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An Alaska case study: Solar photovoltaic technology in remote microgrids

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Solar photovoltaic (PV) technology is a nascent but promising energy option in remote Alaskan microgrids and serves as an example for isolated electrical grids worldwide. This study examines community scale solar PV installations in Alaska, ranging in size from 2.2 kW in Ambler to 50 kW in Galena. Total installed costs arguably show a trend toward lower values with larger installation sizes although prices in Alaska are still significantly higher than in the rest of the United States. Capacity factors range from 6% to 15%. However, it should be noted that some installation configurations, particularly in the northwestern part of the state, were installed with the goal of a broad production curve rather than maximum power production. *Published by AIP Publishing.* https://doi.org/10.1063/1.4986577

INTRODUCTION

Significant volatility in fuel prices in the past decade and concerns over energy security have thrust isolated grids such as those found in rural communities, island states, and remote military installations using conventional fossil fuel power generation into an energy crisis. Many of these remote locations are turning to renewable energy to reduce fuel consumption and costs and to ensure a more independent and reliable energy source.

Over 200 remote communities in Alaska are largely dependent on diesel generators and arguably have the highest electric rates in the nation due to the logistics of importing fuel. These stand-alone village microgrids typically serve 300–450 people with average loads of ∼200 kW (AEA, 2011). As such, the microgrids provide ideal laboratories to test and validate variable generation and load control strategies with broader applications to high-penetration renewable islanded systems globally. The renewable energy contribution in many small Alaska communities is already much higher proportionally than what utilities in larger grids nationally would even consider although they are on a trajectory that will require doing so in future operations.

One of these renewable energy sources is solar photovoltaic (PV) power (Schwabe, 2016). Although Alaska's high latitude creates large fluctuations in sunlight throughout the year, computer simulations show the solar PV potential in Alaska to be on a par with or greater than that in Germany, the largest solar PV power market in the world (Wirth, 2015). Furthermore, Alaska's cold temperatures increase system voltage, reduce electrical resistance, and yield higher-than-rated outputs associated with reflected light and albedo effects (Nelson, 2003 and Brennan *et al.*, 2014). These factors, combined with declining module prices, are making solar PV technology more economical. Solar PV arrays have been installed in all areas of the state from the southwest to the Arctic, and low sun angles and long daylight hours represent opportunities to mount panels vertically on walls as well as on the east and west sides of buildings.

This review of solar PV technology in Alaska is a result of Alaska Senate Bill (SB) 138. In this bill, the Alaska State Legislature created an uncodified section of law entitled: "Plan and Recommendations to the Legislature on Infrastructure Needed to Deliver Affordable Energy of the State to Areas That Do Not Have Direct Access to a [proposed] North Slope Natural Gas Pipeline." To support the Alaska Energy Authority (AEA) in its development of an Alaska Affordable Energy Strategy, the Alaska Center for Energy and Power (ACEP) contracted with AEA to document technology development needs specific to Alaska with regard to renewable and sustainable energy technologies. The intention was to determine what targeted, energy technology development solutions could be implemented in Alaska to make energy more affordable in the Alaska Affordable Energy Study area. While the focus was on technology research solutions, other factors such as logistics, labor, and training were also addressed. Drafts of technology reviews were vetted by expert roundtables in late February and early March 2016.

These reviews are not meant to be exhaustive discussions of energy technologies in Alaska or proper designs for each technology, and they should not be used as guides for the choice and installation of specific systems. As such, not all possible issues with power production and each technology are addressed. Data for each technology were collected from surveys and publically available databases. Only completed projects, or projects with clearly reported data, were included in each technology analysis. These distinctions and descriptions of data sources are included in each technology review.

METHODS

To obtain information regarding the current state of the solar industry in Alaska, we consulted installers, community development staff, and Alaska Energy Authority (AEA) staff. Many of the systems installed in communities around the state are currently being monitored, and data are available via online portals. Cost information is harder to acquire. For state-funded projects, cost information is available from the AEA, but few projects have been funded by the state. Cost information is sometimes available via community development staff. This case study covers community installations that range in size from 2.2 kW in Ambler to 50 kW in Galena. Significant data collection is still needed for specific details such as module technology type, mounting types, and other characteristics that can help to further refine analysis.

DISCUSSION

To illustrate the solar resource in Alaska, Fig. 1 shows the expected average daily solar radiation levels for varying surface angles for different cities in Alaska relative to Seattle and Phoenix in the continental United States (ACEP, 2012). Anchorage (61°N) is located in south-central Alaska, Fairbanks (65°N) is in the interior, and Kotzebue (67°N) is in the far north. Figure 1(c) shows the amount of solar radiation that horizontal collectors would be expected to receive throughout the year, with the highest radiation levels in May and June. In the graph showing the collectors tilted at 15° steeper than the latitude angle and tilted vertically, a strong improvement in springtime performance is seen. The graphs in the figure show that Fairbanks and Kotzebue receive almost 5 kWh/m^2 day in March and almost 6 kWh/m^2 day in April. This early season performance improvement is attributed to more direct radiation from the low sun angles and high levels of reflected radiation from the snow-covered ground. Significant space-heating demands also coincide with this springtime arctic solar resource. While solar PV power is not a viable year-round resource for Alaskan communities, it can be of use for seasonal applications and paired with other energy sources for winter energy demands.

Figure 1 uses data from the National Renewable Energy Laboratory (NREL), collected between 1961 and 1990 and based on averaged values of radiation. It does not account for weather patterns and cloud cover. In the NREL model, the albedo of snow was taken into account to calculate reflected radiation (NREL, 1992). Surface albedo was adjusted depending on the presence of snow cover. If there was snow on the ground, the surface albedo was set to 0.6 (albedo for snow ranges from ∼0.35 for old snow to 0.95 for dry new snow). If no snow was indicated, the surface albedo was set to 0.2, a nominal value for green vegetation and some soil types (NREL, 1992).

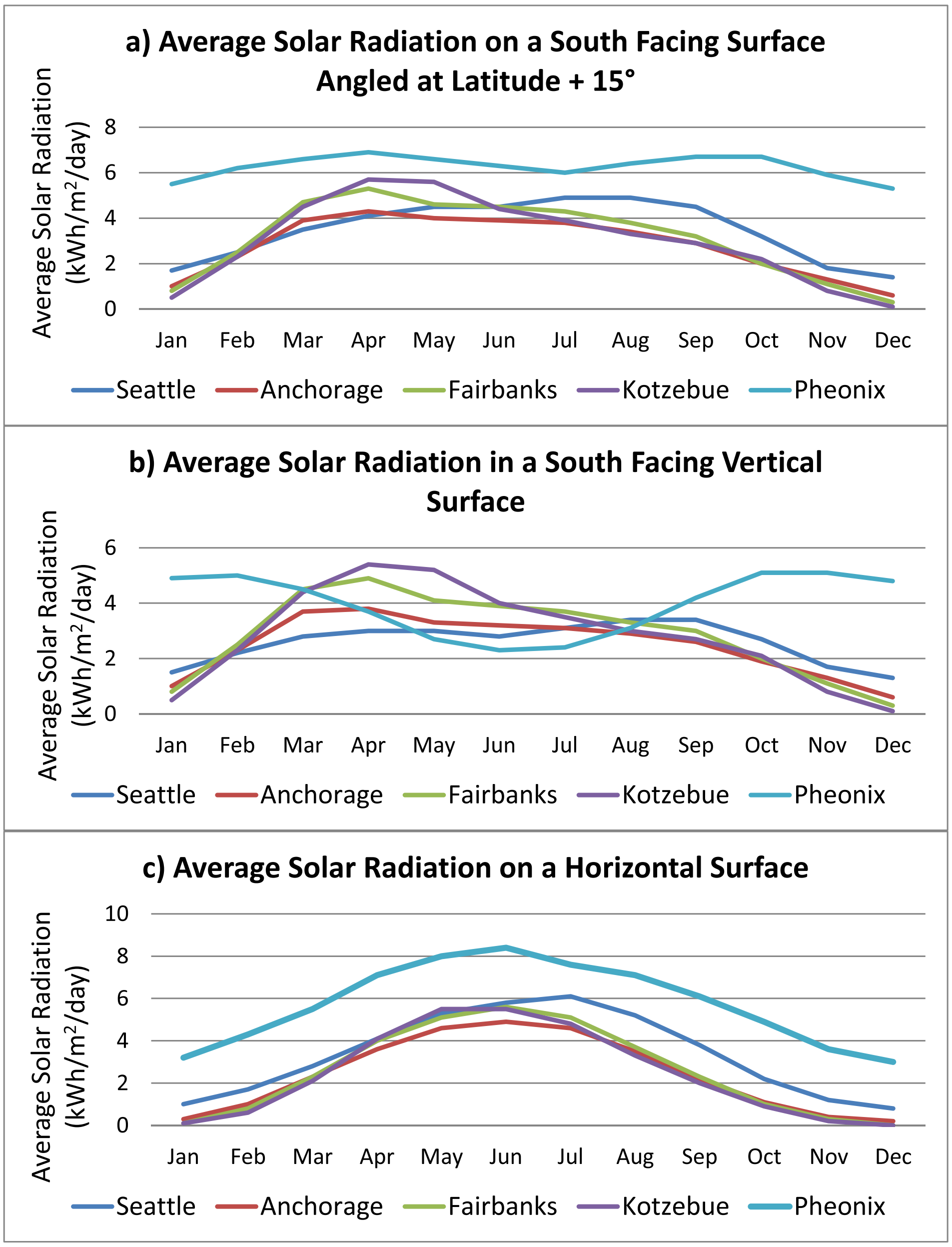

FIG. 1. Expected average daily solar radiation levels for varying surface angles by city in Alaska, compared with Seattle and Phoenix.

Total installed costs

Total installed costs in \$/W plotted as a function of installation size show a trend toward lower costs with larger installation sizes, as seen in Fig. 2. In this case, total installed costs are the sum of labor, parts and materials, and shipping. In Alaska, the 6.7 kW installation in Galena (\$3.19/W) and the 18 kW installation in Fort Yukon (\$3.89/W) were accomplished with creative means to cut costs. In Fort Yukon, these means included volunteer labor and a shipping deal. For a number of other installations, figures are based on verbal estimates from batched purchases and are not public record. The inconsistency of information is indicative of the nascent solar PV industry in Alaska. In general, however, prices in Alaska are still higher than prices in the contiguous United States. According to the Lawrence Berkeley National Laboratory (LBNL) report, "Tracking the Sun VII" (Barbose *et al.*, 2014), in the Lower 48, "Installed

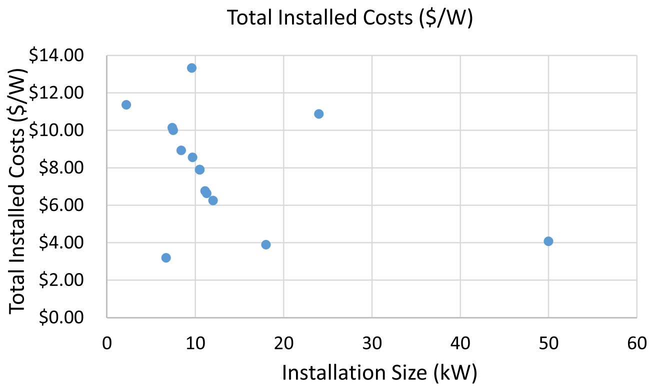

FIG. 2. Total installed costs ($/kW) as a function of installation size (kW) show a trend towards lower costs with larger installation sizes.

prices exhibit significant economies of scale, with a median installed price of $4.8/W ($4800/kW) for systems ≤ 2 kW completed in 2013, compared to $3.1/W ($3100/kW) for commercial systems >1000 kW" (p. 2).

Operation and maintenance (O&M) costs

The cost calculation for operation and maintenance (O&M) of a PV system is an area of increasing interest. Most systems around the United States have been installed within the last 8 years, and limited O&M cost data exist (Enbar *et al.*, 2015). In Alaska, most grid-tied PV systems have been installed for less than 5 years. According to the Electric Power Research Institute, O&M costs include scheduled maintenance and cleaning, unscheduled maintenance, and inverter replacement reserves, with costs up to $47/kW/yr for non-tracking systems (Enbar and Key, 2010). The O&M figures from a report by Black and Veatch (2012) and by the LBNL (Bolinger *et al.*, 2015) are $20–$50/kW/yr for non-tracking PV systems. Obviously, this range is wide due to limited data and the short amount of time that grid-tied PV systems have been installed. In addition, industry's best practices are just beginning to emerge.

The Cold Climate Housing Research Center (CCHRC) has some of the oldest grid-tied solar installations in Alaska; it maintains three pole-mounted PV systems on two-axis tracking systems with a total installed size of 8 kW. A relay has needed replacement, but otherwise very little maintenance has been required. According to staff at the CCHRC, 4 h of maintenance are devoted to the systems per year (2 h twice each year). Assuming $60/h, yearly maintenance costs equal $30/kW/yr, without taking into account inverter replacement. The trackers are locked at a fixed angle of 80 degrees azimuth facing due south between November and February, when solar insolation is at a minimum and temperatures are coldest; they are set to track the rest of the year.

One aspect of O&M in Alaska that deserves special mention is that of snow clearing. A study by students at the University of Alaska Fairbanks involved simulating the cost and benefit of clearing snow from a hypothetical 1 MW solar installation that faced south at a panel angle of 70°. The study plainly demonstrated that the cost savings from increased generation of electricity due to snow having been cleared from the panels did not justify the cost of labor to perform the task of clearing snow. This study was performed in Fairbanks, where winds are light and extended cold temperatures cause snow that occurs in fall and winter to remain on the ground into springtime. The results would likely be the same, if not more exaggerated, in Western Alaska, where high winds blow and mid-winter warm-ups melt snow from roofs (Vilagi and Brown, 2015).

During discussions with a number of individuals involved in the solar industry in Alaska, it was generally agreed that O&M costs might be approximately $100 per installed kW of PV power on the high side [Most solar systems within Alaska have been installed in the last

5 years, and little maintenance has been needed. The figure of $100/kW was reached after discussions with Ingemar Mathiasson (Northwest Arctic Borough), Robert Bensin (Bering Straits Development Company), Jeremy Osborne (Yuut Elitnuarviat), and David Pelunis-Messier (Tanana Chiefs Conference)]. Note that many of the PV arrays installed around the state have not needed any maintenance since installation. Given all the documents reviewed to date, for PV systems less than 20 kW in Alaska, O&M likely ranges from $50/kW/yr on the road system or in hub communities to $100/kW/yr in more remote areas. Operation and maintenance costs are not completely dependent on the system size; they are also a function of the level of local expertise available for repairs, the cost of travel to and from the site, occasional cleaning and inspection, unscheduled warranty work, and inverter replacement reserves.

Expected life

Most installers assume a system life of 25 years although they are useful to consider expected lifetimes of individual components. Panels are typically warrantied for 10 years on materials and 25 years for power output, and inverters can be warrantied from 10 to 20 years. No failure has been reported to date.

Capacity factors and diesel offset

Capacity factor is a function of weather, system design, system installation location, angle, and azimuth. It is a unitless ratio of the average power generated, divided by the rated peak power. Note that many of the systems installed in the Northwest Arctic Borough were installed in a semicircular fashion, with the goal of a broad production curve rather than maximum power production at midday. More systems are installed around the state than the ones reported here; however, insufficient data were available to obtain capacity factor information on the systems not listed.

In Table I, the diesel offset was calculated by dividing the community diesel power plant efficiency (found in reports by the AEA on power cost equalization) by the system's annual solar production to obtain gallons of diesel offset by the solar PV installation. While additional factors contribute to the amount of diesel fuel offset by a renewable energy system, this method provides a rough approximation.

Levelized cost per kW

The simple levelized cost of renewable energy (cents/kWh) was calculated at 70.5 cents/kWh based on the following inputs into the National Renewable Energy Laboratory (NREL) levelized cost of electricity (LCOE) calculator:

Period: 25 years
Discount rate: 3%
Capital cost (average): $8000/kW
Capacity factor (average): 9%
Fixed O&M Cost: $100/kW/yr
Variable O&M cost: none
Heat rate: none
Fuel cost: none

Considering the capacity factors for installations in Alaska, the LCOE ranges from 42.3 to 105.8 cents/kWh over a capacity factor range of 6%–16%, all other variables remaining constant. Similarly, factoring in the range of capital costs for installations in Alaska, which are assumed to be equal to the total installed costs for our purposes, since solar PV costs are predominantly capital costs, the LCOE ranges from $0.40–$1.22/kWh over a capital cost range of $3190–$13 300/kW.

TABLE I. Capacity factors and diesel offsets for selected solar installations in Alaska.

Village	Rated size (kW)	PV capacity factor (%)	2013 community diesel efficiency (kWh/gal)[a]	Average daily solar performance since installation (kWh)	Annual diesel offset (gal)
Ambler	8.4	9	14.1	17.5	453
Ambler IRA	2.2	12	14.1	6.1	157
Kobuk	7.4	6	14.3	10.8	275
BSNC		9	16.2	37.3	840
Shungnak	7.5	7	14.3	12.4	316
Noorvik	12	6	12.4	17.6	518
Noatak	11.3	8	14.1	21.1	546
Deering	11.1	10	13.6	26.9	721
Selawik	9.7	11	13.9	25	656
Yuut Elitnaurviat (Bethel)	10	14	13.7	33.6	895
Kaltag	9.6	9	13	21.7	609
Galena	6.7	12	13.1	18.6	518
Ruby Washeteria	5.4	10	13.4	12.8	348
Ruby Health Clinic	5.5	8	13.4	10.8	294
Manley	6	9	12.5	12.3	359
Nenana	4.4	12	GVEA[b]	12.5	
CCHRC[c]	8	15	GVEA	29.7	

[a]From the Alaska energy data gateway.
[b]Nenana is on the Golden Valley Electric Association (GVEA) grid, which receives power from a number of generation sources including hydro, coal, natural gas, fuel oil, and wind. Due to this variety, no diesel efficiency is given, and no diesel offset is calculated.
[c]The CCHRC has 3 tracking PV systems. The performances of these systems were averaged to determine capacity factors and summed to calculate the average daily performance.

Conditions for the greatest efficiency

Photovoltaics work best under clear, cold, and sunny conditions. Photovoltaic panels are more efficient and produce more power at colder temperatures, and high springtime snow albedo can reflect more solar radiation towards steeply angled panels. These cold, clear conditions and long days with high albedo ground cover usually make April the highest production solar month in most locations around Alaska.

At cold temperatures, short-circuit current decreases slightly, while open-current voltage increases rapidly (LG Solar, 2017). For example, power output at −25 °C can be approximately 25% higher than output at the standard test condition cell temperature of 25 °C, given the same irradiance (LG Solar, 2017). Note that this temperature dependence has been best characterized at temperatures higher than standard test conditions and that this temperature-power correlation needs further independent research and field characterization in Alaska's below-freezing environments.

Cost curve over time

The cost curve for using solar PV technology in Alaska over time is virtually impossible to establish given that installations in the state are fairly recent and that there are inconsistencies in data and differences in the installation approach (i.e., some installations are bid out, some use volunteer labor, some find ways to cover shipping, etc.). As a point of reference, we can look to national trends showing a steady decline in cost over the last two decades from LBNL's publication "Tracking the Sun VIII" (Barbose and Darghouth, 2015), where the following is reported:

Starting in 2009, installed prices resumed their descent and have fallen steeply and steadily since, with average annual declines of 13%–18% per year across the three customer segments. These recent price declines are the result of reductions in global PV module prices, as well as declines in other hardware costs and 'soft' costs. Within the last year of the analysis period, from 2013 to 2014, median installed prices fell by \$0.4/W (9%) for residential systems, by \$0.4/W (10%) for non-residential systems $<$500 kW, and by \$0.7/W (21%) for non-residential systems $<$500 kW (Barbose, 2015).

Anecdotal evidence suggests that solar module prices and equipment prices have dropped in Alaska, as they have in Lower 48. The costs of shipping and installation remain higher than in the rest of the nation.

Cost data

Cost data for solar installations in rural Alaska (Table II) are difficult to obtain. Often the contractor bids on a job as a lump sum, and separating labor from equipment and materials is difficult to do accurately. Of note, the 6.7 kW installation in Galena (\$3.19/W) and the 18 kW installation in Fort Yukon (\$3.89/W) were accomplished with creative means to cut costs. In Fort Yukon, these means included volunteer labor and a shipping deal. For a number of installations, figures are based on verbal estimates from batched purchases and are not public record.

Transportation

Further data collection is needed for this category.

Technology trends

In Alaska, options in solar PV systems include micro-invertors, which are attached to each panel and prevent an entire string of panels from going offline if just one panel is damaged. To date, solar PV systems in Alaska have comprised only mono-crystalline and poly-crystalline silicon modules. Module costs continue to drop, and efficiencies continue to increase, especially for non-silicon technologies. Other technologies may lend advantages for use in Alaska. Finally, concentrated solar PV technology is a candidate for generating heat as well as electricity but may not be suitable for Alaska.

Storage systems

Currently, energy storage is not a significant component of solar PV systems in Alaska. An off-grid utility-scale example outside Alaska that may provide guidance in this direction is the 600 kWh Absorbent Glass Mat battery bank in the Star Island solar installation in Maine. In addition, Tesla's 7 kWh Powerwall batteries may provide promising storage solutions for smaller installations.

Refurbishment/upgrade market

In the broader solar PV market, systems are generally replaced rather than upgraded. Both used and surplus panels are available. However, purchasing used panels introduces the possibility that the panels may not work properly. Surplus panels are usually older models that the manufacturer sells at a greatly discounted rate. Because these panels are older, they may not be quite as efficient as brand new panels but can still be a reasonable value.

Realized cost savings

Cost savings from integrating renewable power are difficult to gauge due to technical and incentive impacts at the entire power systems level.

At the technical level, for example, the effects of diminished losses of secondary services such as recovered waste heat and reductions in fuel efficiency are hard to gauge, as they depend not only on average reductions in load but also on specific operating schemes regarding minimum allowable load on diesels and on spinning reserve kept.

TABLE II. Cost data for selected solar installations in Alaska.

Location	System size (kW)	Installation date (month/year)	Installed cost by major components[a] Hardware ($)	Support structure	Labor/travel ($)	Shipping ($)	Cost/Watt ($)	Total cost ($)
Installed systems. Costs were based on percentages of estimated total system cost[b]								
Ambler	8.4	3/2013	41 250	Included in hardware	11 250	22 500.00	8.93	75 000
Ambler IRA	2.2	3/2013	13 750	Included in hardware	3750	7500.00	11.36	25 000
Kobuk	7.4	3/2013	41 250	Included in hardware	11 250	22 500.00	10.14	75 000
Shungnak	7.5	10/2013	41 250	Included in hardware	11 250	22 500.00	10.00	75 000
Noorvik	12	10/2013	41 250	Included in hardware	11 250	22 500.00	6.25	75 000
Noatak	11.3	11/2013	41 250	Included in hardware	11 250	22 500.00	6.64	75 000
Deering	11.1	11/2013	41 250	Included in hardware	11 250	22 500.00	6.76	75 000
Kotzebue-1	10.5	10/2014	45 650	Included in hardware	12 450	24 900.00	7.90	83 000
Kotzebue-2	10.5	11/2014	45 650	Included in hardware	12 450	24 900.00	7.90	83 000
Selawik	9.7	11/2014	45 650	Included in hardware	12 450	24 900.00	8.56	83 000
Kiana	10.5	8/2015	45 650	Included in hardware	12 450	24 900.00	7.90	83 000
Buckland	10.5	2015	45 650	Included in hardware	12 450	24 900.00	7.90	83 000
Kivalina	10.5	2015	45 650	Included in hardware	12 450	24 900.00	7.90	83 000
Installed systems with detailed cost records								
Eagle	24	7/2015	115 552	Included in hardware	94 632		10.88	261 000
Kaltag	9.6	2012	78 657	Included in hardware	15 946	6465.00	13.33	128 000
Galena	6.7	11/2012	14 400	2000	5000	City covered shipping cost	3.19	21 400
Fort Yukon	18	7/2015	45 000	Included in hardware	20 000	5000.00	3.89	70 000
Galena	50	Dec 2015 estimate only		Lumped together in bid		30 000.00[c]	4.07	203 613

[a]Systems in Ambler, Kobuk, Shungnak, Noorvik, Noatak, Deering, Kotzebue, Selawik, Kiana, Buckland, and Kivalina (shaded in green) were installed by Bering Straits Development Company through coordination with the Northwest Arctic Borough. Costs for these systems were difficult to separate from the main lump sum bid. Based on input from Rob Bensin, costs were separated using 30% for logistics, 15% for labor, and the remainder for racking, hardware, and materials. Systems in Eagle and Kaltag were installed by the utilities using funding from the Renewable Energy Fund. Systems in Galena and Fort Yukon were installed with assistance from the Tanana Chiefs Conference.
[b]Systems were bid as a group (Bensin, 2016).
[c]This system was only bid and not installed. Per price quote, "Heavy equipment to be provided for trenching/anchors/material handling." In addition, shipping was not included but was estimated after discussions with the energy manager at Tanana Chiefs Conference. Shipping is estimated here at $30 000 per Dave Pelunis-Messier, based on other similar systems in the Interior.

CONCLUSIONS

Solar photovoltaic (PV) technology is a nascent but promising energy option in remote Alaskan microgrids and serves as an example for isolated electrical grids worldwide. This study examines community-scale solar PV installations in Alaska, ranging in size from 2.2 kW in Ambler to 50 kW in Galena. Total installed costs arguably show a trend toward lower values with larger installation sizes although prices in Alaska are still significantly higher than in the rest of the United States. Capacity factors range from 6% to 15%. However, it should be noted that some installation configurations, particularly in the northwestern part of the state, were installed with the goal of a broad production curve rather than maximum power production.

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