one strategy may be significantly more cost effective than the other.

Sensitivities

The most cost-effective architecture depends in part on outside factors such as fuel price and discount rate. In general, deploying renewable energy (or implementing energy efficiency) is economically favored by high fuel prices and low discount rates. The table below shows the various values used for these items. The "base" scenario is the one with the low fuel cost and the low discount rate.

The lower discount rate generally represents some combination of grants or concessional financing. The higher rate is more typical of commercial financing.

The higher fuel costs are the average of 2012-2015 costs. The lower fuel costs reflect 2016 costs.

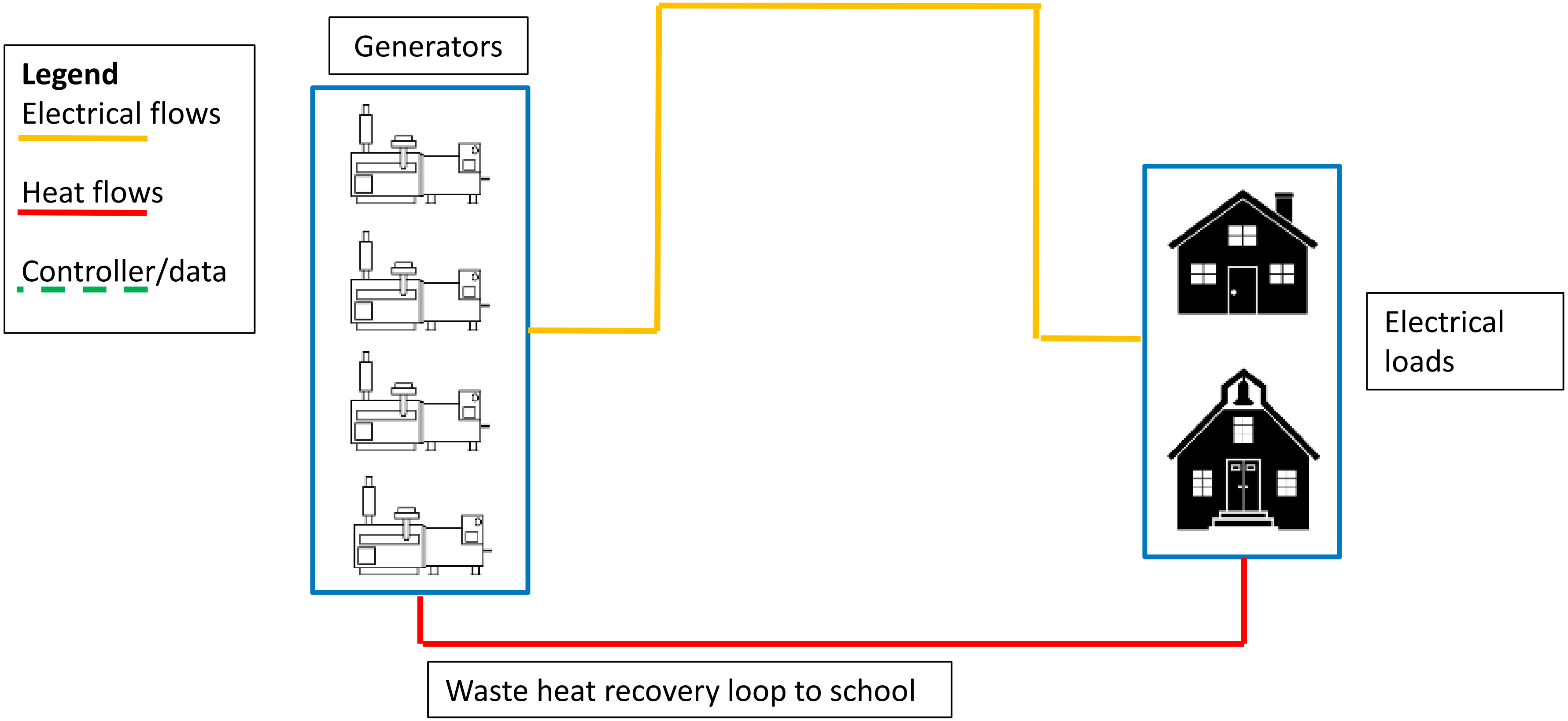
Table 13

ITEM	VALUES
Nominal Discount Rate	4%, 8%
Diesel Fuel Cost ($/gal)*	$5.60/gal, $4.00/gal
Heating Oil Cost ($/gal)*	$8.00/gal, $6.00/gal
Energy Efficiency	No energy efficiency (no change in consumption) With energy efficiency (10% reduction in electrical consumption, 25% reduction in thermal consumption). Implementation cost of $925,000

*The diesel fuel cost and heating oil cost are linked. They were not independently varied.

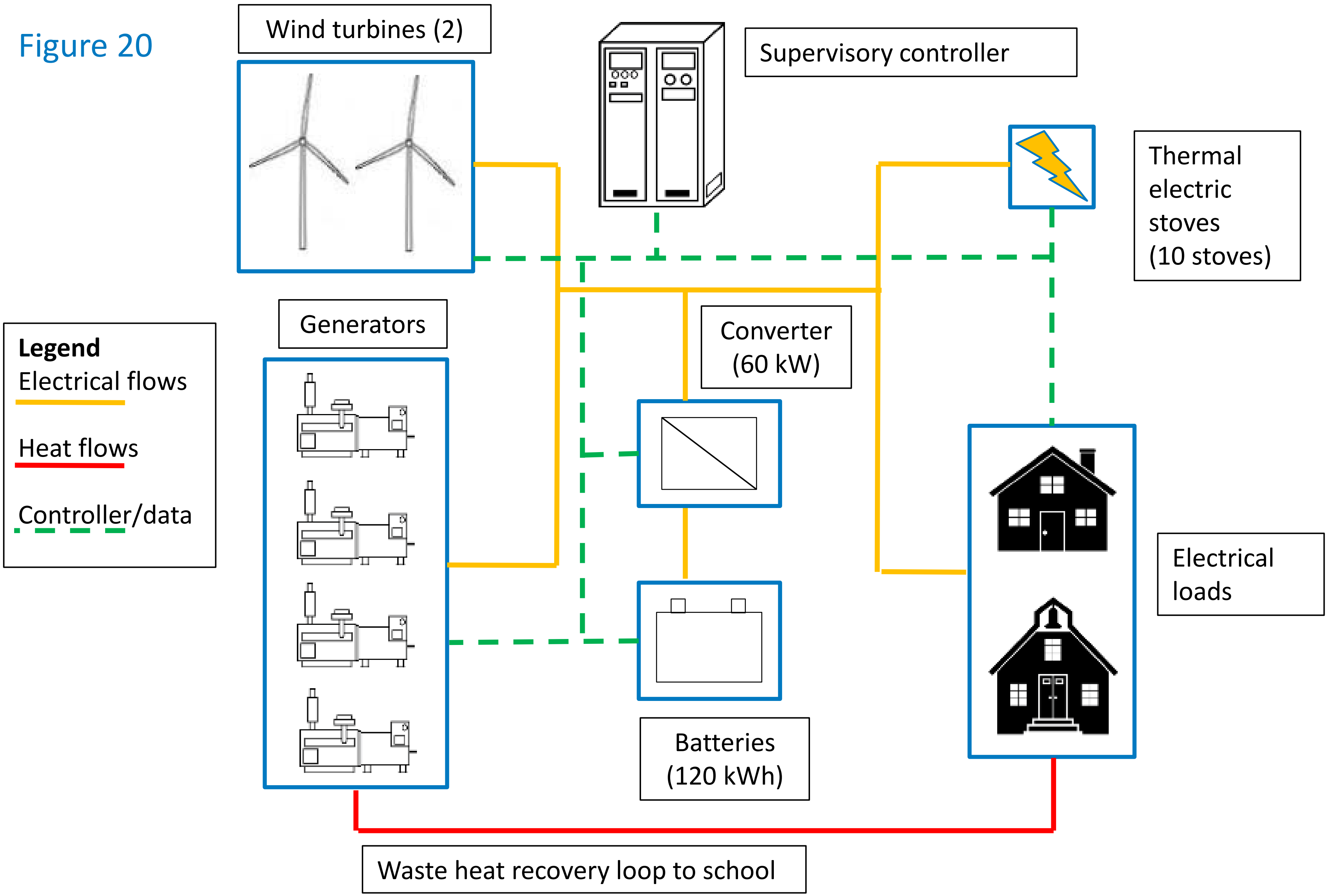
Current Situation – Base Configuration

Figure 19



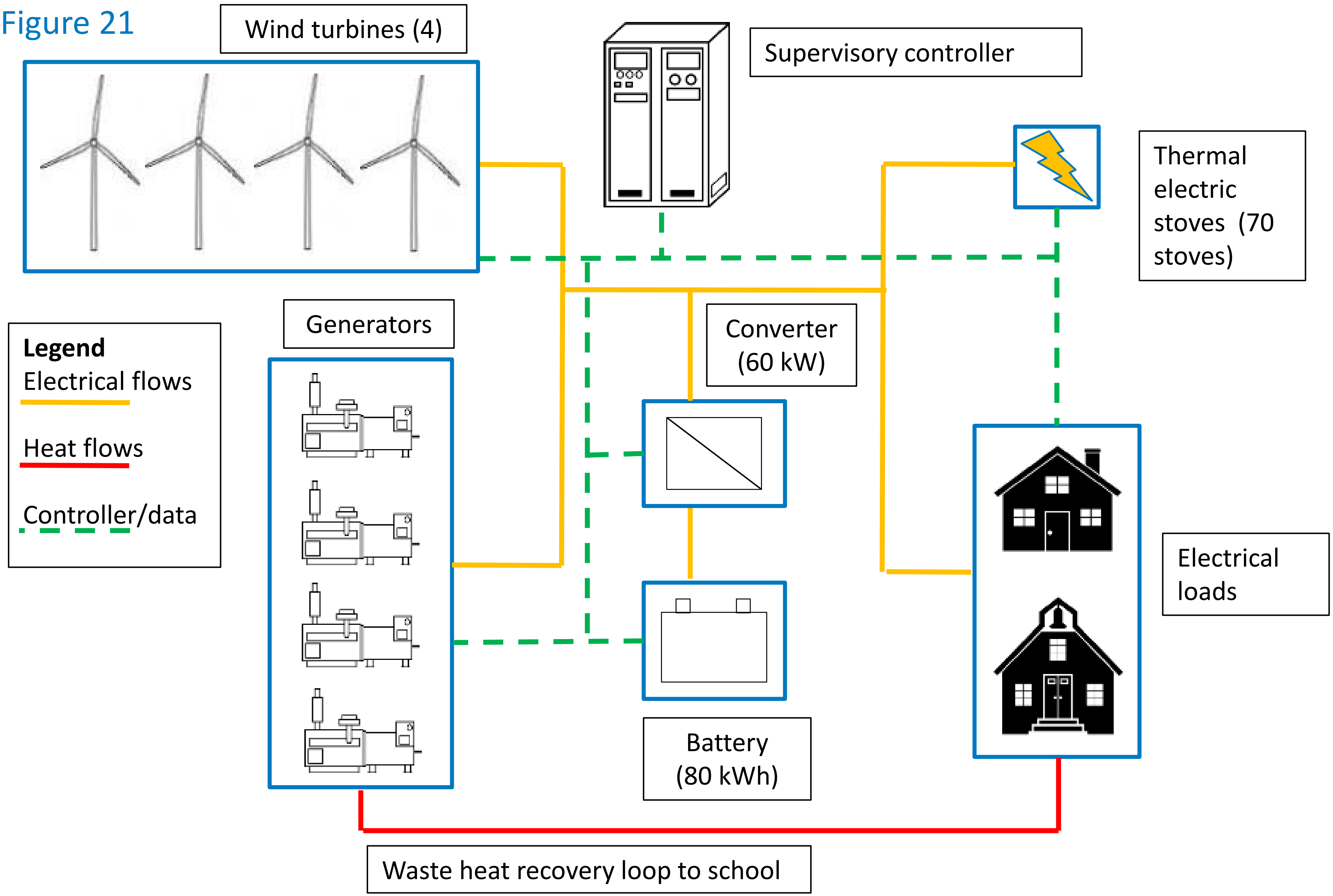
Economically Optimum System (with or without Energy Efficiency) – Two Turbines

Figure 20



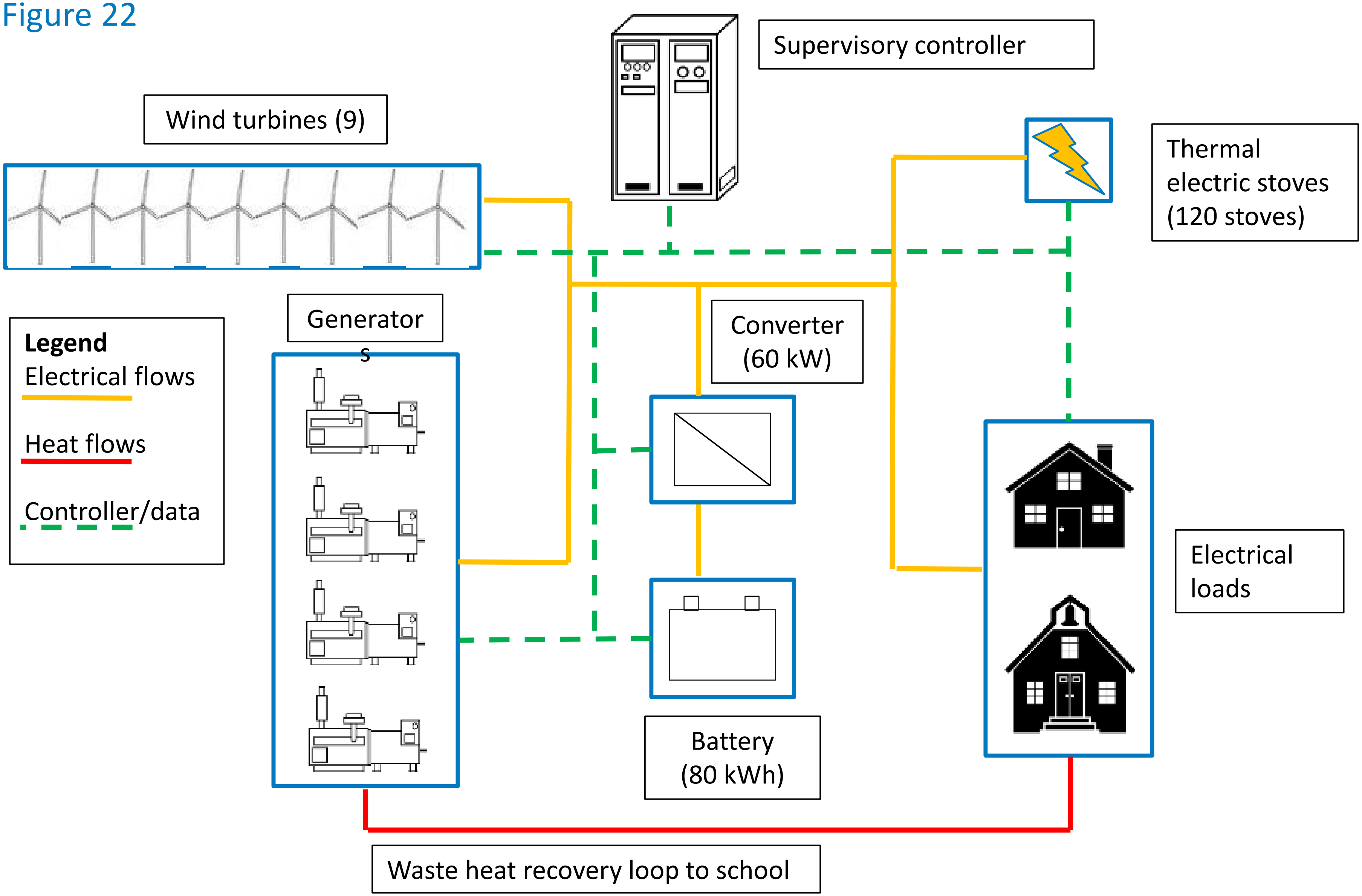
50% Total Imported Fuel Reduction (with Energy Efficiency) – Four Turbines

Figure 21



50% Total Imported Fuel Reduction (No Energy Efficiency) – Nine Turbines

Figure 22



Results Discussion (1 of 4)

Table 14 shows selected performance and cost metrics for the conceptual designs previously presented. Results are shown with and without energy efficiency. The information in Table 1 is presented graphically in Figures 5–8, where various metrics are plotted as a function of the number of wind turbines. **All values are for the lowest-cost configuration featuring the given number of wind turbines.**

Each turbine produces slightly more than 200,000 kWh per year. This is equal to almost half the community's current electricity consumption.

Figure 23 shows imported fuel consumption plotted against the number of wind turbines in the system. In addition to showing total fuel consumption, the figure breaks out diesel fuel consumption (for electricity) and heating oil consumption. As can be seen, the initial two turbines mostly serve the electric load, thus mostly displace fuel used for electricity. Heating oil consumption stays flat or even increases a bit. Due to the wind turbines, the generators run much less often and thus produce much less waste heat that can be recovered and used. Meanwhile, only a small fraction of the wind turbine production is going to serve the thermal load. This increases the use of heating oil for heat.

After the initial two turbines, diesel consumption decreases very little with each additional wind turbine while heating oil consumption declines with each additional turbine. Total fuel consumption decreases the most with the initial two wind turbines. More fuel is required to create a kilowatt-hour of electricity than to create a kilowatt-hour of heat. Thus wind turbine energy serving an electrical load leads to a greater fuel reduction than the same amount of wind energy serving a thermal load. By mostly serving the electric load, the initial two turbines lead to a sharper drop in total fuel consumption than succeeding turbines, which mostly serve the thermal load.

Results Discussion (2 of 4)

Beyond a certain point, each additional turbine (even those mostly serving the thermal load) reduces fuel consumption by less than the preceding turbine. This is explained by examining the values for spilled energy in Table 13. Examining the no-energy efficiency case with zero turbines, the quantity of spilled energy is relatively small (slightly more than 50,000 kWh/year). This represents waste heat recovery during the summer when there is little or no thermal load. The first two turbines only slightly increase the quantity of spilled energy. With the addition of additional turbines, the proportion of spilled wind energy increases with each additional wind turbine. With nine turbines, the quantity of spilled energy is greater than the combined production of three turbines. Each additional turbine serves less load than the preceding turbine, thus it reduces total fuel consumption by a smaller increment than the preceding turbine.

These factors explain the decreasing marginal utility of additional wind turbines, both in reducing imported fuel consumption and economically. Increasing the number of wind turbines from zero to two reduces total fuel consumption by 20,000 gallons (20%) (for the no-energy efficiency case). In comparison, increasing the number of wind turbines from seven to nine reduces annual fuel consumption by only 5,000 gallons (5%).

Finally, comparison of total fuel consumption with and without energy efficiency shows the impact of energy efficiency. Implementing the assumed energy efficiency measures reduces total imported fuel consumption by roughly 20,000 gallons/year.

Without energy efficiency , nine wind turbines are required to achieve a 50% reduction in total imported fuel use. With energy efficiency , only four wind turbines are required to achieve a 50% reduction in total imported fuel use.

Conceptual Design Comparisons

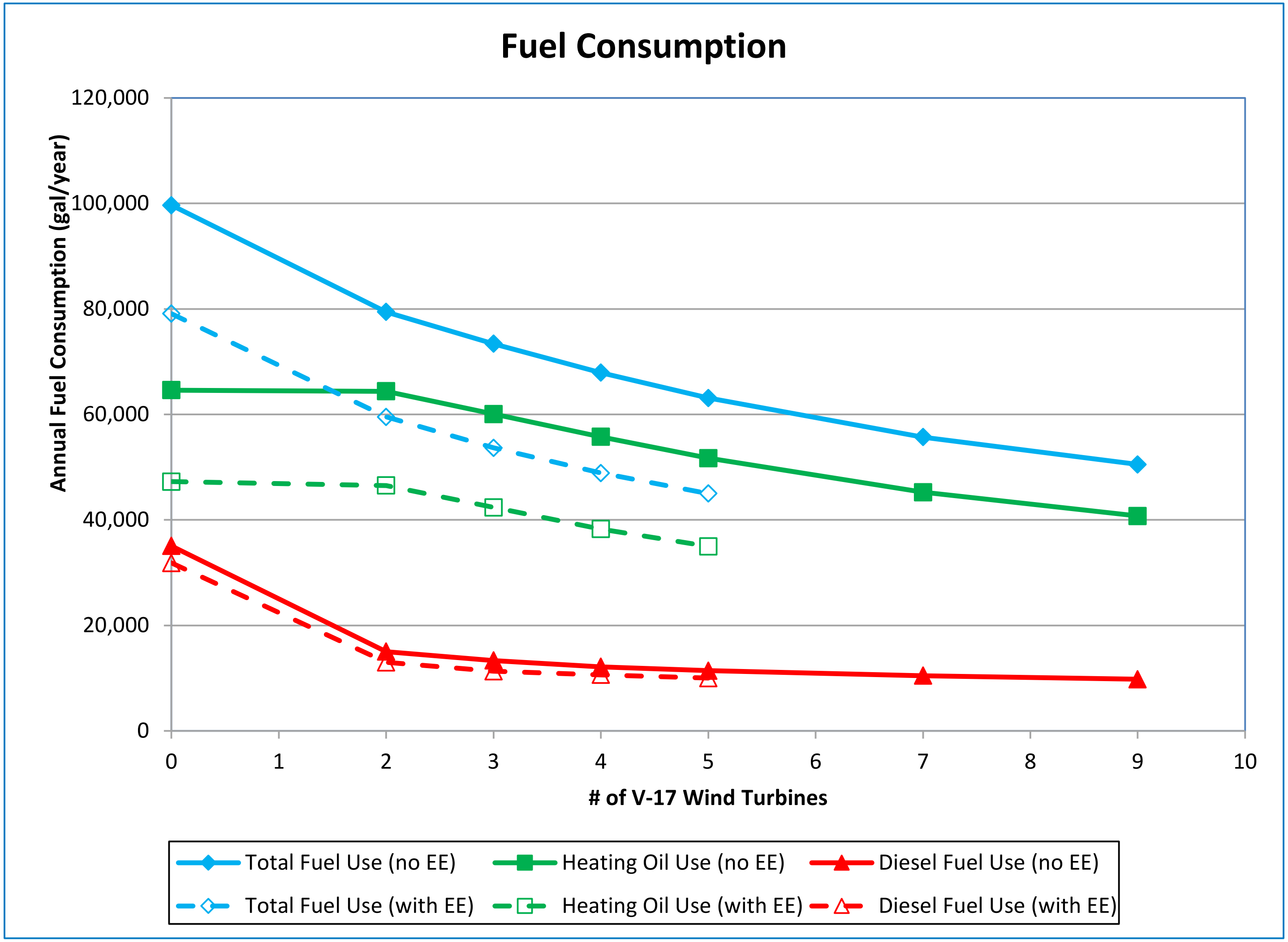
Table 14

Sensitivity Scenario	<================ Low-Cost Fuel, Low Discount Rate =======================>						
Energy Efficiency	No	No	No	No	Yes	Yes	Yes
Architecture/V-17	0	2	4	9	0	2	4
Battery Storage (kWh)	0	120	80	80	0	120	80
*Thermal Electric Stove Capacity (kW)	0	125	300	700	0	125	300
Converter Capacity (kW)	0	60	60	60	0	60	60
Dispatch Strategy	LF	CC	CC	CC	CC	CC	CC
ENERGY CONS. & PROD							
Elec Cons (kWh/yr)	426,249	426,249	426,247	426,249	383,798	383,798	383,798
Elec Prod (kWh/yr)	426,249	598,043	968,322	1,959,549	383,798	573,874	949,271
Thermal Consumption (kWh/yr)	2,101,919	2,101,919	2,101,889	2,101,919	1,576,435	1,576,435	1,576,435
Thermal Production (kWh/yr)	2,154,609	1,995,558	1,722,195	1,264,837	1,623,624	1,457,109	1,198,815
PERFORMANCE METRICS							
Wind Turbine Production (kWh)		408,170	816,341	1,836,766		408,170	816,341
Excess (Wasted) Energy (kWh/yr)	52,690	58,805	158,608	693,146	47,189	61,354	182,692
Total Diesel Generator Run Hours	8,760	4,126	3,554	2,800	8,760	3,373	3,120
Total Fuel Consumption (gal)	99,662	79,416	67,911	50,522	79,098	59,521	48,895
Diesel Fuel Consumption (gal)	35,054	15,032	12,157	9,788	31,837	13,005	10,635
Heating Oil Consumption (gal)	64,608	64,384	55,754	40,734	47,261	46,516	38,260
COST METRICS							
Life Cycle Cost ($)	$9,321,702	$7,859,839	$8,517,026	$11,197,590	$8,375,799	$6,991,452	$7,741,863
Initial Capital Cost ($)	$0	$509,062	$1,968,649	$5,668,850	$925,000	$1,434,062	$2,893,649

* One stove has a capacity of 6 kW LF: Load Following CC: Cycle Charging

Fuel Consumption vs. Number of Turbines

Figure 23



Results Discussion (3 of 4)

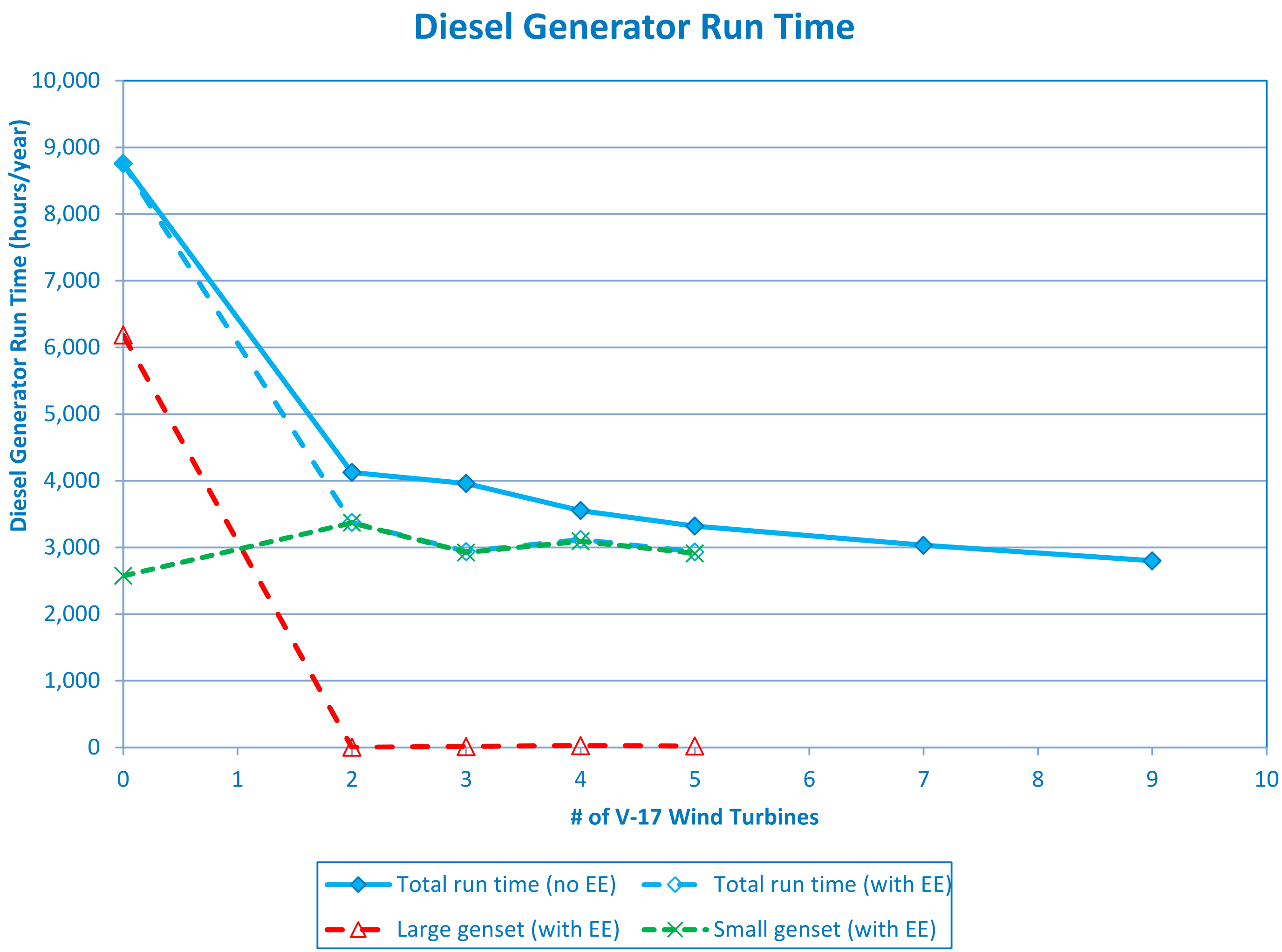
Figure 24 shows diesel run time versus the number of wind turbines. With zero wind turbines, the larger generator runs much more than the small generator. With two turbines, the large generator hardly runs at all, while the run time of the small generator increases from 2,600 to 3,400 hours per year. Additional wind turbines have little effect on generator run time.

What happens as the number of turbines increases? The reduction in large generator run time is due in part to the battery storage system. This system can cover the system spinning reserve requirements, allowing for more efficient dispatch of diesel generators. For example, while in principle a 60-kW generator could supply a 50-kW average load, in practice a larger generator would be dispatched to meet spinning reserve requirements. The initial two wind turbines mostly displace electricity from the diesels, allowing for the smaller diesel to be dispatched or for the diesels to be turned off. As the number of turbines increases (in this case beyond two), the energy from the additional turbine mostly displaces heating oil.

Figure 24 shows that energy efficiency has a modest effect on diesel generator run time.

Diesel Run Time vs. Number of Turbines

Figure 24



Results Discussion (4 of 4)

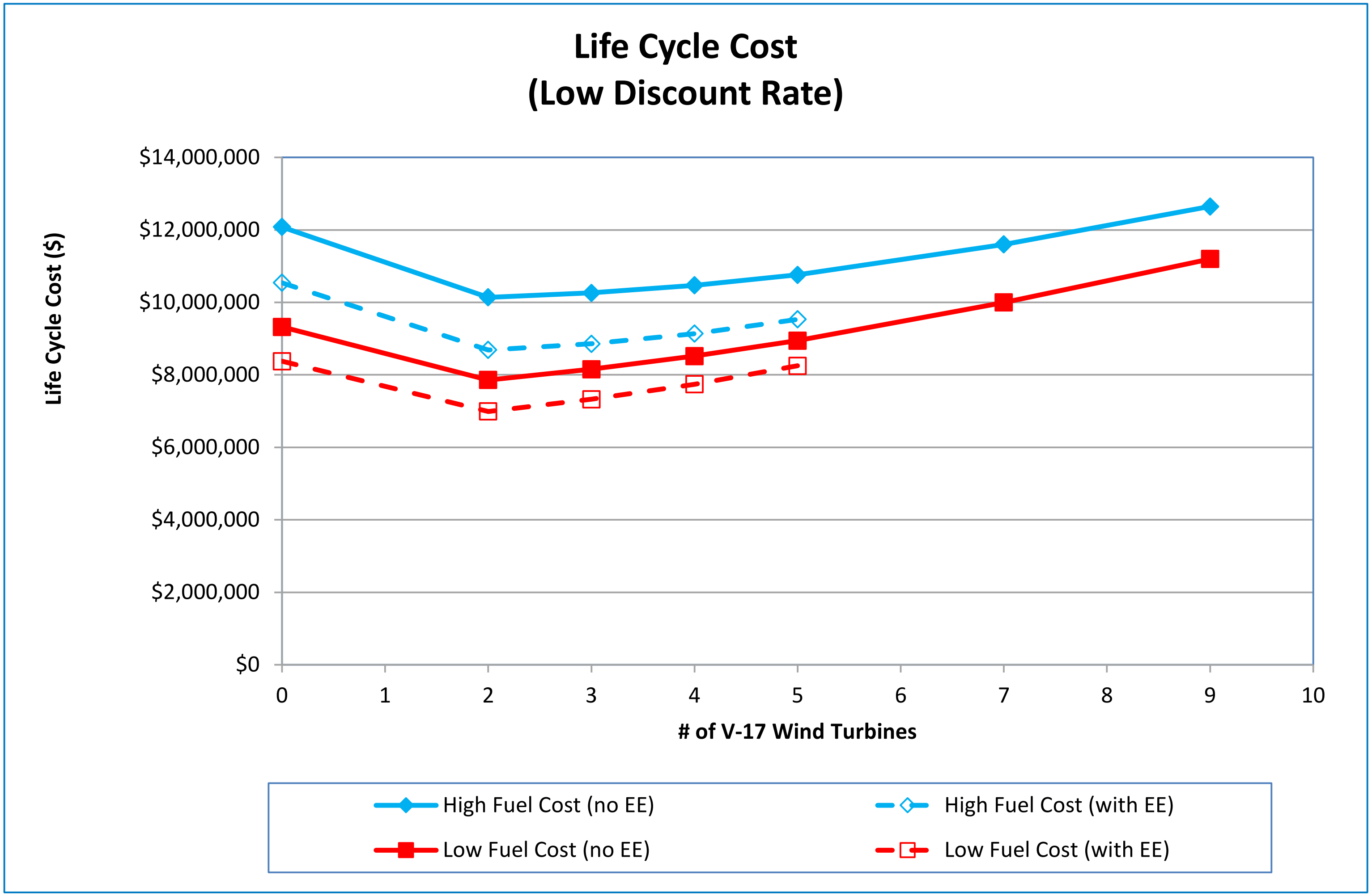
Examination of Figure 25 and Figure 26 shows that for all sensitivity cases, the lowest life cycle cost architectures feature two wind turbines. This is not particular surprising because, as a sunk cost, the first two turbines are nearly “free,” only requiring the installation of a new control/integration system to allow them to be switched on. Under all the sensitivity cases, the two-turbine architecture (without energy efficiency) reduces the life cycle cost by roughly 15%. When combined with energy efficiency, the two-turbine architecture reduces the life cycle cost by 19% to 28%.

As the number of turbines increases, the differences between the sensitivity cases becomes more apparent. A low discount rate (the situation more favorable to both renewable energy and energy efficiency) permits installation of more turbines before the life cycle cost exceeds that of the base architecture (zero wind turbines and no energy efficiency). With low-cost fuel, up to five wind turbines can be installed before the life cycle cost exceeds that of the zero-wind-turbine case. With high-cost fuel, the corresponding number of wind turbines is eight. Under the low discount rate scenarios, energy efficiency implementation leads to significant savings. With the lower fuel cost, energy efficiency implementation savings range from $1,000,0000 (zero wind turbines) to $750,000 (five wind turbines). Under the high-fuel-cost scenario, the savings are even greater.

With a high discount rate, fewer wind turbines can be economically installed. With low-cost fuel, the limit is four wind turbines; with high-cost fuel, the limit is five turbines. Under a high discount rate, the cost savings from energy efficiency implementation for a given number of wind turbines is small. This should not be interpreted to mean that energy efficiency has little value under these circumstances. As demonstrated in Figure 27, energy efficiency allows for a given level of fuel reduction to be achieved with fewer wind turbines and at lower cost than without energy efficiency. As shown in the figure, the five wind turbine architecture with no EE and the two turbine architecture with energy efficiency have similar fuel consumption. Even under the lower-fuel-cost scenario, the latter architecture has the lower net present cost.

Life Cycle Cost vs. Number of Wind Turbines (Low Discount Rate)

Figure 25



Life Cycle Cost vs. Number of Wind Turbines (High Discount Rate)

Figure 26

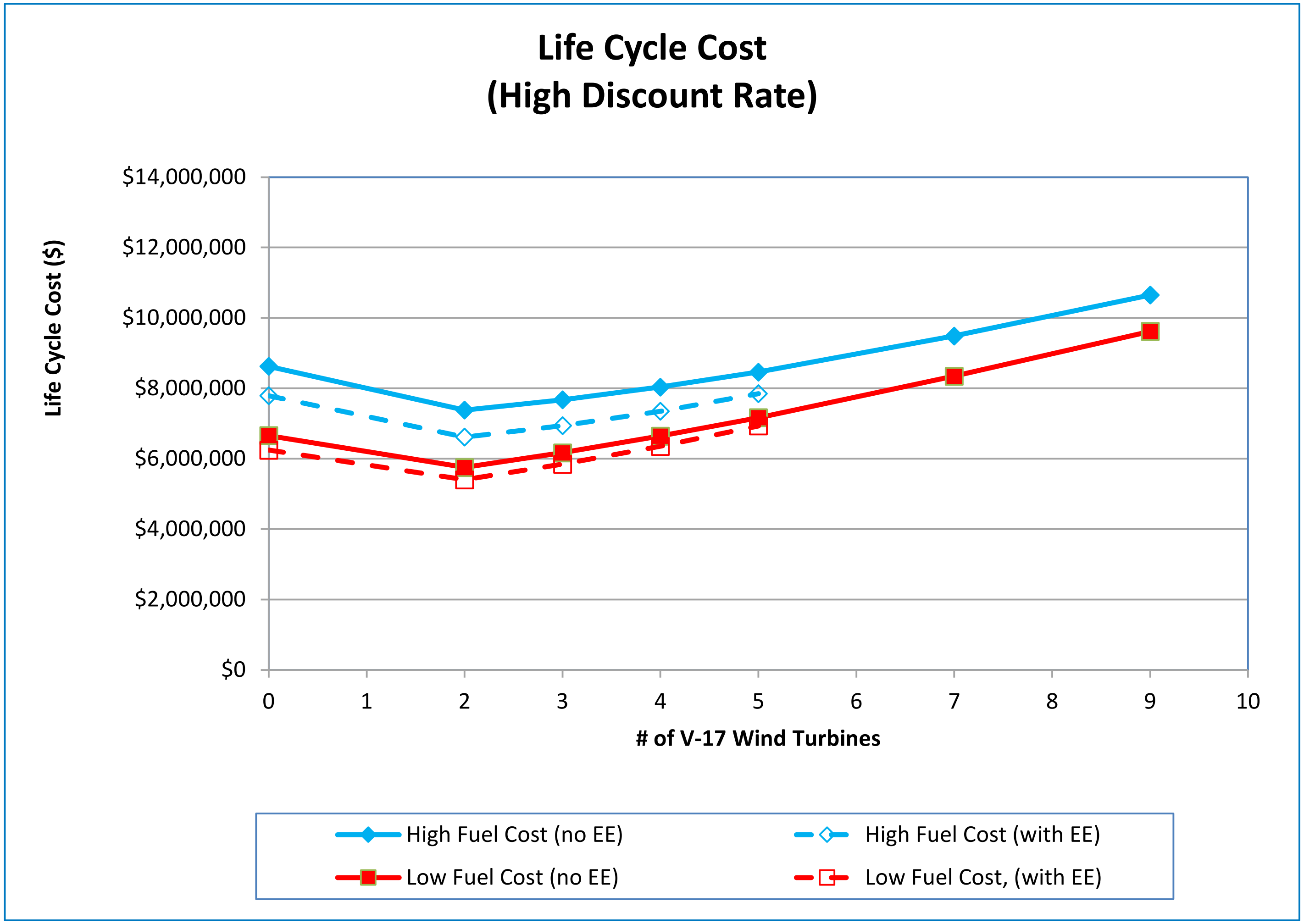
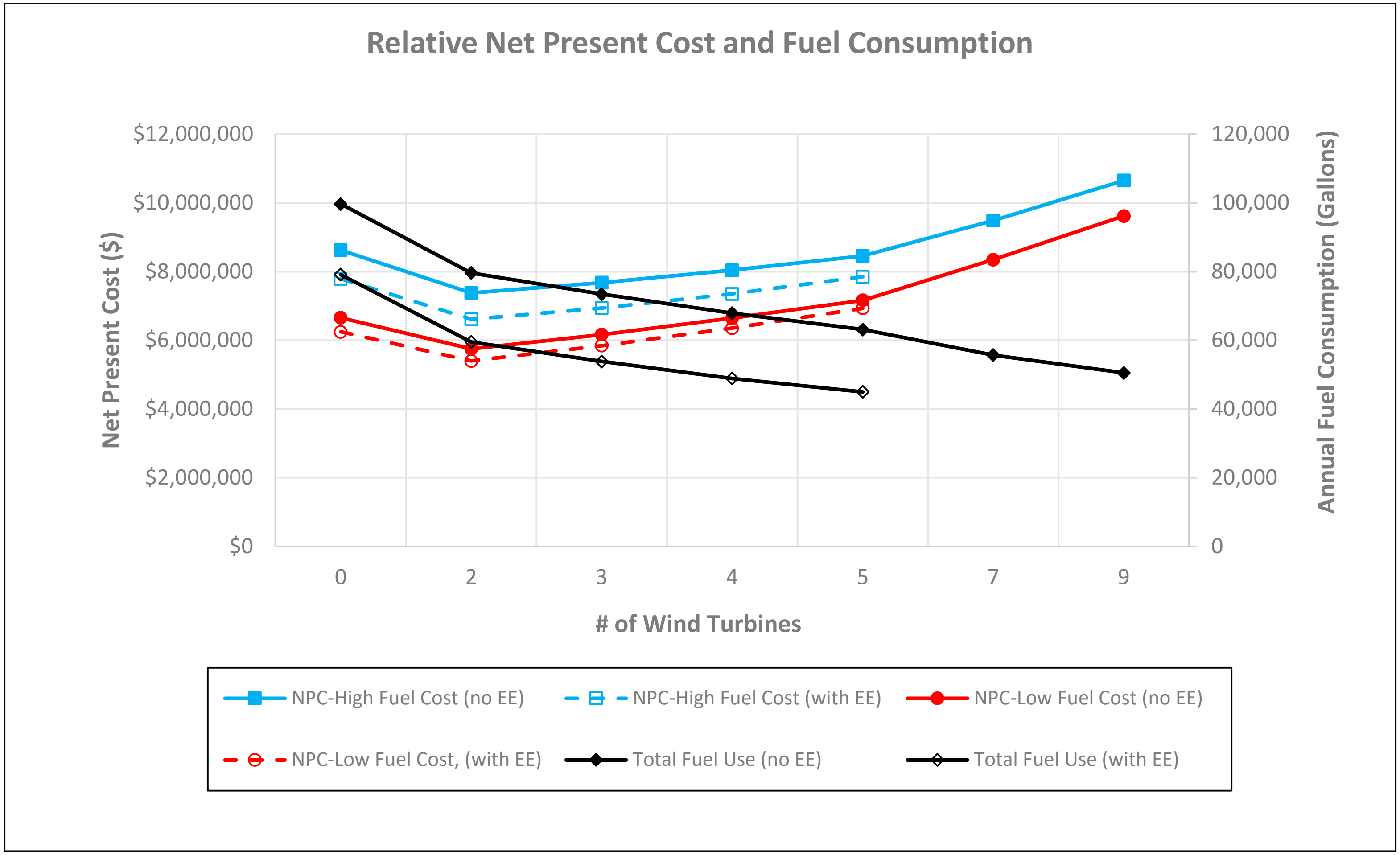


Figure 27



Relative Net Present Cost and Fuel Consumption
Net Present Cost ($)
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$0
Annual Fuel Consumption (Gallons)
120,000
100,000
80,000
60,000
40,000
20,000
0
0
2
3
4
5
7
9
# of Wind Turbines
NPC-High Fuel Cost (no EE)
NPC-High Fuel Cost (with EE)
NPC-Low Fuel Cost (no EE)
NPC-Low Fuel Cost, (with EE)
Total Fuel Use (no EE)
Total Fuel Use (with EE)

Cost Breakdown

The next slide shows the cost breakdown (by component) of the lowest-cost two-turbine system with energy efficiency. The listed costs are annualized costs. The category labeled “Other” represents the energy efficiency implementation cost. A salvage credit is given to components that have useful remaining life at the end of the analysis period (which in this case is 20 years).

As the Figure 28 makes clear, the combined (electricity + thermal) energy costs are dominated by heating oil costs, which are $280,000 per year. The remaining components with significant costs include the small (60-kW) diesel ($72,000/year), energy efficiency implementation (Other) ($62,000/year), and the wind turbines ($28,000/year). The wind turbine cost is unusually low because the turbines are already in place. The wind turbine costs include just the cost to replace the failed controls/integration equipment and O&M.

Cost Breakdown – Two Wind Turbines with Energy Efficiency

Figure 28

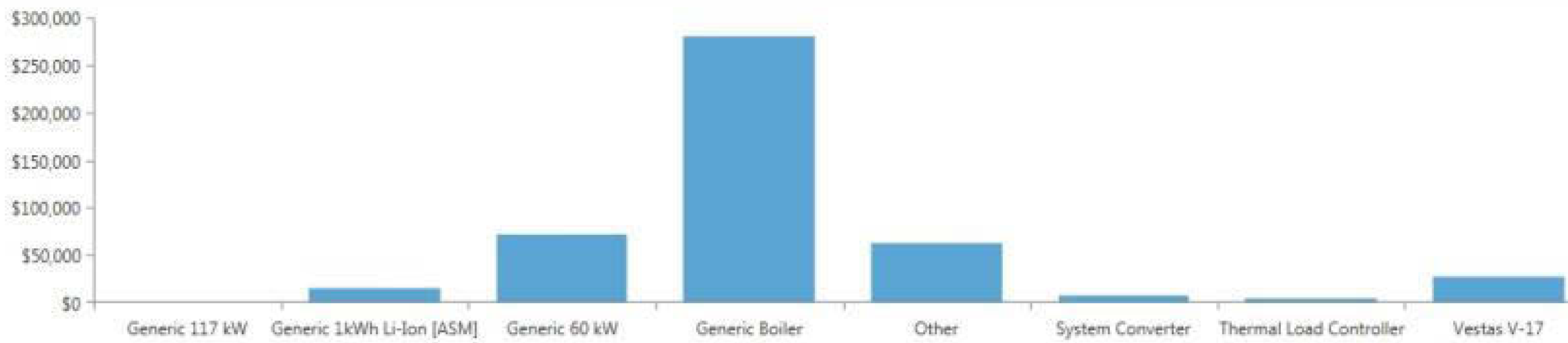
System Architecture:
Vestas V-17 (2)
Generic 60 kW (60.000000 kW)
Generic 117 kW (117.000000 kW)
Generic 1kWh Li-Ion [ASM] (6 strings) HOMER Cycle Charging
System Converter (60 kW)
Thermal Load Controller (1 quantity)

Total NPC:	$6,991,452.00
Levelized COE:	$0.3778
Operating Cost:	$372,518.90

Thermal Load Controller | Emissions
Cost Summary | Cash Flow | Compare Economics | Electrical | Thermal | Fuel Summary | Generic 60 kW | Generic 117 kW | Renewable Penetration | Generic 1kWh Li-Ion [ASM] | Vestas V-17 | System Converter | Generic Boiler

Cost Type
- Net Present
- Annualized

Categorize
- By Component
- By Cost Type



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 117 kW	$0.00	$0.00	$46.80	$125.00	$0.00	$171.80
Generic 1kWh Li-Ion [ASM]	$8,982.19	$4,674.48	$2,400.00	$0.00	($1,493.42)	$14,563.25
Generic 60 kW	$0.00	$0.00	$20,214.00	$51,981.99	$0.00	$72,195.99
Generic Boiler	$0.00	$0.00	$0.00	$279,570.03	$0.00	$279,570.03
Other	$62,003.91	$0.00	$0.00	$0.00	$0.00	$62,003.91
System Converter	$6,870.67	$0.00	$599.99	$0.00	$0.00	$7,470.66
Thermal Load Controller	$4,863.93	$0.00	$0.00	$0.00	$0.00	$4,863.93
Vestas V-17	$13,406.25	$0.00	$14,400.00	$0.00	$0.00	$27,806.25
System	$96,126.94	$4,674.48	$37,660.80	$331,677.01	($1,493.42)	$468,645.81

Details

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Analysis Assumptions and Inputs (1 of 3)

Table 15

Item	Value	Note
Annual electric load (kWh)	426,429	Average load – 47.7 kW
Peak electric load (kW)	82	
Annual thermal load (kWh_{th})	2,101,919	Average load – 240 kW_{th}
Peak thermal load (kW_{th})	959 kW_{th}	
Generator (both) CAPEX ($)	$0	Assume use of current generators
Generator (60 kW) OPEX ($/hr)	$6.00	
Generator (117 kW) OPEX ($/hr)	$11.70	
Generator (both) lifetime (years)	infinite	Generator replacement rolled into OPEX
Generator (60 kW) fuel curve intercept ($L/hr/kW_r$)	0.0300	
Generator (60 kW) fuel curve slope (L/kWh)	0.2600	
Generator (117 kW) fuel curve intercept ($L/hr/kW_r$)	0.0220	
Generator (117 kW) fuel curve slope (L/kWh)	0.2600	
Generator (both) minimum load (%)	30%	
Diesel fuel cost ($/gal)	$5.60 ($1.48/L)	Low-cost fuel case - $4.00/gal ($1.06/L)
Heating oil cost ($/gal)	$8.00 ($2.12/L)	Low-cost fuel case - $6.00/gal ($1.59/L)

Analysis Assumptions and Inputs (2 of 3)

Table 16

Item	Value	Note
Wind turbine (V-17) CAPEX fixed cost ($)	$200,000	Cost of controls to allow operation of the two wind turbines present
Wind turbine CAPEX marginal cost ($/turbine)	$700,000	Only applies to third and follow-on turbines. Marginal cost of first two turbines is $0
Turbine replacement cost ($/turbine)	$560,000	No fixed cost on replacements
Turbine OPEX ($/year/turbine)	$14,400	
Turbine lifetime (years)	20	
Average hub height (26 m) wind speed (m/s)	6.9	
Battery CAPEX fixed cost ($)	$50,000	
Battery CAPEX marginal cost ($/kWh)	Varies	HOMER (0 – 200 kWh): $700/kWh HOMER (> 200 kWh): $480/kWh
Battery replacement cost ($)	See note	75% of battery CAPEX
Battery lifetime (years)	See note	HOMER: lifetime based on usage REopt: 10 years
Converter CAPEX fixed cost ($)	$50,000	
Converter CAPEX marginal cost ($/kWh)	Varies	HOMER (0 – 160 kW): $875/kW HOMER (> 160 kW): $600/kW
Converter replacement cost ($)	See note	75% of converter CAPEX
Converter lifetime (years)	20	

Analysis Assumptions and Inputs (3 of 3)

Table 17

Item	Value	Note
Inflation rate (%)	1%	
Discount rate (real) (%)	3%	Sensitivity - High discount rate: 7%
Energy efficiency (electrical)	None	Sensitivity - EE: 10% reduction at $2.00 per annual kWh saved
Energy efficiency (thermal)	None	Sensitivity - EE: 25% reduction at $1.60 per annual kWh saved

Model Description: REopt

- Mixed Integer Linear Program
- Based on NREL's REopt modeling platform for energy system integration and optimization
  - Mathematical model written in the MOSEL programming language
  - Significant site-specific and client-requested customizations
- Solves energy balance at every time step (8760) for entire year
  - Load must be met from some combination of grid purchases (not applicable in this analysis), on-site generation, or discharge from storage
  - Does not consider power flow or transient effects
  - Has perfect prediction about upcoming weather and load events
- Technology modules based on empirical operating data
  - Performance and cost equations must be linearized
- Finds optimal technology sizes (possibly 0) and optimal dispatch strategy subject to resource, operating, and goal constraints
  - Objective function is to minimize life cycle cost of energy
  - Resulting life cycle cost is guaranteed optimal to within a known gap (typically 0.1%) subject to modeling assumptions

Model Description: HOMER

- Hybrid Optimization Model for Electric Renewables (HOMER)
- Commercially available micro-grid simulation and optimization software http://www.homerenergy.com/
- Calculates energy balance for every time step (typically an hour) for entire year
  - Load must be met from some combination of grid purchases, on-site generation, or discharge from storage
  - Does not consider power flow or transient effects
- Technology modules based on empirical operating data
- Finds optimal technology sizes and optimal dispatch strategy subject to resource, operating, and goal constraints
- Objective function is to minimize life-cycle cost of energy
- Two available optimization methods
  - HOMER proprietary optimizer
  - "Search space": For each decision variable, the user enters the value(s) to simulate. HOMER will simulate every combination of values.

Thank You!

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