ANALYSIS OF THERMAL INTERCONNECTIVITY OF UTILITIES IN RURAL ALASKA

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ANALYSIS OF THERMAL INTERCONNECTIVITY OF UTILITIES IN RURAL ALASKA

A

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Introduction

Throughout the arctic there are two primary community utilities with dramatically contrary thermodynamic concerns. These are the intensely exothermic diesel electric power generation, and the strongly endothermic water and sewer utility. In this context exothermic processes must expel excess heat while endothermic process requires heat input. Failure of engineers, community planners, funding agencies, and interest groups to recognize the full social, economic, and environmental impact to the sustainability of utilities has come at tremendous cost. This is exemplified in many remote Alaskan communities such as Toksook Bay, Minto, Deering, and Kotlik.

In harsh arctic environments communities rely on fuel deliveries to provide energy for the basic modern utilities of power and sanitation. These areas are extremely remote and not supported by any form of formal road or rail system. Energy delivery is especially impacted by this restriction as fuel delivery is dependent on sporadic barge service or in some cases delivery by aircraft. Limited by a short delivery season due to ice and water levels, barge service must be optimized by availability of adequate storage capacity.

Isolation and lack of energy delivery infrastructure has necessitated the use of power generation that is heavily exothermic. In remote Alaska this primarily comes in the form of diesel electrical power servicing power girds without the benefit of electrical interconnectivity between multiple users and providers. The result is a system that provides this basic utility at high cost, and without extended regard to byproduct heat.

Prolonged seasons of freezing temperatures, permafrost laden soil and constraining service mechanisms have led to an extremely endothermic process of providing basic water and sewer utilities. Large quantities of heat must be produced for freeze prevention, and the same limitation of isolation and lack of energy delivery infrastructure constraining the power systems also make producing heat very expensive.

The constraints on energy delivery translate directly into elevated costs for that energy and the services provided. For the state of Alaska, communities which rely on diesel power generation have the highest cost, and the lowest use (Melendez and Fay, 2012). Whether the fuel would be transformed for use as either electricity or heat it is essential to wisely utilize the absolute maximum potential of energy delivered.
Alternative energy resources are often available and abundant in remote areas, but the same isolation that limits delivery of fuel also impedes the harvesting of these resources.

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As a result, utilities normally rely on the basic technologies of diesel electrical generation and oil fired heat. Focusing on the primary utilities of electrical power and sanitation services the opportunity of maximizing the use of this energy becomes essential to maintaining affordable services in the remote arctic.

The complicated challenges associated with providing remote and small scale utilities are not limited to energy, but it is a primary concern. These constraints will be expanded to explore the hypothesis that without a comprehensive approach to thermodynamic intertie between these services long term sustainability cannot be achieved at modern levels. This paper intends to demonstrate through analysis and example that by combining the byproduct heat produced during remote power generation to supply the freeze prevention heat requirements of supplying water and sewer services, utilities can fractionalize the energy required to provide services. Examples of operating systems will be explained for understanding of the basic premise of thermally intertied utilities. Review of current literature and published data will be combined with case studies and examples to recognize the cost of service which is the primary influence on sustainability.

Heat requirements of Sanitation Systems

Sanitation services in the arctic are provided by a variety of means, largely depending on the local environment. Not all communities have the luxury of in-home piped services, and in some communities the service is delivered manually referred to as haul systems. These communities rely on a local team to deliver services at intervals by means of a delivery service. Some communities have a combination of piped service and haul, where either water or sewer is piped into the home, and the other service is delivered manually. The energy requirements likewise vary greatly on the amount of heat required to provide that service.

Regardless of delivery method there will always be a central point of service with heat energy requirements. These heat requirements for arctic utilities vary greatly depending on scale, age and type of service provided. A relative comparison can be seen in Figure 1. This is an averaged comparison of values recorded in communities, and is independent of system size and age. Individual system type calculations are demonstrated by the Equations 1.1 through 3.1. As the system complexity and heat requirement increases, the opportunity for energy optimization likewise grows.

Dividing systems by type provides a basic methodology of calculating anticipated heat requirements. For the water utility, systems have a heat requirement for production, and often storage as well. When this water is distributed by a pipe network the subdivisions of above ground distribution or below ground distribution become logical. Above ground systems are always designed to circulate unless they are a summer only service, while the systems with buried mains may be either circulating or more traditional dead end mains. When piped sewer is provided the same above and below ground categories apply, but subcategories of gravity, vacuum, and low-pressure sewer help divide the types further.

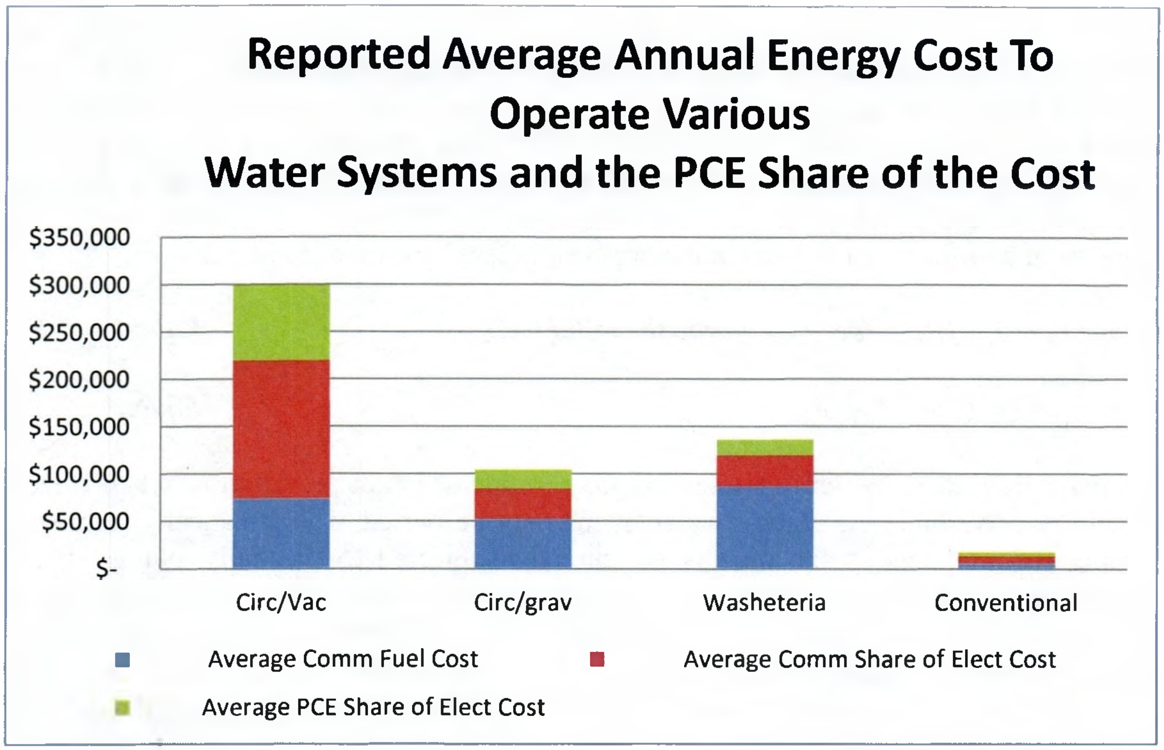

Figure 1. Average Annual Energy Cost by System Type (Reitz et al., 2011).

Surface Circulating Water. In many locations the presence of permafrost or unstable soil prohibits water mains from being buried. In this case, for water to be delivered year round the main must be circulated and heated to prevent freezing. These mains may be insulated independently or together inside of a common carrier known as a utilidor. Heat loss calculations are shown in Equation 1.1 (Smith et al.,1996) for independently heated water mains and in Equation 2.2 (Smith et al., 1996) for the utilidor. Above ground circulating systems require adequate heat addition to ensure that the circulating water returns to the origin with sufficient energy to prevent it from freezing which is dependent on length of the loop and also the environment. These systems are often set to a design day temperature and not modulated to reflect the actual outside temperature. The heating load is the loop, however, loading cannot be determined solely on the losses to the environment as the quantity of water being used or the amount of make-up water required and its storage temperature will also require the addition of heat.

Individually Insulated Pipes. Heat loss in insulated pipe, often referred to as Arctic Pipe can be approximated in Equation 1.1. Where T_W is the temperature of the fluid, water in this case, T_a is the Temperature of air outside of the arctic pip, and R_I is the thermal resistance of the insulation. Thermal resistance of the water film, air film, pipe, and jacket layer are negligible.

$$q = (T_W - T_a)/R_I \qquad \textit{Equation 1.1}$$

Utilidor. Heat loss for a utilidor is variable depending on the configuration, number of pipes, there fluids and temperatures. To find the combined heat loss, heat loss is first calculated for individual pipes using Equation 2.1, Where T_J is the temperature of the particular fluid in a pipe, J=1,2,3..., Where T_U is the temperature inside the utilidor, and R_J is the thermal resistance of the individual pipe which may be individually insulated. Combining the heat transfer will be the total heat loss of the utilidor and is equal to the interstitial space temperature T_U minus the outside air temperature T_a divided by the total resistance of the utilidor R_U shown in Equation 2.2 (Smith et al., 1996). A generic diagram of a utilidor can be seen in the upper right hand corner of Figure 2.

$$q_U = (T_J - T_U)/R_J \quad \textit{(per pipe inside the utilidor)} \qquad \textit{Equation 2.1}$$

$$q_U = \sum_J q_J = (T_U - T_a)/R_U \qquad \textit{Equation 2.2}$$

Buried Circulating Water. In areas where permafrost is not prevalent or when frozen ground is very stable circulating water mains may be buried. This drastically stabilizes heating requirements as the pipe is not directly subjected to the daily swings in air temperature. Although circulating water may be buried in areas with permafrost, this type of system is often used where the majority of the loop can be buried below the surface zone of influence. Equation 3.1 (Smith et al., 1996) is the heat loss calculation for insulated pipe buried inside the zone of influence, but without the added complications of thawed and frozen soil resistances. Where T_W is the temperature of the circulating water, T_S is the surface temperature, R_I and R_G are the thermal resistance of the insulation and ground respectively.

$$q = (T_W - T_S)/(R_I + R_G) \qquad \text{Equation 3.1}$$

Surface Sewer. Surface sewer service is delivered by either vacuum or low pressure. Vacuum sewer may be either individually insulated or it may share a utilidor with a circulating water main, however, a vacuum system will still require a discharge line which must be individually heated and insulated. The alternative to a vacuum system line is the low pressure sewer, which will be individually insulated. Sewer in a utilidor can kept above freezing by its proximity to the circulating water mains. In the case of individual vacuum lines heat must be added indirectly through adjacent hydronic or electric heating as the sewage cannot be heated directly. Electrical resistive heating being economically prohibitive for long runs, the lines are heated by parallel lines circulating an antifreeze like propylene glycol. A diagram of a circulated above ground water and sewer system in a utilidor can is represented in Figure 2. Location at which heat must be added are shown in red.

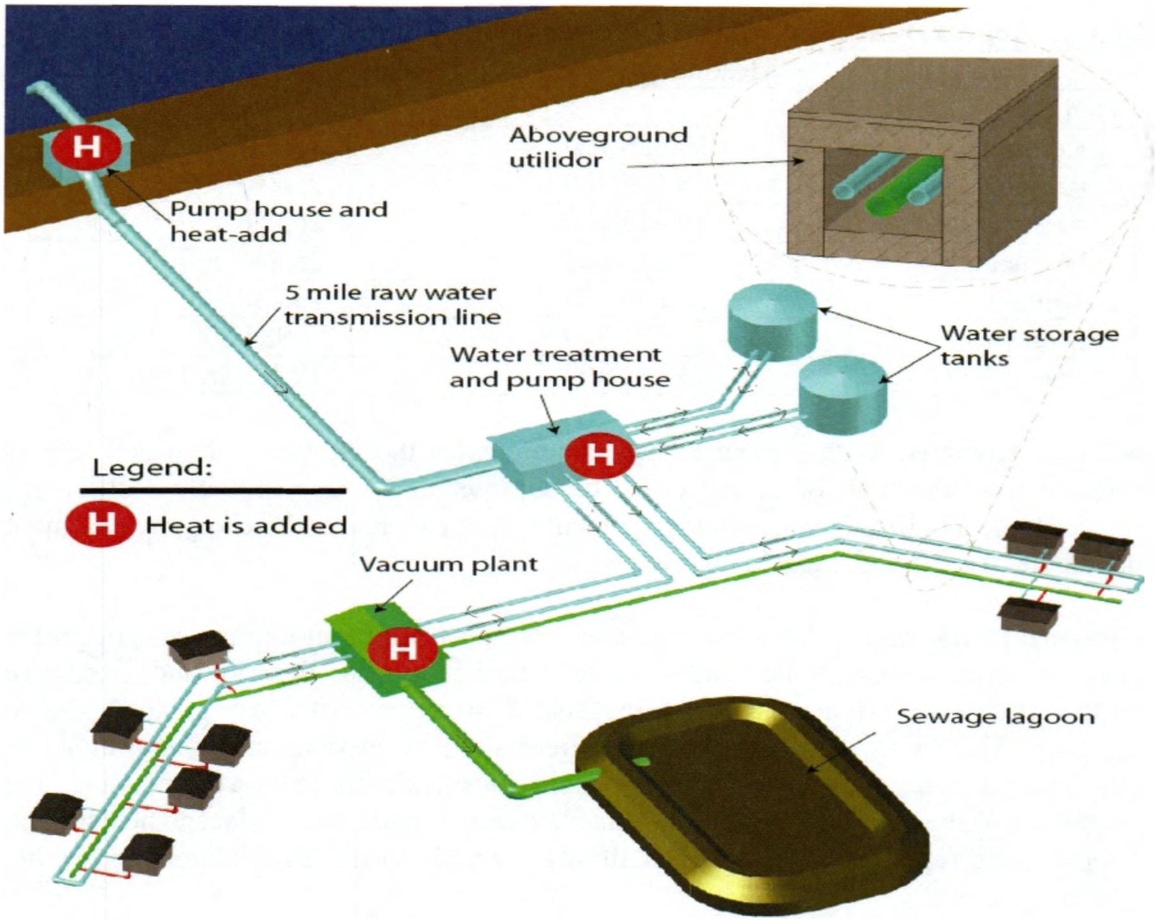

Figure 2. Layout of a vacuum sewer system and circulated water system (Reitz et al., 2011).

Buried Sewer. When possible, buried sewer is preferred to surface systems. These systems may be either vacuum, low pressure, or more traditional systems of gravity lines assisted with lift stations. The heat loss with a buried sewer system is reduced, as such the system requires much less addition of heat. One disadvantage, however, is the added complications of thawing a frozen line, or locating and repairing a leak if it becomes necessary.

Actual Heat from Fuel. A number of inefficiencies reduce the energy that is transferred to the system. Boiler inefficiencies, jacket losses, and hydronic losses all contribute to the quantity of energy extracted from each liter of fuel. Additional complications with operating and maintaining boilers also contribute indirectly to the final cost of extracting this heat from the fuel. Energy values when converted to heat can be found in Table 1 for various fuel types, also shown is the calculated heating value when observed average efficiencies shown in Table 2 are included. Although fuel oil #1 or #2 are typically used in remote utilities, other fuel types are listed for comparison.

Table 1. Approximate Heat values of various fuels (Adapted from Bartok, 2004)

Fuel Type	Heating Energy (J/L)	Heat Energy at 66.7% eff. (J/L)
Fuel Oil		
Kerosene	37,626,700	25,097,000
#2 Fuel Oil	38,602,200	25,747,700
#4 Fuel Oil	40,413,900	26,956,000
#6 Fuel Oil	42,643,600	28,443,300
Gasoline	34,839,500	23,238,000
Natural Gas	10,621,900	7,084,800
Propane	25,781,300	17,196,000

Boiler Efficiencies. With respect to heat requirements the efficiency at which heat is produced from the fuel source must also be considered. As seen in Table 2 efficiency rates for typical boilers in water treatment plants greatly increases the energy requirement and thereby the fuel that must be burned.

Additional inefficiencies also affect the transfer of heat from fuel into the system, jacket losses, system losses, boiler stack losses, boiler cycling losses, and excessive temperatures; these are accounted for in Table 2 by an estimated overall total system efficiency. The values listed are averaged from field evaluations and observations of active systems. These low efficiencies are an obvious detriment to cost of operating, and are additive to the always present cost of maintenance, repairs, and replacement. The sum of these costs represents the total benefit with regards to utilizing alternative heating sources.

Table 2. Average Boiler Test Efficiencies (Adapted from field notes 2009-2014[2])

Region	Average Test Efficiency	Avg. Est. Total System Efficiency
Northwest	72.6%	62.4%
Yukon-Kuskokwim	73.8%	61.7%
South-Central	71.2%	68.2%
Central	76.4%	74.5%
Average	73.75%	66.7%

Heat Available

The heat available for recovery from diesel power plants is often referred to as 'waste heat' because it is a byproduct of electrical generation as the excess is rejected to atmosphere as waste. The amount of energy available for recovery varies depending on a number of factors, primarily engine type, size and electrical loading.

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[2] Boiler tests were conducted during site visits to various Alaska rural water systems, during maintenance work, or while conducting energy audits between October 2009 and September of 2014. To formulate results tests measured carbon dioxide exhaust content and stack temperatures. Only results for typical cast iron boilers were used in the table averages, system efficiencies are estimates based on inspector's observations.

Anticipated Heat. It is convenient that for any given small system electrical loading is somewhat predictable, as such, if there are no major configuration changes within the generation system the heat available will likewise be predictable throughout the normal annual cycle. Compiled manufacturer's predicted heat rejection rates for a sample of typical rural Alaska generators can be seen in Table 3. In an effort to optimize power production efficiencies power plants operate an assortment of generators chosen to handle the cyclical loads that are anticipated. A loading of 80% is shown as this represents an approximate average of engine loading. The limited scale of power production leaves the system with limited options for meeting the demand, and optimum efficiency cannot always be met. Even when the appropriate size generator is installed it may not be available due to maintenance or failure, in which case a larger generator or sometimes two generators must be operated.

Table 3. Heat production by various generators (Manufacture's data[3])

Generator Size Avg. (kW)	80% Loading (kW)	Byproduct heat (kJ/kWh)
160	128	1970
261	209	1520
500	400	1280
1260	1010	2520
1125 (marine Jacket)	900	3150

Quality of Heat. A principal consideration in the feasibility of using byproduct heat is the temperature at which that heat may be delivered to the intended use; this is often referred to as 'quality of heat'. The quality of heat or delivered temperature when compared to the recipient affects the rate and efficiency of heat transfer, and thus the required infrastructure needed to absorb a useable quantity of heat. The source temperature of the byproduct heat combined the distance and insulation values of the transfer line will factor heavily into the ability to deliver an adequate differential temperature when compared to the minimum operating temperature of the receiving system.

Additional Heat. This paper focuses primarily on the heat available from engine coolant jacket heat. It should be recognized, however, that additional heat may be available by capturing the heat from engine exhaust, after cooler heat, and wind turbine dump loads. If installed, the anticipated addition of heat should be considered in the economic feasibility. If these are not in place, then the benefit would need to be analyzed independently and is beyond the scope of this paper.

Competition for Heat. In some instances there may be multiple competing interests in the recovered heat available. Even though the availability of low cost heat, with relatively small maintenance requirements is highly valued, a number of factors often limit its feasibility. An intended user of recovered heat must be able to accept low temperature heat on an unpredictable schedule, must have a use near the source, and must have sufficient demand to justify the capital costs of installing a system. Once installed the

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[3] Heat rejection rates averaged from the most common generator types operating in Alaska. Values used in the calculation were compiled by the Alaska Energy Authority from manufacturers published estimates.

user must also consider the resources required to insure the long-term function of the system.

While competition for heat may be limited by energy available, it shouldn't necessarily be viewed as a detriment to a proposed system. In some cases the combined loading of multiple facilities may justify the capital costs required for a project. In addition multiply parties with a common interest in harvesting this energy may also better provide for the technical assistance and maintenance required to keep the system operational for all parties. Schools are the largest single facility, or facility complexes in small Alaskan communities. Their size and heavy use also requires a great deal of heat energy, and can be a major heat load for a recovered heat system, either independently or when combined with service to a sanitation utility.

How the system works

Recovering byproduct heat is a relatively basic process. Although the mechanisms may vary, the principle concept is to divert the energy carrying fluid to the recovery unit before it is passed through the heat exchanger which would otherwise eject the heat to the environment, typically the air. The primary source of recoverable heat from generators is the engine jacket cooling fluid either directly or a from a secondary coolant fluid passing a secondary loop heat exchanger. An example of a heat exchanger plumbed in series with a secondary coolant loop is shown in Figure 3; the plate-and-frame heat exchanger is at the bottom of the photo. The secondary coolant loop is running horizontally along the wall, with the heat exchanger connections and servicing bypass valves shown in the corner of the room. Additional heat can be extracted from exhaust gases, but this heat is typically combined with a secondary cooling system, where it can be extracted as part of the primary jacket heat capture.

Thermostatic controls. Various control mechanisms are implemented in controlling the excess heat generated by small scale power plants in the arctic. They range in complexity depending on the design and size of the plant. The most basic systems are controlled similar to way that diesel driven heavy equipment is regulated, where the mechanical thermostat inside the engine regulates coolant flow to a radiator in order to maintain a targeted engine temperature. Most systems except for the smallest will also implement fan controls on the radiators to control the airflow across the radiators or even modulate airflow to maintain a desired coolant return temperature.

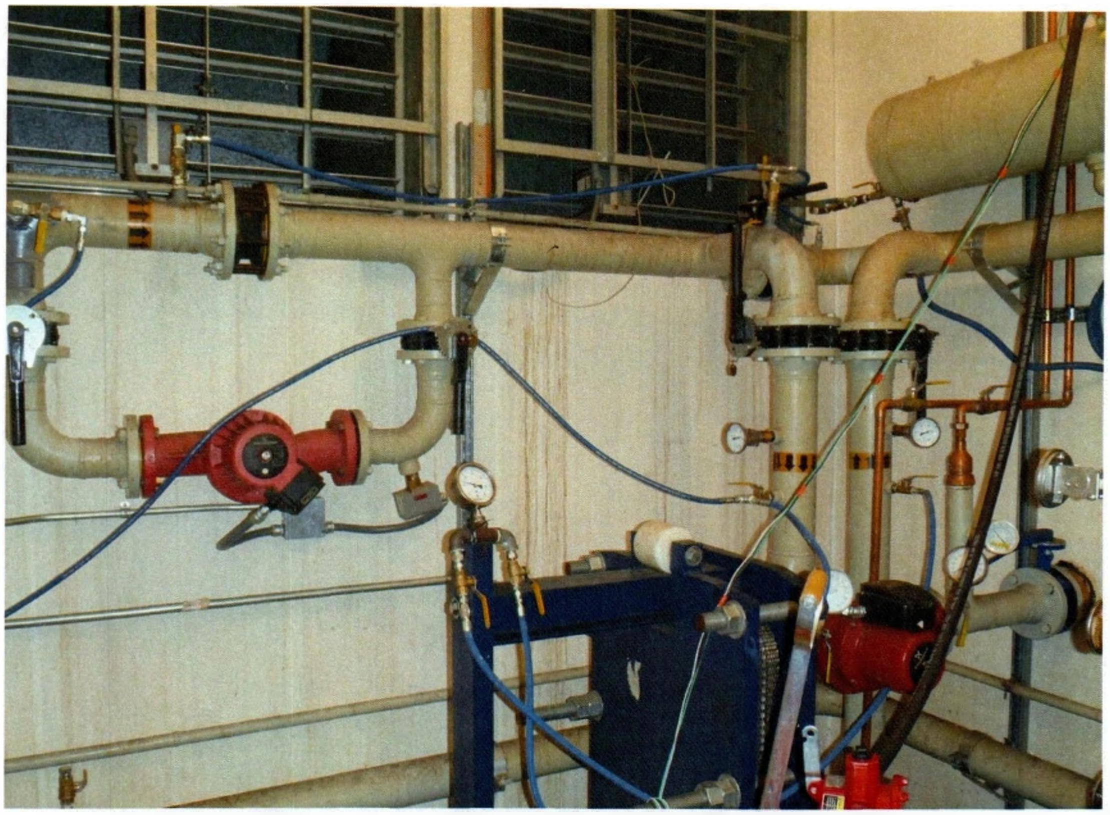

Figure 3. Basic Secondary Coolant Loop Tie-in

The majority of small community diesel generation systems in the arctic employ multiple generators with a combined secondary coolant loop. The temperature of this loop can be regulated in a variety of ways to maintain the desired temperature inside the secondary loop. One option is mechanical thermostatic control, shown in Figure 4, this is a simple devise that operates at a factory-set temperature by opening a bypass valve and redirecting flow when the target temperature is reached. Other systems operate by redirecting flow by use of valves connected to carefully controlled actuators. This provides much more precise temperature control, but also adds additional complication in geographical regions where technical support may be limited.

Byproduct heat when sold like any other commodity incentivizes the capture of this heat rather than expelling it to atmosphere. Generating profit justifies better thermostatic control and less waste through poor insulation and excessive facility heating.

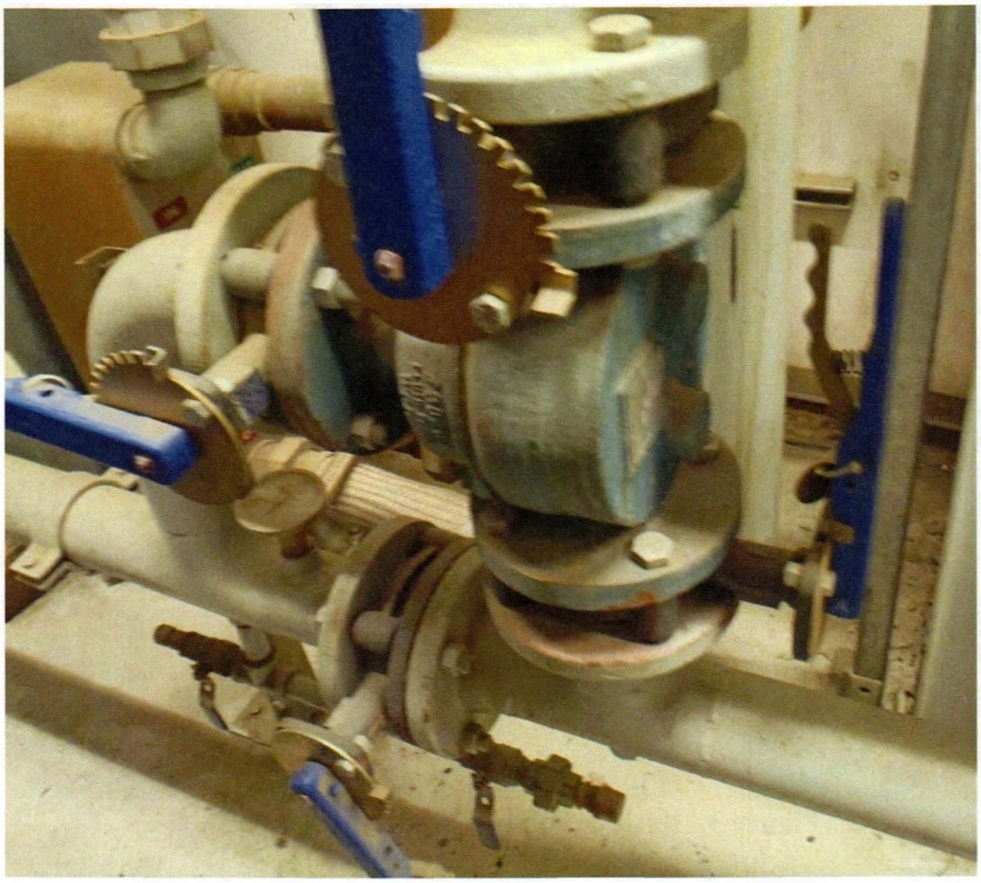

Figure 4. Mechanical Thermostatic Valve and Piping

Integration. Larger facilities may justify more complicated control strategies and interfaces. Figure 5 shows a heat recovery system connected to the secondary coolant loop of a power plant. This system controls the heat from each of four generators by motor actuated control valves and then passes the secondary coolant through a wind boiler dump load. The control panel shown lower left maintains the secondary loop temperature by control of the pump shown lower center in order to ensure adequate heat for facility use and engine pre-heating needs. Excess heat is sent the heat exchanger in the lower left corner for transfer to the community's water and sewer facility.

Sanitation Utilities' Capacity to Use Recovered Heat

Utilization of recovered heat is a factor of proximity and heating needs. In theory any load is capable of utilizing recovered heat, but to justify the infrastructure necessary to deliver that heat there must be an adequate load within feasible distance from the heat source. Water treatment systems and sewage treatment facilities are ideally suited to absorb large quantities of low quality heat. This is due to the heating required to keep large quantities of water and sewage from freezing. While this represents a large heating load, the temperatures required are relatively low when compared to the cooling system temperatures of a power plant.

Figure 5. Heat Recovery System Savoonga, Alaska.

Proximity. Ideally the sanitation utilities would be adjacent the power generation, or even combined into a single facility. As with any circulated hydronic system in the arctic heat loss to the environment is critically important. The high differential temperatures of the transfer fluid when compared to the low ambient temperatures of outside air greatly increase heat loss. Distances beyond a few hundred meters require insulation thicknesses that stress the economic viability of initial system installation for direct hydronic transfer.

Alternative Delivery. With circulated water systems it is sometimes also possible to use potable water as the transfer medium to deliver heat to other portions of the system. This was accomplished recently in Sleetmute Alaska. Although the power generation occurs nearly 900 meters from the water treatment facility the circulated main was only a few meters from the power plant. Figure 6 shows the simplicity of the system. A portion of the water passing through the nearby main is pumped through a double-walled heat exchanger inside power plant. All system operating parameters are maintained by the electronic controller which can be seen in the photo. The controller modulates the orange colored control valve to its right, and operates the pump shown lower right.

Figure 6. Heat Recovery System Sleetmute, Alaska.

Economic Viability. Economic viability for sanitation services in remote parts of the arctic rely heavily on the ability to provide service at affordable levels. As reviewed in the discussion of heat requirements the level of service is dependent on technical factors and also the ability to afford the level of service chosen. More complex systems providing higher levels of service will require more energy input assuming that other design parameters remain the same. Sanitation systems that employ recovered heat into their operational strategy will reduce cost which makes the opportunity for higher levels of service feasible.

Case Studies

Although the basic principles of heat recovery systems are straight forward there are many examples of how systems have failed to operate due to lack of either operational understanding or appropriate technical support. Failure to recognize the economic impact of these system leads to complacency about their operation. Simplicity is of vital importance to making heat recovery systems retain their utility in remote communities. Technical or engineering support in remote areas is limited, as such, any system installed must characteristically be easy to understand and maintain.

Where technical support may be available for these systems its need must also be recognized. When there is a failure to understand the thermodynamic potential of overlapping public utilities and more directly the economic benefit, there is a lack of importance placed on this particular part of a large utility system.

Toksook Bay. The community of Toksook Bay, Alaska demonstrates the need for technical assistance for remote communities. In 2007 a heat recovery system was installed and started providing limited heat to the water treatment plant. Unfortunately, the system had faulty wiring and the system failed to perform at its potential. 2012 the problem was identified and the repairs made. The resulting energy savings from this activity were 66% of fuel consumption for the following year. These saving translate directly to the sustainability of the system. The savings allow for reduced rates and for the managers to accumulate funds necessary for long term replacement and repair costs in the system.

Deering. The community of Deering Alaska is in western Alaska, 215 km northeast of Nome Alaska. Water is pumped to two water storage tanks during a short period in summer for use the remainder of the year. There is no piped distribution; instead the individual homes receive water via a haul system, where a tank trailer is pulled with and all-terrain-vehicle to delivered water to small storage tanks in homes holding approximately 200 l. The combined utilities facility contains the water treatment plant, Power plant, and Washeteria. Washeterias are a community service facility that provides public use of washers, dryers, showers, restrooms, and saunas. Deering's Washeteria contains 8 washers, 5 dryers, and two combined shower/restrooms. Of these services, the dryers represent the largest load on the combined facility's heating system.

The Deering water plant is in a combined facility and is a model for overlapping utility resources. Problems with the system also exemplify why technical oversight is critical to the success and sustainability of these systems. The facility was designed and built with a heat recovery system installed. However, the heat recovery system was poorly controlled and was shut down when there were indications of heat being back-fed to the power plant. This condition occurs when heat being produced by the boiler system is transferred to the cooling system of the generators, and then to the radiators. As a result of the back-feed indications the system was shut down, boilers were used to provide all heating needs for the water treatment plant and washeteria, while the radiators on the generator coolant loop provided engine cooling.

Deering's heat recovery system was successfully renovated in 2012 by addition of simple controls and a pump. After the repairs heating fuel required at the combined facility was reduced by 3,100 l per winter month representing an 85% savings of the combined facility's boiler use. The simple controller seen on the left center of Figure 7, and the pump to the right allowed for more accurate control of the heat flow between the two systems, and prevented the undesirable transfer of heat from the boiler system to the cooling system.

Figure 7. Example of a simple boiler tie-in Deering, Alaska.

Minto. The community of Minto Alaska is in north central Alaska, 80 km northwest of Fairbanks Alaska. The water system is circulating water with gravity sewer. The Minto water treatment shares a wall with the community's power plant. The excess heat produced by the power plant was designed to go into a standard radiator configuration at the very right edge of Figure 8, also shown is the insulation added to prevent unnecessary heat loss form the radiator piping which was installed in open air with the radiators. In 2011 a heat recovery was installed eliminating the need for heating fuel to be burned within the plant to heat the storage tank, circulating loops, or facility.

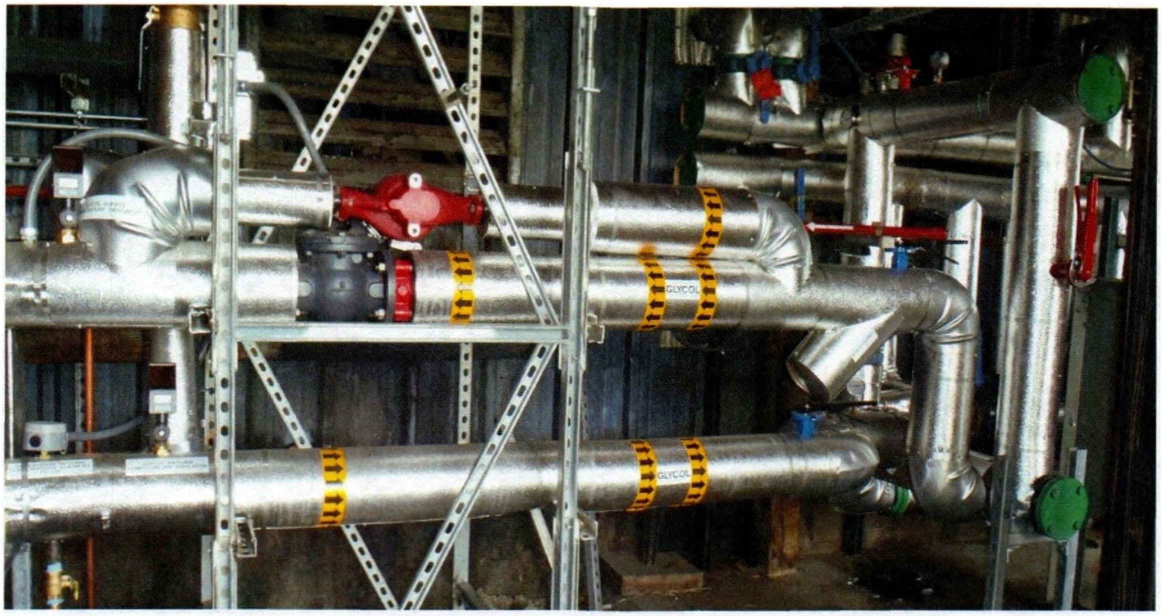

Figure 8. Insulated heat recovery piping Minto, Alaska.

Kotlik. The community of Kotlik, Alaska lies on the outlet of the Yukon River on the Yukon-Kuskokwim Delta. The community's heat recovery system delivered heat to the water treatment plant which in turn provided heat to the facility, water storage tank, and circulating water main and vacuum sewer utilidor. The system was never properly commissioned, and as a result the system was shut down because of a lack of understanding of the complicated and constant manual adjustments required. In January of 2013 the system was renovated, and the need to burn fuel oil for normal operations was eliminated. Since that time the facility has burned no fuel for heating needs. The savings translates directly to sustainability, as the collected revenues can be reserved for replacement parts and supplies.

Kotlik is a good example of the need for simplistic systems. The required upgrade is shown in Figure 9. The system was re-commissioned using a basic three way valve shown diverting flow through heat exchanger inside the box in the bottom right corner. The controller mounted to the wall (out of view) controls the flow based on system parameters including system temperature, and heat supply temperatures.

Figure 9. Recovered Heat Upgrades Kotlik, Alaska.

Monitoring. A key element in the continued success of these systems is the recognition of divergence from operational expectations. This can be observed indirectly over the long term as a result of monitoring fuel consumption, but oversight by someone familiar with the systems operations and the potential system capacity can quickly identify problems. Heat sales incentivize monitoring, as there is also the indirect opportunity to recognize problems in the form of decreased revenue on the part of the supplier, or the decreasing bills on the part of the user before excess fuel use is evident.

Calculated Thermal Overlap

By graphically comparing the available thermal resource of byproduct heat with the estimated thermal load of a utility, the fuel savings potential becomes apparent. Figure 10 is an example of the analysis for a north-west Alaska water system and power plant. The blue area represents the calculated thermal load on the system using historical data for heating degree days. As might be expected the demand is highest in winter months, and lower in summer. This application assumes a washeteria with dryer facilities, which is represented by the significant heating load even in summer when temperatures are warmer. Also shown is the anticipated production of byproduct heat of a generator with a marine jacket. Generator loading drops in summer months due to less electrical use, and with the decline the available heat also decreases. The portion between the two curves above the available heat curve would be the anticipated heating demand on the water utility's boiler system.

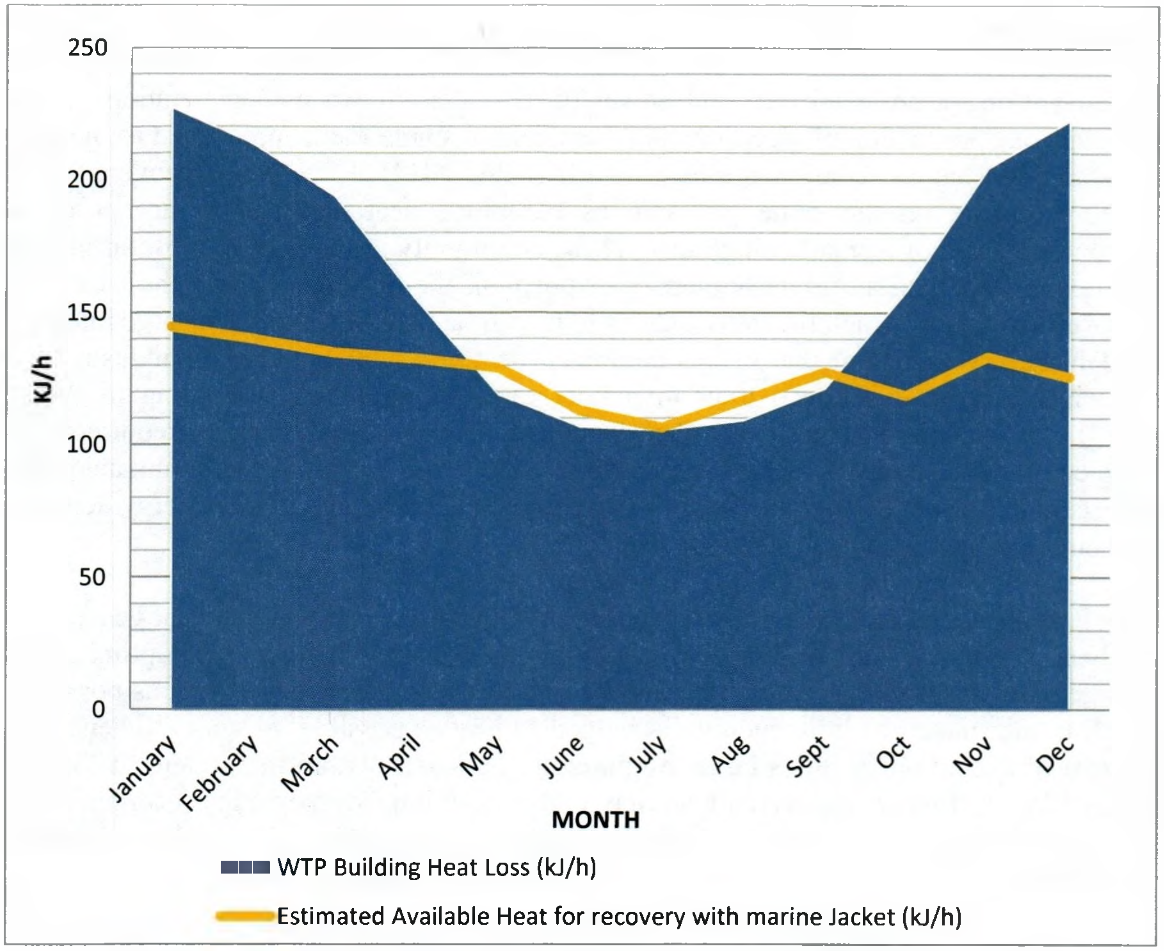

Figure 10. Example of Comparative Heat Produced and Consumed.

Analysis. This calculated overlap of thermal byproduct potential with utility demands is valuable for determining the potential economic benefit of a proposed system. The anticipated savings in heating fuel can then be used as justification for project funding. The analysis also directs attention to time periods when other efficiency measures might be most beneficial focusing on heating loads beyond recovered heat potential. An additional justification from this analysis might also be in the form of retro-fit of facility boiler systems. With the addition of recovered heat, the new heating system demand will be much lower; addition of a boiler to cover this smaller load will produce the heat required within the range of optimal efficiency.

This analysis, while valuable, requires many assumptions. The availability of observed heat usage and rejection, along with better understanding of a systems operational condition will improve the reliability of analysis results. As evident in case studies heat recovery systems connecting a sanitation utility to a nearby power plant often adequately provide all the heat required. This might be a result of variances in assumptions and actual system performance, or could also be a result of operational changes made locally in an effort to capitalize on available recovered heat.

Cogeneration

Cogeneration. Combined heat and power (CHP), also known as cogeneration, is the simultaneous production of electricity and heat from a single fuel source, such as: natural gas, biomass, biogas, coal, waste heat, or oil (EPA, 2014). Effectively recovered heat systems operate on the same principle as combined heat and power; accept on a distribution scale of a small community. These community systems have a footprint that is often smaller than an urban university or hospital, the difference being the lack of a larger utility grid in which the individual utilities can be tied. Without these large interties available every argument that makes combined heat and power viable for industrial or municipal complexes is even truer in remote rural communities. According to Wong (2014) the system efficiency for the combined electrical and heating requirements produced independently is 47%, as opposed to 85% when the produced simultaneously. The economic benefit of cogeneration is carefully studied, the greater the energy demand the better efficiencies can be accomplished.

Overlapping benefits. A carefully balanced combined system; balancing heat generation and heat requirements are optimized by targeting efficiencies on either side. Optimization is targeted by electrical producers to achieve as much power per liter of fuel as possible, which in turn means as little energy discharged as heat as possible. System efficiency on the part of sanitation facilities target minimizing the losses within the system. Although an abundance of cheap recovered heat may make these improvements less economically viable, dependence on recovered heat could be devastating if the heat became unavailable.

Economics and Sustainability

The primary measure of a system's sustainability is the ability to generate revenues adequate to support a systems operational, equipment replacement costs, and major repairs and upgrades. This is true for either a power generator or a sanitation system. Critical to the economics of either is finding efficiencies where ever possible.

Figure 11 shows as sampling of remote Alaskan communities' sanitation costs by relative percentage. Labor and Energy represent the greatest portion of cost associated with Water and Sewer utility costs. Labor costs tend to be a fixed requirement with marginal variations due to operator turn over and emergency repairs. Energy costs are, however, tied directly to operational efficiencies. Although the graph in Figure 11 includes the cost of electricity with energy the largest expense is the cost of Heating Fuel. Efficiencies in the operations of a sanitation facility can reduce the demand for heat, but taking advantage of recovered heat can greatly impact the overall cost of operating a sanitation facility.

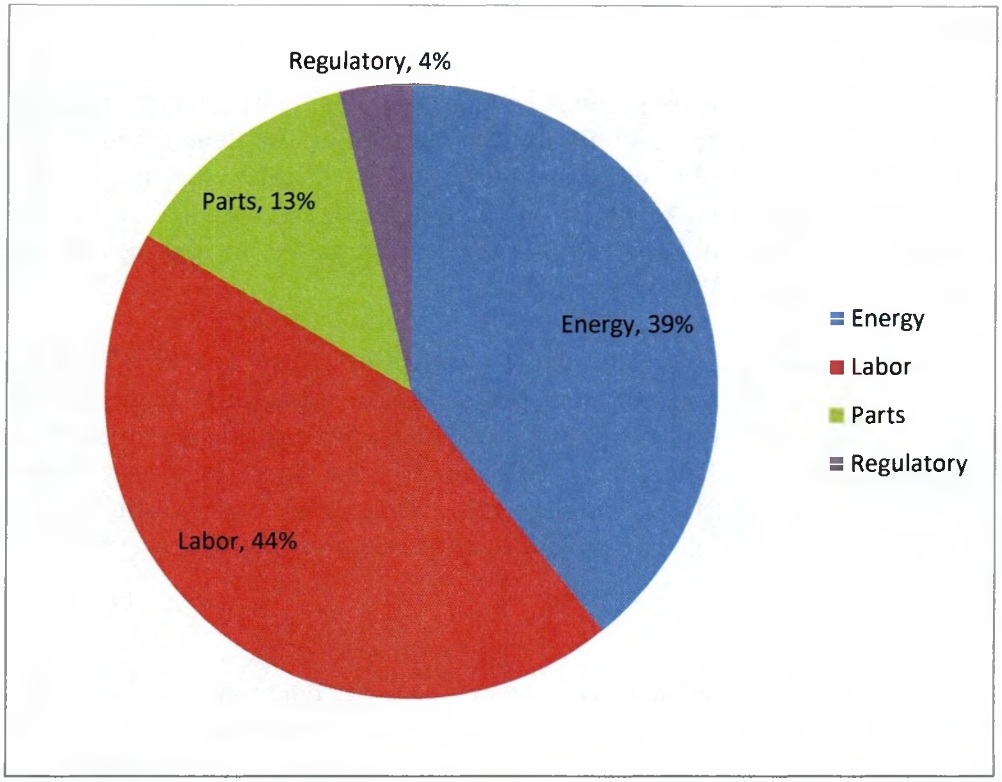

Figure 11. Proportion of Arctic Sanitation System Expense (Nichols et al., 2013).

Reducing overall costs should first look at minimizing heat use. Assuming that heat loss in a utility system has already been minimized as much as possible the next step is to reduce the cost of the heat which is necessary. When recovered heat is available to the sanitation system in a small community the heating requirement, when properly managed, can effectively be carried by typical byproduct heat of electrical generation. This heat might be from a common utility manager and not charged for directly, or could be sold by a separate entity through a purchase agreement. Sales rate structures vary, but a common formula is 50% of cost the displaced heating value of fuel. Assuming an optimistic fuel to heat production efficiency of 75% the realized savings to the utility would be 62% of fuel cost. Additional savings are gained through deferred stress on heating equipment, and associated maintenance activities.

Cost of Service. The complications of operating sanitation services lend directly to the cost to operate those systems, Figure 1 shows the relative cost of the main system types in Northern Alaska. Although the graph does not account for number of services or the geographical spread of the systems, the relative comparison is valid on an averaged basis. This can be compared to Figure 11 and the electrical proportion of expense can be seen with heating fuel being significant in all system types.

Recommendations

Power plant heat recovery systems have been proven to be effective in a variety of situations to include their use in small arctic communities. As demonstrated; locations with the infrastructure located in close enough proximity to each other harness the most advantage of maximizing the potential of energy delivered. To capitalize on this the value thermal interties must be recognized at key opportunities in the development of community planning and facility location choosing.

It is also important to consider the total effect of energy delivery. Heat recovery has the added benefits of more efficient power plant cooling, and reduced load from cooling fans. Further analysis is warranted to calculate the compounding energy savings of not running generator fans, more efficient cooling, combined cost of deferred maintenance, and the effects of implementing renewable energy sources. This is especially critical during the planning phase of major renovations or new systems.

Conclusion

The level of service for sanitation services in remote arctic communities is directly tied to the ability of the system to keep heating requirements at economically viable levels. Even at optimum operating states the cost of producing heat at level required to provide modern in home plumbing may be unsustainable if oil-fired boilers are the only available heating source. Economic viability may only come in the form of co-location of wasted heating sources, and the carefully planned overlap of the energy delivered to a community.

Focusing on the sustainability of modern levels of utility service, the correlation between economic viability and affordable heat production has been clearly examined. The availability of byproduct heat should always be of great interest to any heat producers within proximity to this thermal opportunity that is commonly wasted. It has likewise been demonstrated that sanitation utilities often have a great need for heat in the arctic, but their overall sustainability is a factor of many diverse variables. It cannot be said, however, that sanitation levels are dependent on anything except levels of resources available. Reflecting on this information it can be said that the level of service and the economic feasibility of sanitation systems are greatly improved by the overlap with power generation facilities.

The demonstrated benefits suggest through documented examples that thermal management becomes more critical as isolation increases and accessibility decreases for arctic communities. Overlapping thermal management is essential to maintain economic viability and levels of service are heavily tied to adequate funding. It is unlikely that resources will be sustained at levels able to keep up with current and increasing energy demands. This leaves only the option to capitalize on available heat, consume much less, produce required heat and power with much more economical means, or a combination thereof.

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References

Bartok, J.W. (2004). *Approximate Heating Value of Common Fuels.* University of Connecticut. Storrs, CT.

Environmental Protection Agency Website. (2014). website: http://www.epa.gov/chp/basic/ Accessed : 13 Nov 2014.

Smith, D.W., Ryan, W.L., Christensen V., Crum, J., and Heinke, G.W. (1996). "Cold Regions utilities monograph, third edition." American Society of Civil Engineers and the Society of Canadian Civil Engineers. New York, NY.

Nichols, J.P., Reitz, D., and Mercer, C.J. (2013). *Energy Solutions for Rural Alaska Water Systems,* The Military Engineer. No.686., Nov-Dec. Society of American Military Engineers. Prince St. Alexandria, VA.

Melendez, A.V. and Fay, G. (2012). *Energizing Alaska: Electricity around the State.* Research Summary No.73. Institute of Social and Economic Research, University of Alaska Anchorage. Anchorage, AK.

Reitz, D., Ronimus, A., Remley, C., and Black, E. *Energy Use and Costs for Sanitation Facilities in Rural Alaska a Survey (2011).* Alaska Native Tribal Health Consortium Division of Environmental Health and Engineering. Website : http://www.anthctoday.org/dehe/documents/Latest%20Energy_Use_and_Costs_for_Rural_Alaska_Sanitation_Facilities__A_Survey.pdf. Accessed: 17 Nov 2014.

Wong, J. B. (2012). *Distributed Generation and Alternative Energy*, Strategic Planning for Energy and the Environment. Vol.32, No.2., Liburn, GA.