Universität für Bodenkultur Wien

University of Natural Resources and Life Sciences, Vienna

Department of Water, Atmosphere and Environment

Institute of Sanitary Engineering and Water Pollution Control

CONCEPT DESIGN FOR A BIOCHAR SANITATION SYSTEM IN KIVALINA, ALASKA

Master thesis

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THERESA THEURETZBACHER

Supervisor: Priv.-Doz. DI Dr. GÜNTER LANGERGRABER

Student number 0740225

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Abstract

Residential homes in Kivalina, an Inupiat village located on a barrier island in Alaska north of the Arctic Circle, lack toilets and running water. Residents use honey buckets (paint buckets lined with plastic trash bags) as toilet replacement to collect human waste.

A concept design for a sanitation system that converts human solid waste into biochar will address these issues. The various infrastructural, climatic, economic, environmental, and social contexts were researched to ensure an appropriate infrastructure for the future biochar sanitation system in Kivalina.

To collect information on-site about the community village sanitation rapid rural appraisal (RRA) and participatory rural appraisal (PRA) as methodologies were applied. The survey data was analyzed statistically, numerically and graphically.

Two installation types of the UDDT (Urine Diverting Dry Toilet) model Villa 9210, an under-floor collection system (37 houses) for houses on piles and an in-home collection system (48 houses) where the feces are collected in the toilet, were introduced in Kivalina. The final design of the under-floor collection chamber was kept simple with minimizing moving parts and with the requirement to be easy to maintain and to repair. A pilot toilet installation was successful. Monitoring showed that minor adaptions on the toilet interface and the heat trace have to be implemented.

In summary, the current hauling system is socially not fair; wealthier families have to pay less than poorer families. The total operational costs of the proposed biochar sanitation system shows an increase of user fee per month of 61 % in comparison with the current system but offers a better performance. Compared with sewer and technical wastewater treatment plants the biochar sanitation system shows with US$ 4,820 per household low total capital costs.

The proposed biochar sanitation system provides a host of important community benefits to Kivalina. Reduced handling and open storage of human feces will decrease rates of waterborne diseases and the contamination of aqueous and terrestrial habitats. Further, it will decrease the need for additional village infrastructure and individual investments.

Kurzfassung

Das typische Wohnhaus in Kivalina, einem Dorf auf einer vorgelagerten Halbinsel in Alaska, nördlich des Polarkreises, hat kein fließendes Wasser und daher auch keine Spültoiletten. Die Bewohner benützen „honey buckets“ (Farbeimer mit einem Müllsack) als Toilettenersatz, der täglich gelehrt werden muss.

Im Rahmen der Masterarbeit wurde ein Konzept für ein Sanitärsystem mitentwickelt, das mit Hilfe von UDDTs (Urine Diversion Dry Toilets) Fäkalien sammelt und daraus in einem Reaktor Biokohle herstellt. Dadurch können die gesundheitlichen und ökoligischen Probleme eliminiert werden, die mit der Benützung von “honey buckets“ einhergehen. Die verschiedenen infrastrukturellen, klimatischen, sozialen und ökonomischen Aspekte in welche das System implementiert wird, wurden recherchiert und analysiert.

Rapid Rural Appraisal (RRA) und Participatory Rural Appraisal (PRA) sind Methoden, die verwendet wurden, um Informationen zur Abwasserentsorgung vor Ort zu sammeln. Die Umfragedaten wurden statistisch, numerisch und grafisch ausgewertet.

Zwei Installationsarten des ausgewählten UDDT Modells Villa 9210 wurden in Kivalina vorgestellt. Ein Außer-Haus-Sammelsystem (37 Häuser) für Häuser auf Pfählen und ein Im-Haus-Sammelsystem (48 Häuser), indem die Fäkalien direkt in der Toilette gesammelt werden. Für die Planung der Außer-Haus-Sammelkammer wurde auf klimatische Bedingungen einfache Wartung, Benutzerfreundlichkeit und einer Sammelkapazität von 110 Tagen geachtet.

Das aktuelle Entsorgungssystem von “honey bucket“ Müll ist sozial ungerecht, wohlhabende Familien müssen weniger als arme Familien zahlen. Die gesamten Betriebskosten des vorgeschlagenen Sanitärkonzeptes sind um 61 % höher als die Betriebskosten des derzeitigen Systems. Zusätzlich bietet das Sanitärkonzept jedoch eine angemessene Sammlung und Entsorgung von Fäkalien. Im Vergleich zu konventionellen Systemen zur Behandlung von Abwässern, sind die Investkosten des entwickelten Sanitärkonzeptes mitUS$ 4820 pro Haushalt sehr gering.

Zu den Vorteilen des entwickelten Sanitärsystems zählen, die Eliminierung der offenen Lagerung von Fäkalien und das Hantieren damit, die Kontamination von Lebensräumen und eine komfortablere und hygienischere Toilettenbenützung. In den USA sollte jedem Haushalt der Zugang zu sicherer Abwasserentsorgung gewährleistet sein.

1. Introduction

Kivalina is an Inupiat village 134 km (83 mi) north of the Arctic Circle in Northwest Arctic Borough, Alaska, United Stated and 129 km (80 mi) northwest of Kotzebue. The coastal village is situated at the southern tip of a barrier island located between the Chukchi Sea and a lagoon at the mouth of the Wulik and the Kivalina River as shown in figure 1.

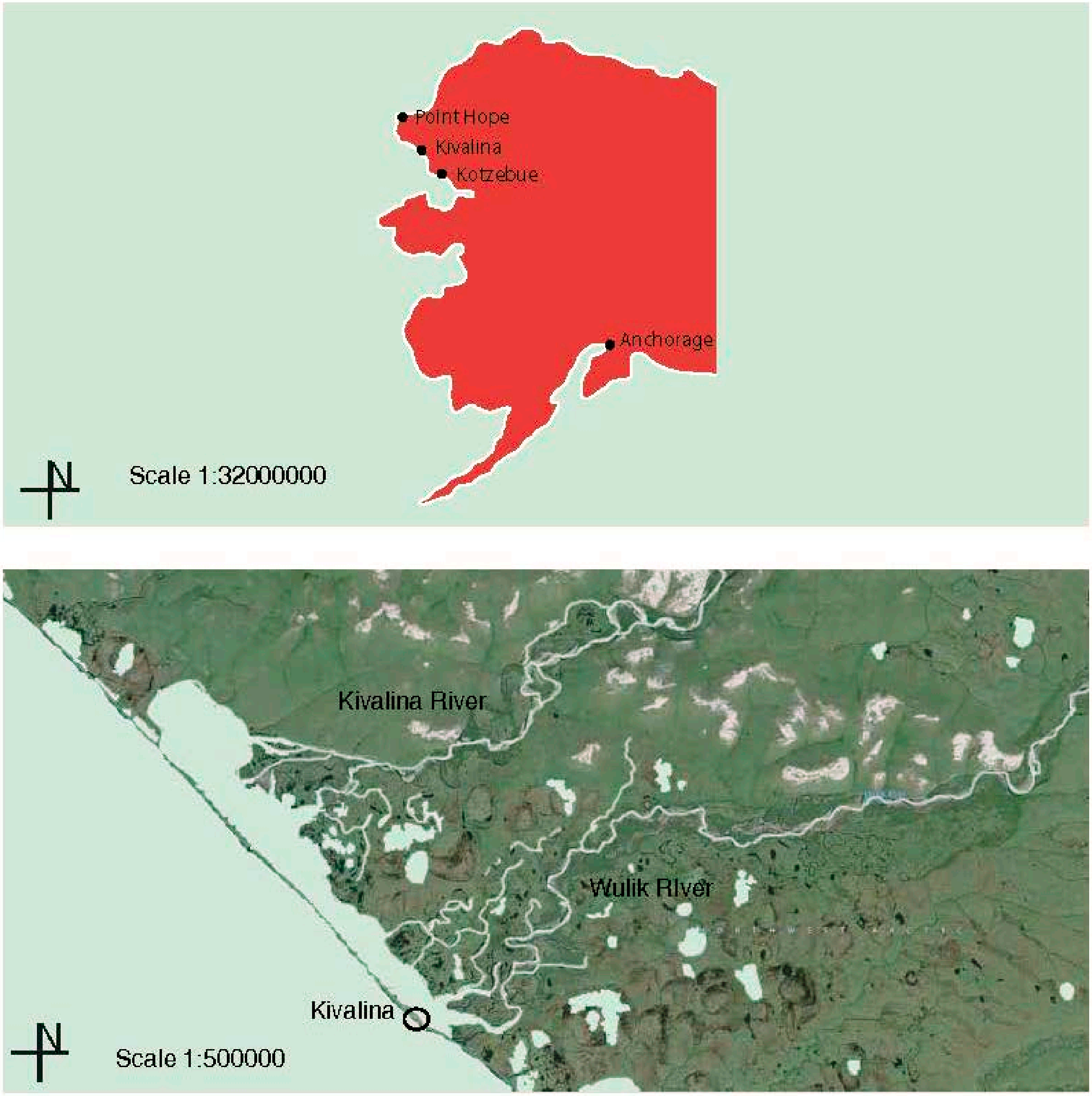

Figure 1: Location of Kivalina

Kivalina is threatened by the impacts of climate change and is facing re-location. Due to late forming sea ice, which protects the village from violent fall storms, the village is increasingly vulnerable to wave action and flood events. Rates of erosion are dramatic (while the historic extent of the Kivalina region comprised thousands of acres, coastal erosion has reduced Kivalina's current surface area from 22 ha (54 ac) to less than 11 ha (27 ac) (Gray, 2010).

Residential homes in Kivalina lack flush toilets and running water. People use honey buckets (paint buckets lined with plastic trash bags and covered with portable seats) to store and haul human waste. Kivalina is not a unique case in rural Alaska native villages. More than a third (38.79 %) of households are lacking complete plumbing (Gasteyer and Vaswani, 2004).

Former efforts by State agencies to implement hauling systems or wastewater treatment facilities have failed. The Arctic climatic conditions, high energy costs and the remote area makes construction and operation of piped systems too expensive for the households. Furthermore, plans to relocate the village have led to limited investment in basic water and sewer services over the past 20 years.

Inadequate access to water and wastewater management threatens human health and was the catalyst to start a new approach to combat the difficult challenges in the Arctic wastewater management.

2. Objectives

The Climate Foundation (developed biochar reactors for human solid waste) and Re-Locate Kivalina (multidisciplinary NGO working with Kivalina as an auxiliary governmental relocation agency) received the “2013-15 North American Partnership on Environmental Community Action grant” to develop a concept design for a biochar sanitation system in Kivalina. The sanitation system collects human solid waste from liquid waste separately whereby human solid waste is converted into biochar. This system will be an off-grid flexible and movable way to sanitize human solid waste and use the end product as a resource.

The master thesis “Concept Design of a Biochar Sanitation System in Kivalina, Alaska” was generated within this project. The focus within the thesis was put on researching existing UDDTs suitable for Kivalina and for its adaptability to Arctic climates, on local waste management economics, on commercial feasibility and on possible future uses of the biochar in Kivalina.

The various architectural, infrastructural, economic, environmental, and social contexts into which the infrastructure needed for the biochar sanitation system will be placed in Kivalina was researched within two field trips. The aim of the first field trip in July 2013 was to conduct basic information about Kivalina’s water and wastewater infrastructure and usage. The second field trip in September 2014 intended to verify and improve the concept feasibility on-site.

The feasibility study comprises planning considerations consisting of a winterization study and a community layout, which gave comprehensive basic planning information in form of an architectural building survey. The goal of the winterization study was to adapt the required infrastructural components of the developed toilet facility to the Arctic climate.

The aim of describing and developing installation details including specifications on the chosen UDDT, collection chamber and a pilot trial was to show the operability and functioning in Kivalina.

Furthermore the goal was to determine and compare local waste management economics of the different sanitation utility steps (collection, emptying, transport) containing time effort, costs and social pattern, to be able to implement well-functioning aspects of the current system in a future waste hauling system.

Also an important objective of the thesis was the conduction of a commercial feasibility study where the proposed biochar sanitation system was divided into the system areas UDDT, hauling and the biochar reactor to summarize the overall affordability of the project and to compare it with the current system.

To complement the objectives, possible uses of biochar in Kivalina were identified.

The objectives of the thesis can be summarized as follows:

Main objective:

- Support developing a biochar sanitations system for Kivalina to ensure safe access to sanitation

Specific objectives

- Spatial and climatic planning considerations
- General and specific installation details for the under-floor und in-home collection model
- Local waste management economics
- Financial analysis of the sanitation system (toilets, hauling systems and biochar reactor)
- Possible uses of the biochar in Kivalina

3. Fundamentals

3.1 Water and Sanitation Basics of Kivalina

Information about basic water and sanitation usage in Kivalina was collected during the first field trip in July 2013.

To compile basic information before the start of the main project the source, supply, consumption and disposal of water and wastewater, standardized interviews with villagers were performed. The questionnaire was designed in a way that it was possible for the interviewee to give all the needed information while filling up their water buckets, which, on average, takes two minutes.

Water

The public water system in Kivalina consists of two water tanks with a storage capacity of 2,650 m³ (700.000 gal) for the raw water tank and 1,893 m³ (500.000 gal) for the treated water tank. Kivalina is operating on a "fill and draw" system, which means that the tanks are filled up once a year in summer (July-August). In order to fill the tanks, water is pumped out of the Wulik River with a pumping rate of 37.854 l (10.000 gal) per hour. During filling, the pump, which is located on a boat, operates day and night. The pump is equipped with an additional external gas tank with a capacity of 12 gal, to decrease the re-filling frequency to every 10 hours. The water is then transported via flexible hoses into the raw water tank. The hose segment throughout the lagoon has to be brought out every year for pumping. The hose segment located on mainland stays there throughout the year; however it is very vulnerable to leaks. The water in the raw water tank is treated with a multi-layer-sand-filter and two bag filters before it gets disinfected with chlorine and stored in the treated water tank. The chlorine concentration and the turbidity are measured on a daily base during pumping.

The residents of Kivalina are not connected to a piped water supply system and have to haul the water at a hose between the washeteria and the treated water tank. The coin-operated payment station is broken. The school is hooked up to a piped water supply system.

The price varies between the customers, residents have to pay US$ 0.25 per 19 l (5 gal), and commercial customers have to pay US$ 1.50 per 19 l (5 gal). The water from the tank is not considered clean and fresh so different other sources are additionally used to collect water. Five different sources of water were identified: water from the Wulik River and the Kivalina River, bottled water, rainwater, and ice- or snow-water in winter. Boats are the entry point for accessing the river water individually, the Kivalina Native Store provides access to bottled water, water buckets being used for collecting rainwater are the access point for rain and the snowmobile makes ice and snow accessible.

Beside others, our questionnaire contained the following detailed questions:

- For how many people do you collect water?
- Do all live in the same house?
- Number of buckets for drinking water and washing water
- Do you treat it before you drink it?
- Do you or others in your family use the washeteria?
- Do you collect water from other water sources?
- Is the situation different in winter?

All together data from 72 households could be collected at the water tank to get fundamental answers of the water consumption. Male familiy members are often in charge (77 %) to haul water with an average age of 29 years. In general, the age ranged from 9 years for the youngest and 75 years for the oldest.

During the interview period at the water tank 50 (69 %) interviewees came to haul water with an ATV (All Terrain Vehicle), 2 (3 %) interviewees came by car, 4 (6 %) interviewees hauled water with a hand wagon and 16 (22 %) interviewees had to carry the water by foot.

Accoding to the information of the interviewed persons a household in Kivalina has on average 70 l (19 gal) drinking water per day and 81 l (21 gal) of washing water per day available. Resulting in a total consumption of 28 l (7 gal) per person and day. The minimal available total consumption was 2 l (0.5 gal) and the maximum total consumption 200 l (53 gal) per day, leading to an average cost of US$ 2 per household and day. 84 % of the households treat (filter, reverse osmosis, boiling) the water before they drink it.

Also different water sources are widely used in Kivalina, 81 % of the households collect rain water, 55 % collect river water, 19 % buy bottled water, 57 % collect ice in winter. The washeteria was used by about half (54 %) of the villagers when it was open.

This outcome was the base for the selected and proposed sanitation system including it’s infrastructure. The need for a water-less toilet and an off-grid reactor to treat human waste became the fundamental elements of the proposed biochar sanitation system suitable for Kivalina.

Wastewater

In Kivalina, homes are not connected to a sewer system. The wastewater which is generated by washing-, cleaning- and cooking activities disposed immediately after use in front of the houses where it infiltrates into the ground in the summer. According to the U.S Congress (1994) there are five levels of service in the indigenous people communities in Alaska to categorize different levels of disposal systems. Gunnarsdóttir et al., 2013 summarized these five levels as shown in Table 1. Level A is the most rudimentary service and practiced in every home in Kivalina.

Table 1: Five levels of services for the indigenous people communities in Alaska (Gunnarsdóttir et al., 2013)

Level	*Sanitary solution*	*Collection and discharge*
A	Pit toilets, privies, bucket toilets	The buckets are carried by the residents to a disposal site, but in some cases they are emptied on the ground in the immediate vicinity of the residence or to nearby pit bunkers.
B	Bucket toilets	Buckets are hauled by a community employee, individual residents haul their waste to bins at central collection points, and when filled, the buckets are hauled to the community sewage lagoon
C	Flush toilets	Holding tanks and hauling of wastes to a disposal area is done by a truck service. The tanks which are emptied periodically by a pump or a vacuum collection vehicle operated by the community are either large insulated tanks located outside the residence or smaller containers located inside the home.
D	Flush toilets	Septic tanks or leach field
E	Flush toilets	Piped sewerage

Instead of flush toilets, the residents of Kivalina use the “honey bucket”- a plastic bag inside a plastic bucket with a toilet seat on top. The human waste is collected in a plastic bag that is being exchanged when full and stored in front of the house. People have to make their own arrangements to bring it to the dump. These plastic bags are a health hazard due to accidental spills during storage and collection and leaching from the dump site into the lagoon.

Different wastewater treatment systems have been proposed and built in the past, but due to high maintenance and operation costs these systems failed or have never been operational. Currently every family is in charge to bring their own waste to the dump—an open pit landfill that is out of compliance with state and federal environmental health and safety laws—. This process requires a vehicle and a family member who is willing to bring the ripped and leaking “honey buckets” to the dump.

Figure 2 shows the location of Kivalina, the dump and the landing strip.

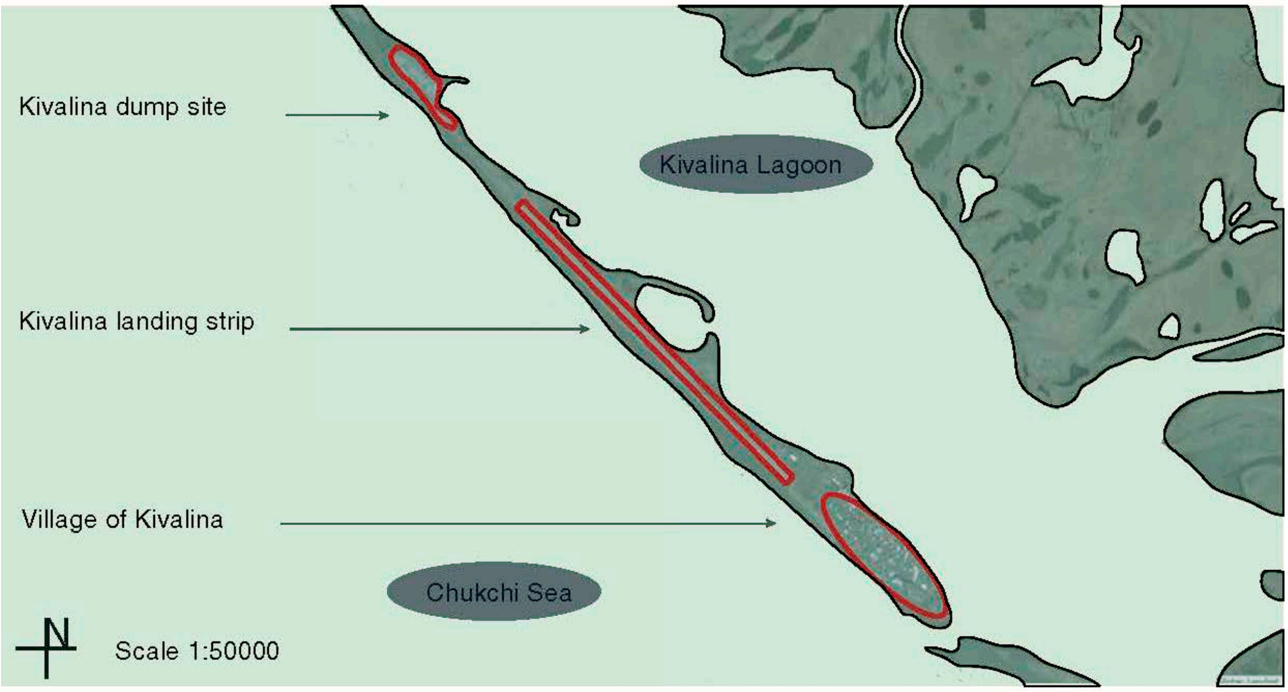

Figure 2: Location overview of Kivalina

<u>Solid Waste</u>

In Kivalina cash income accrues mostly from wage employment, sale of commodities (fish, crafts) or transfer payments (employment insurance, social assistance, old age pensions). Income in kind accrues from subsistence production. Primarily kinship principles are a major factor for economic and social relations among households in Kivalina. These relations ensure access to resources, organization of labor for productive activities and the distribution of goods and services (Usher et al., 2003).

Cash is a scarce resource, making the informal economic activities like exchange of services and goods among family and neighbors extremely valuable, because they reduce the need for cash (Goldsmith, 2008). The economy of a household is connected by kin ties to other households in extended families. Enhancing the village’s resource production in form of recycling feces could contribute to increasing the cash economy in Kivalina.

An integrated interdependence between the formal and the informal sector has evolved in Kivalina.

The open dump of Kivalina is located north of the airport. Kivalina is threatened by floods which leads to contamination of the environment including traditional food (berries, fish), and drinking water. Beside the floods, toxic overflows at the open dump site, where solid waste is disposed, present an ongoing hazard. Though controlled burning should take place in burn boxes, waste is often burnt in open air burning where debris might as well pollute the drinking water source. The perimeter fence of the dump is partially destroyed and gives wild animals the opportunity to enter the dump. As site access is unrestricted, no controlled dumping can be assured. Hazardous waste can be found throughout the entire dump. The tribal council is collecting batteries, light bulbs, plastic bottles and aluminum cans which are transported to Anchorage to be recycled.

Knowledge of the waste quantities and generation rates is necessary to determine if additional burning material for the biochar reactor -especially cardboard- is available. As specific data about the waste composition in Kivalina is not available a summary of 6 comparable Northwest Territories (NWT) communities by Smith, (1996 b) was used and can be seen in table 2.

Table 2: Waste composition for six NWT communities adapted from Smith (1996 b)

Component	***Average (% by weight)***	***Range (% by weight)***
Food	19.6	21.4- 15.9
Cardboard	10.9	14.4- 8.6
Newsprint[1]	2.1	6.0- 0.3
Other paper products	15.3	18.5- 10.2
Cans	4.8	6.7- 2.5
Other metal products	5.5	7.4- 3.9
Plastic, Rubber, Leather	12.2	14.3- 8.8
Glass, Ceramics	4.1	6.5-1.7
Textiles	3.7	4.4- 2.8
Wood[2]	11.3	20.0- 4.5
Dirt	3.8	4.8- 2.5
Diapers	6.7	11.6- 3.5
Total	100	-

Table 2 shows that on average 10.9 % of the waste is cardboard and 11.3 % of the waste is wood, which can be used as additional burning material for the biochar reactor. A high percentage of the available cardboard is shipped in by the local store and by residents. Also diapers could be used as additional material to increase the caloric value. This would have a great benefit to the open dump because 28.9 % of waste volume could be avoided and would save space on the landfill.

Political Institutions

Two councils officially govern the village. Among other tasks, the city council operates and maintains critical village infrastructure, including water, roads, and utilities. The tribal council aims at preserving Inupiaq cultural heritage through social, economic, and cultural programs and services. Federal and state agencies provide village leaders with technical, financial, and material assistance.

[1] The higher number is because of local paper and daily southern newspaper. The other communities are all less than 1%.
[2] The percentage of wood varies depending on the season depending when construction work is going on.

3.2 Benefits of the Biochar Sanitation System

Through adapting an innovative sanitation system and human waste management in Kivalina consisting of UDDTs, an improved and efficient waste collection and a biochar reactor numerous environmental- and health benefits as well as climate change adaption can be provided.

Healthy Community and Ecosystems

In combination, biochar and UDDTs address key public sanitation issues in Arctic North America. Kivalina is lacking wastewater treatment facilities and in-home water supply infrastructure, making sanitation the most critical threat to human and environmental health in the village. Due to the use of honey buckets, water shortage, and severe overcrowding, rates of communicable disease and skin, gastrointestinal, and respiratory infections are high (Daley, 2013). Raw sewage from the dump pollutes water sources, food sources, and fish and wildlife habitat. Achieving 100 % sanitation through burning of feces, improvement of the waste hauling system and a hygiene toilet use is significantly contributing to a healthier community and ecosystem.

Climate Change and Re-location

Kivalina is threatened by the impacts of climate change and is facing re-location. The proposed biochar sanitation system copes with many of these climate change impacts.

The containerized biochar sanitation system can be transported by shipping container to future village relocation sites. UDDTs, a prerequisite to a fully functioning biochar system, use no water for flushing, and are suitable for areas with no piped sewage system and unreliable water supplies.

Boost the Local Economy

UDDT and biochar sanitation technology systems create new resources for local economic development. Potential small business opportunities can be created for residents of Kivalina and other NANA (Regional Alaska Native Corporation) region villages to support the supply and distribution of UDDTs, unit installation, and biochar by-products, as well as community-led training and localized planning efforts. Economic development will prioritize capacitating existing system functionality, support for local operators, and sustaining relationships critical for long-term operation and maintenance.

3.3 Biochar Reactor

“The Climate Foundation” has developed a biochar reactor that converts human solid waste into charcoal which can be used as energy source and contributes to the local economic development. Additionally the reactor eliminates the need for externally delivered power, water or sewers and is financially sustainable (Saddler-French, 2014). The development of the biochar reactor started in 2011 at the “The Reinvent The Toilet Challenge”. The biochar reactor is in a system testing phase. It was developed for a semi-continuous process at input rates of approximately 2 kg/h (Von Herzen et al., 2014).

According to Von Herzen et al. (2014) the aims of the biochar reactor development are sanitation of human solid waste using high temperature and long residence times, high reactor efficiency using Gas Flow Management and Counterflow Heat Exchange to minimize required energy input like propane or natural gas. Another objective is reliability to have most robustness and maintainability. According to Von Herzen et al. (2014) there is only one moving component to reduce possible failure and simplify repair.

The process of the biochar reactor starts with shredding- than the waste is dried in a belt dryer which reduces the moisture content from about 75 % to 30 % with hot air from the radiators. After densification the waste is charred and sanitized between 300-700 °C in an updraft pyrolyzer. A sterling engine as heat recapturing system is used to power the belt dryer and augers of the system. Half of the carbon is released as syngas as free energy source (Saddler-French, 2014). Figure 3 shows a draft of the biochar reactor process.

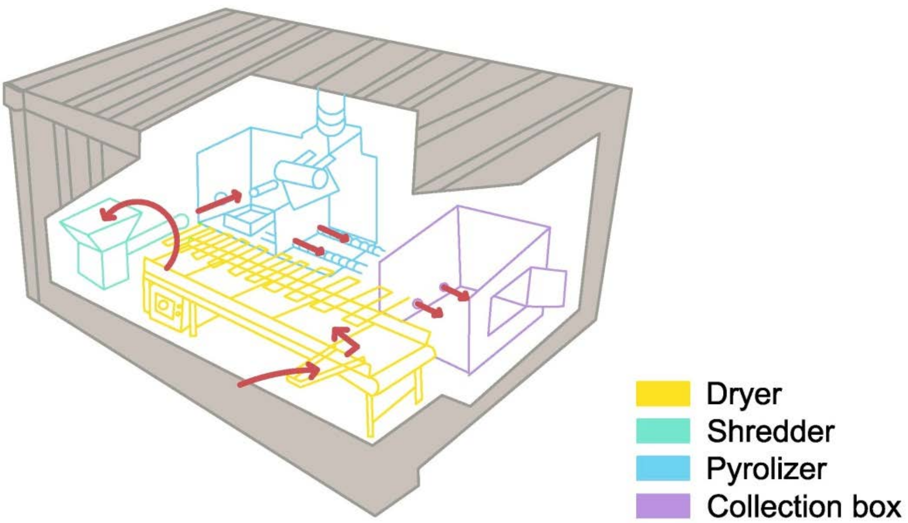

Figure 3: Biochar reactor process (The Climate Foundation, 2014)

One key aspect of the biochar process is that it is a self-sustaining system. This system is able to reuse the heat and produce the electricity which is needed by the process. Therefore there is no need for external electricity and no need for water supply.

The heat of pyrolysis is used in the dryer system. Since human solid waste is a high moisture input material the moisture needs to be low enough to use the input material effectively. The drying system is able to convey the solid waste over the dryer to reduce the moisture content into the 30 % range. When the moisture content of the input material is reduced to this range, it can be passed to the pyrolyzer or catalytic converter or heat engine and ultimately to the condensing heat exchanger.

An important feature of the biochar reactor is the heat exchanger which is condensing 90 % of the water vapor. The resulting heat of condensation is available to the process for drying. A big challenge is the integration of all parts in one system. To get a drying system, a pyrolyzer, a catalytic converter, a heat exchanger, and a heat engine running smoothly together is part of the engineering challenge. The reactor as it is constructed for India can process the waste from thousands of people per day, by converting it to biochar. For Kivalina the reactor will get redesigned and will serve as a model for communities with similar problems across the Arctic region.

Biochar

"*Biochar is a fine-grained and porous substance, similar in its appearance to charcoal produced by natural burning. Biochar is produced by combustion of biomass under oxygen-limited conditions. The definition adopted by the International Biochar Initiative (IBI) furthermore specifies the need for purposeful application of the material to soil for agricultural and environmental gain*" (Sohi et al., 2009).

Black carbon includes all forms of refractory organic matter that originate from incomplete combustion (Sohi et al., 2009).

Charcoal is traditionally produced in kilns at temperatures of 450-500 °C by pyrolytic treatment of wood and biogenic materials. It is used for heating and cooking but also traditionally used as a soil amendment and for odor control (Okimori et al., 2003, Sohi et al., 2009). In Kivalina there is culturally no agricultural practice, therefor the biochar will not be used as a fertilizer byproduct on a larger scale.

Feces

Feces are human excrements without urine and flush water. Compared to urine, feces have a lower nutrient content but a higher rate of organic substances. The volume of feces is influenced by many factors like eating habits, water consumption, age of the person, climate zone, and rural or urban areas (Geurts, 2005). Faechem et al. (1983) pointed out that inhabitant in Europe and Northern America produce between 0.1 and 0.2 kg of wet fecal mass daily, whereas the wet mass ranges from 0.13 to 0.52 kg daily in developing countries. A vegetarian diet causes a higher fecal mass than a mixed diet. In general, the daily feces mass of a person in a rural area is higher than the feces of a person living in an urban area. Additionally, the water content varies considerably. With increasing fecal mass the water content rises. A wet fecal mass of 0.1- 0.15 kg has an average water content of about 75 %, a wet fecal mass of 500 g about 90 %, respectively (Shalabi, 2006).

4. Material and Methods

4.1 Data Collection in Advance

Data collection in advance assures an efficient field research time since no time is wasted in collecting already existing data and a basic understanding of the living condition is given. Existing information about Kivalina of all project partners was exchanged in form of a workshop before the first field trip in July 2013. During this field trip, the water cycle (source, supply, consumption and disposal) of Kivalina was thoroughly investigated. The project proposal is based on these findings.

The geographic location of water and wastewater related sites like the public water-pumping site, the dump, the unfinished wastewater treatment plant and the water fetching places were located via GPS-devices. Two-minute interviews with residents were conducted at the public water tank concerning the resident's water consumption, including information on individual post-treatment of the public water and additional water sources to subsidize their water demand.

In individual interviews with representatives of the city and tribal council and phone interviews with experts from different regional agencies, the current water and wastewater situation was analyzed and ideas for improvement were shared.

Moreover, some residents of Kivalina, who are fetching water from the two rivers (Wulik river, Kivalina river) on their own, were accompanied in order to map the location of the fetching points and to document their fetching techniques.

Additionally to the work with the people on site, all agencies, which have a current or previous involvement in the water and wastewater sector of Kivalina were mapped, in order to visualize these relationships and make the management of the water and wastewater sector more understandable to the parties involved as well as to the public.

At the end of the first on-site stay in July 2013, all project partners collaboratively organized an open house, where information on the different projects was shared and discussions with the people of Kivalina were continued.

Moreover, the findings were presented to the public at the Alaska Pacific University, Anchorage, where also representatives of the Kivalina City and Tribal Councils joined. Based on the experience and the results of the field trip in July 2013, the used methods were optimized for the field trip in September 2014, where investigation continued and the proposed toilet system was introduced and piloted.

4.2 Investigation Procedures

4.2.1 Rapid Rural Appraisal (RRA)

Rapid Rural Appraisal is a method that was used in all project phases as recommended by Freudenberger (1999). The data-collection before the start of the main study was performed to get a sense of the range of issues and to get information about the social, political, institutional, environmental and economic context. The project will intervene into this context to gather basic information and to identify the types of concerns that need to be addressed. This methodology was also used in the project design phase to customize various aspects to peculiar circumstances. In the early project intervention RRA was used to refine the objectives and activities.

The field work in Kivalina was structured according to the pattern of most RRA's as shown in figure 4.

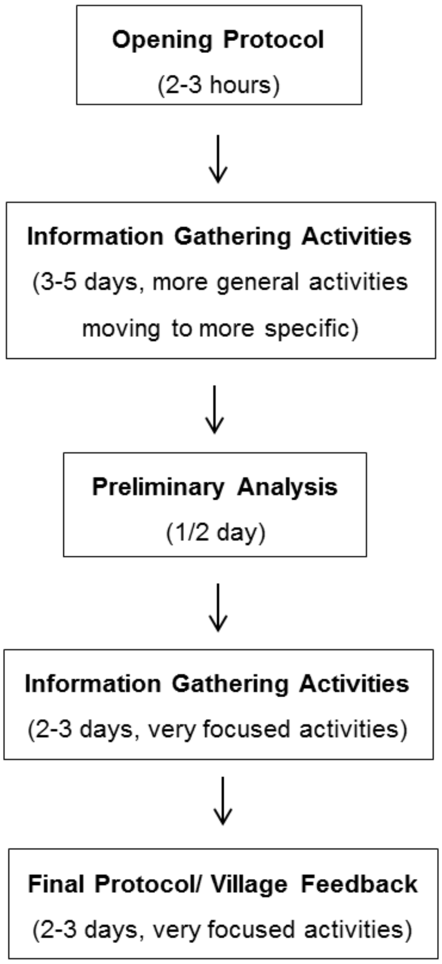

Figure 4: Activities in the field during the RRA study (adapted from Freudenberger, 1999)

During the opening protocol at the Tribal Council, the project concept, the reason for information gathering, the use of the collected information and details about the pilot trial were discussed. Information was gathered both on community, household and individual level to get complete and accurate results as suggested by Freudenberger, (1999). Also periods of reflection in between was considered as important to get an overview about further information needed. The final village feedback session, an open house, ensured an information transfer into the village, informed everyone about the progression of the project and next steps. According to Freudenberger (1999) the feedback session was used as an opportunity to triangulate the gathered information. The following practices were used to carry out the RRA including semi-structured interviews, use of indigenous knowledge, direct observation and triangulation.

Semi-structured Interviews

Most information about the community village sanitation was gathered by holding semi-structured interviews. Semi-structured interviews are a key of rapid appraisal according to

Beebe (1995). The best way to learn about local conditions is to ask local people. An important element is not just to ask direct questions but to get people to talk about a certain subject (Beebe, 1995) by keeping the conversation on the main theme and at the same time keeping the interview moving naturally. A few comments and designed questions enriched the interview. A positive effect of group interviews is that when individuals are free to correct each other, variability within the community can be identified (Beebe, 1995). Interviews with people working in a topic relevant area (water plant operator, waste hauler, clinic facilitator) were scheduled during their work time, to avoid placing a demand on their free time and to get an overview on their work activities.

Use of Indigenous Knowledge

"Rapid appraisal is designed to contribute to an insider's perspective of the system" (Beebe, 1995). "*Using indigenous knowledge involves agreement on the most important components in the system and the most important problems or constraints faced by the local participants*" (Galt, 1985).

Direct Observation

"Direct Observation" is a rapid appraisal tool to validate data in advance by suggesting additional topics for interviews or multiple checks on data collection (Beebe, 1995) and was carried out continuously throughout the whole field research and for data analysis. Direct observation was used to get information about the honey bucket use pattern, the honey bucket waste cycle (storage, collection and transport), the mapping of physical infrastructure and the community layout.

Triangulation

The use of multiple tools (various modes of interviewing, drawing maps, diagraming) was used to reduce the systematic bias which would have an impact if only one tool was used, and to increase the effectiveness of the information gathering process (Freudenberger, 1999).

4.2.2 Participatory Rural Appraisal (PRA)

Participatory Rural Appraisal emphasizes on participatory decision making, which was enhanced and supervised by the project partner "Re-locate Kivalina".

It involves not only the collection of information but also involves the community in planning and decision making, a key factor in project success as many examples have shown (Freudenberger, 1999). Additionally to the RRA where people just had to respond to a questionnaire, a more active form of participation was performed like participating in an open ended discussion, an open house, an “All Agencies Meeting” which allows people to express their own concerns. In addition, the offer to participate in activities such as a walking tour through the town with an engaged community member to learn about village sanitation and the history of village sanitation was always gratefully accepted.

Most of the times a combination of RRA and PRA was performed. An important aim of the RRA and PRA was to include different interest groups of Kivalina in the participation process in order to assure that all possible perspectives are considered. Freudenberger (1999) suggests gathering information from men and women, older and younger people, those who are poorer or richer and people from different family clans and professions. In a pre-study, differences in the community were explored with the help of “Re-locate Kivalina” to select the right combination of respondents. One aim of a PRA is that the community develops a sense of an ownership over the process.

4.3 Survey Data Analysis Techniques

To organize the field trip and to prepare the data analysis, a matrix was used to outline needed information and the tools for getting this information. The matrix is shown in table 3 as well as how to document and filter the gathered information.

Table 3: Matrix of used methods

	Existing maps	GIS- map	AutoCAD- drawing	Group Interview	Individual interview	Reporting form	Numeric Spreadsheet	Photographs	Measurement	Virtual communication	Literature research
Status quo	X	X	X	X	X			X		X	X
Geographic context	X										X
Climatic context			X		X						X
Architectural context	X	X	X		X			X	X		X
Social context				X	X						X
HB using pattern			X	X	X						X
Economic context				X	X		X			X	X
Under-floor collection			X	X				X	X		X
In-home collection											X
Pilot trial			X		X	X		X	X	X	X

GIS maps were generated in ArcGIS to enable easy GPS data analysis, and to use it as a supportive tool for comfortable visualization of statistical data. Existing maps were digitized, actualized and completed. Auto Desk Auto CAD drawings were generated for toilet installation details, the architectural survey, classification of different housing units, the building descriptions, floor plans and cross sections.

The analysis of the honey bucket use pattern was performed via numeric spreadsheets and the software Adobe Illustrator was used for visualization. Individual interviews were hold with household members in charge of the honey bucket disposal and with staff in the water and wastewater sector.

The financial analysis was divided into operational expenditures (OPEX) and capital expenditures (CAPEX). The calculations were performed using numerical spreadsheets. Initial values for the calculation were either collected by interviewing villagers, officials or project partners during the field work or researched in the internet.

Reporting forms (activity calendar, daily and weekly inspection sheets, number of uses sheet) were developed to monitor the operation of the pilot toilet from the distance.

Photographs were taken in all activities as a means of documentation. Measurements were performed in order to get the information needed to draw floor plans of the different housing types.

5. Results and Discussion

5.1 Concept

Piped water and wastewater infrastructure to each household in Kivalina is unlikely to be installed in the near future due to the expected re-location and the unwillingness to invest large amounts of money into the village. Therefore, an alternative to the water and wastewater problem is needed as a high priority. According to information gathered in the first field trip in July 2013 and based on discussions with local people and the authorities, institution and all other project stakeholders, human solid waste should be recycled as valuable natural resource and water usage should be minimized. The following system was chosen and approved by the City and Tribal Council of Kivalina.

In order to use solid waste as a resource it first has to be separated and stored through the use of dry toilets. Two installation types will be developed and introduced in Kivalina as a potential future sanitation system. One is an under-floor collection system for houses on piles. This assures a future human waste collection from outside the house in order to eliminate any possible contact of the toilet users with contaminants. The under-floor collection system enables trained waste collectors to collect the human solid waste without getting into the house. There is no handling with feces inside the house anymore, which corresponds to the wish of the villagers. The collection box will be placed under the house enclosed by an insulated box to provide protection from the arctic climate and to prevent playing children of being exposed to human waste. Figure 5 is showing the concept of the under-floor collection system.

The second system will be an in-home collection system for houses where under-floor collection is not possible due to differences in the existing building structures. The feces will be collected in a bucket situated in the toilet, which can be emptied easily on a less frequent schedule than the current honey bucket system because only solid waste gets collected.

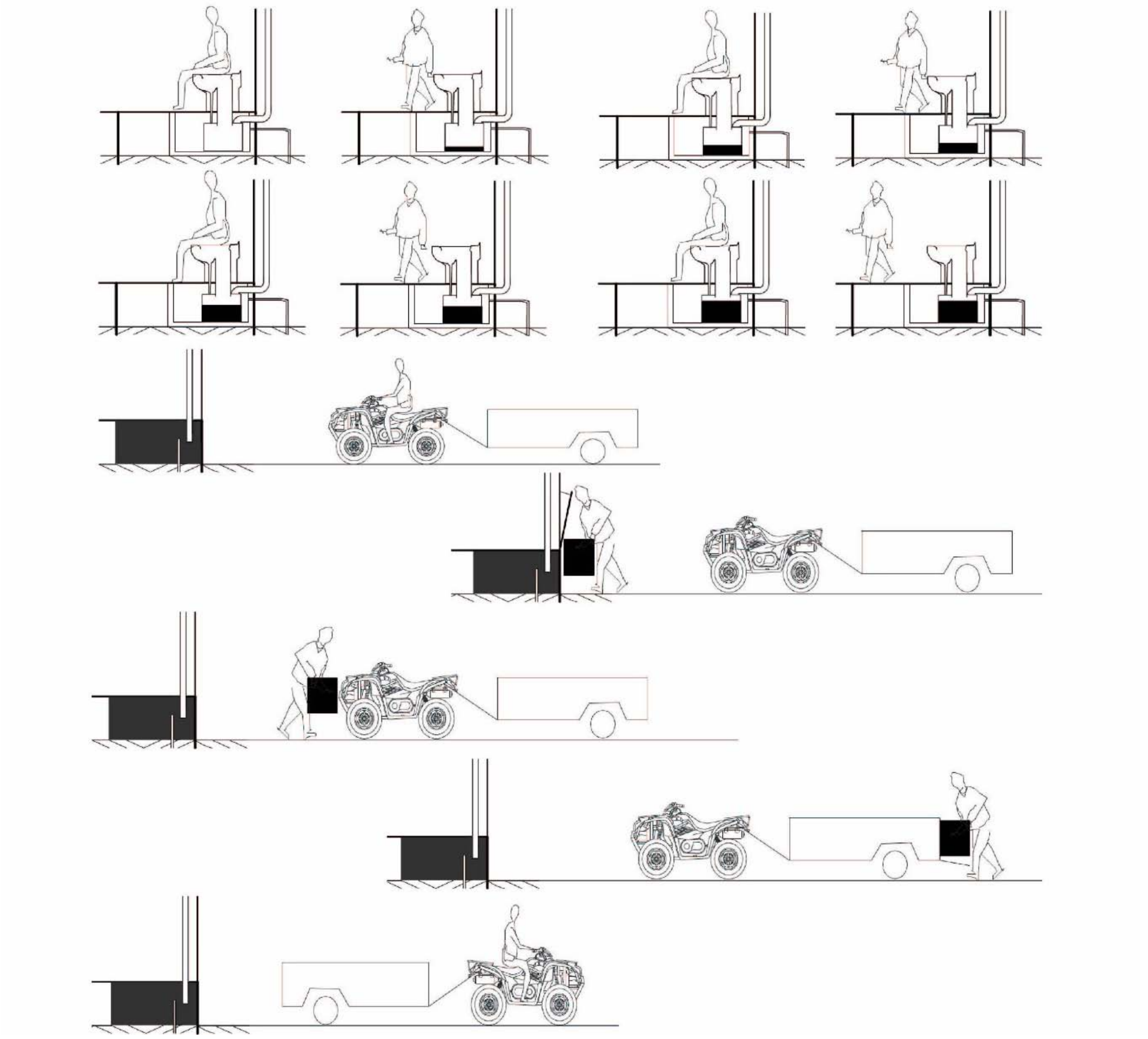

Figure 5: Sketch of the toilet scheme and the waste collection

Human waste is collected by trained staff and transported to the biochar reactor via ATVs and trailer in summer and with a snow machine and sled in winter. Bigger trucks are not suitable for villages like Kivalina due to the strong winter weather condition and gravel roads.

One key aspect of the biochar process is that it is a self-sustaining system. It can reuse the heat from the exothermal pyrolysis to produce the electricity needed for the process. Therefore, there is no need for external electricity and no need for water supply. The end-product biochar is a valuable resource for Kivalina with a wide variety of usages.

Figure 6 is showing the transport to the biochar reactor, the biochar process and the collection of the end- product. The process of the biochar reactor starts with shredding the collected solid human waste- than the waste gets dried in a belt dryer which reduces the moisture content from about 75 % to 30 % with hot air from the radiators. After densification the waste gets charred and sanitized between 300-700 °C in an updraft pyrolyzer. As heat recapturing system a sterling engine is used to power the belt dryer and augers of the system. Half of the carbon is released as syngas as free energy source (The Climate Foundation, 2014).

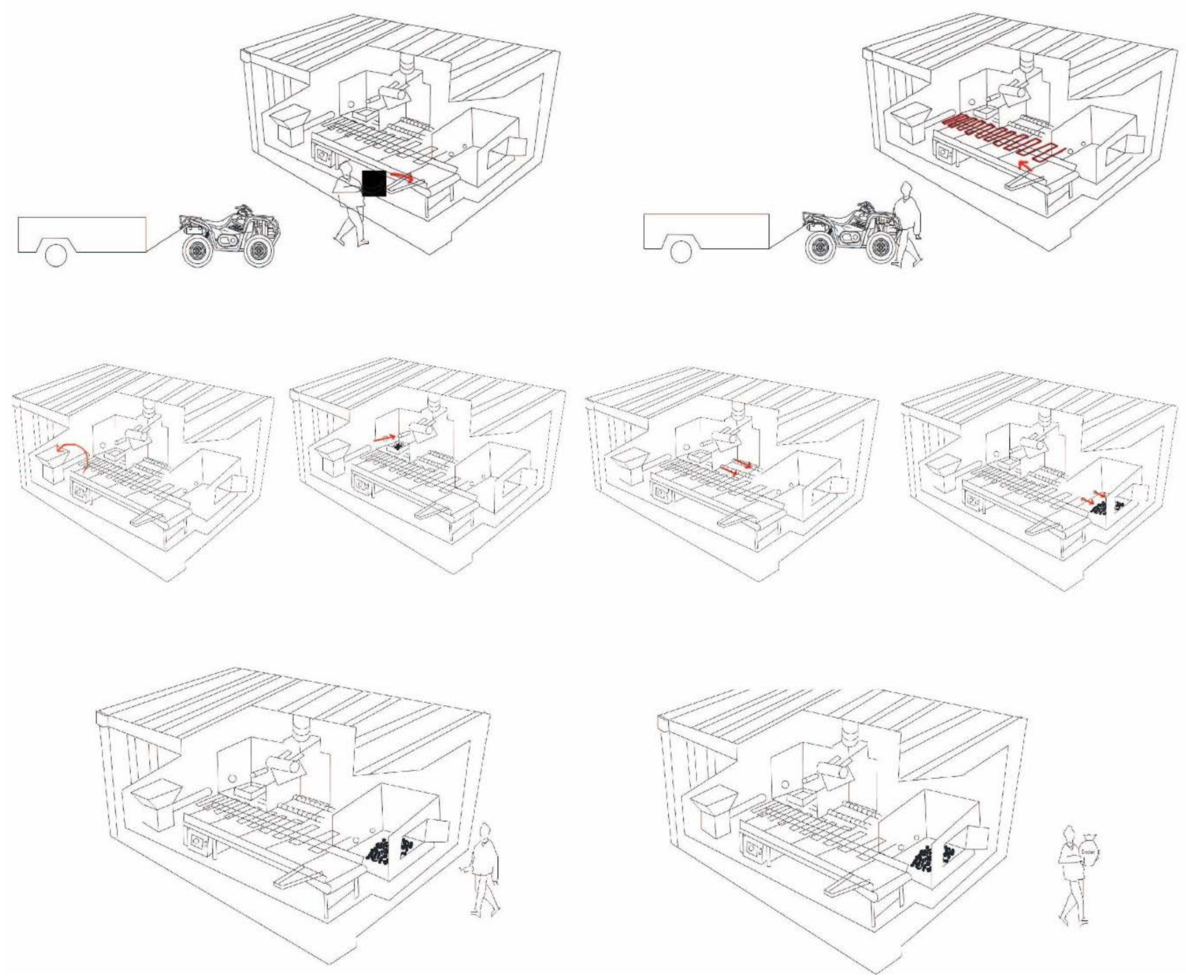

Figure 6: Sketch of the waste collectors feeding the reactor, the biochar process and the end product

Table 4 is comparing the two proposed systems and the current honey bucket system in Kivalina.

Table 4 Comparison between current system and biochar sanitation system, adapted from Smith, (1996 a)

	Current system	**Biochar sanitation system**	
Focus	Honey buckets	Under-floor collection	In-home collection
Public health hazards	Very high: Transmission of communicable diseases through all stages of waste management	Low: Potential for leakage during collection and transport	
Impact on the local environment	Potential problems disposing of honey bucket waste and plastic bags	Fecal matter is 100 % sanitized in the biochar reactor, urine is disposed underground- no groundwater use	
Socioeconomic development	Service restriction can impede development	Development towards sustainability and life cycle thinking	
Convenience and Aesthetics	Annual spring cleanup, odour, lack of proper containment facilities, unsupervised scavenging, daily emptying	Service reliability, maintained containment facilities, monthly emptying, no odour in the houses, possible odour at the reactor,	Service reliability, maintained, emptying period every 2 weeks, no odour in the houses, possible odour at the reactor,
Equity	Level of service much below American norms, inequity within the village	Equity within the village, Following a new path- incomparable system	
Economic aspects	Individual user responsible	Facility operator required, trained waste collectors required	

5.2 Planning Considerations

The toilet installation will address the different housing types of Kivalina and has to be adapted to each house. Therefore, a detailed description of the community layout is necessary and was conducted in September 2014.

5.2.1 Physical Infrastructure - Community Layout

In order to be able to plan a future sanitation on-site solution for every single house in Kivalina including collection of the solid human waste and transportation to the biochar reactor, various architectural building types in Kivalina were studied in cooperation with "Architects Without Borders Austria" and "Re-locate Kivalina". The purpose of the building survey was to capture water, sanitation and project relevant features outside of each housing type existing in Kivalina. This mapping phase included information regarding a water tank installed outside of the house, a facility for rain water collection, the number of floors, where and if there is a honey bucket or waste storage in front of each house, where and if there are any pipelines installed and which transport vehicles are parked in front of the house. Additionally the grid of the piles supporting the structure of the house was measured to be able to plan the under-floor collection. According to the 2013 Alaska Housing Assessment (Wiltse et al., 2014), between 2008 and 2011 58 units have undergone a weatherization retrofit. Newer homes now have a better energy performance. In Kivalina 30 % of the houses are severely overcrowded (more than 1.5 people per room) and 10 % are overcrowded (more than 1 person per room) according to the United States Census Bureau (2011).

As a first step, all buildings were classified into four different classes, residential, commercial, public and school district (figure 7).

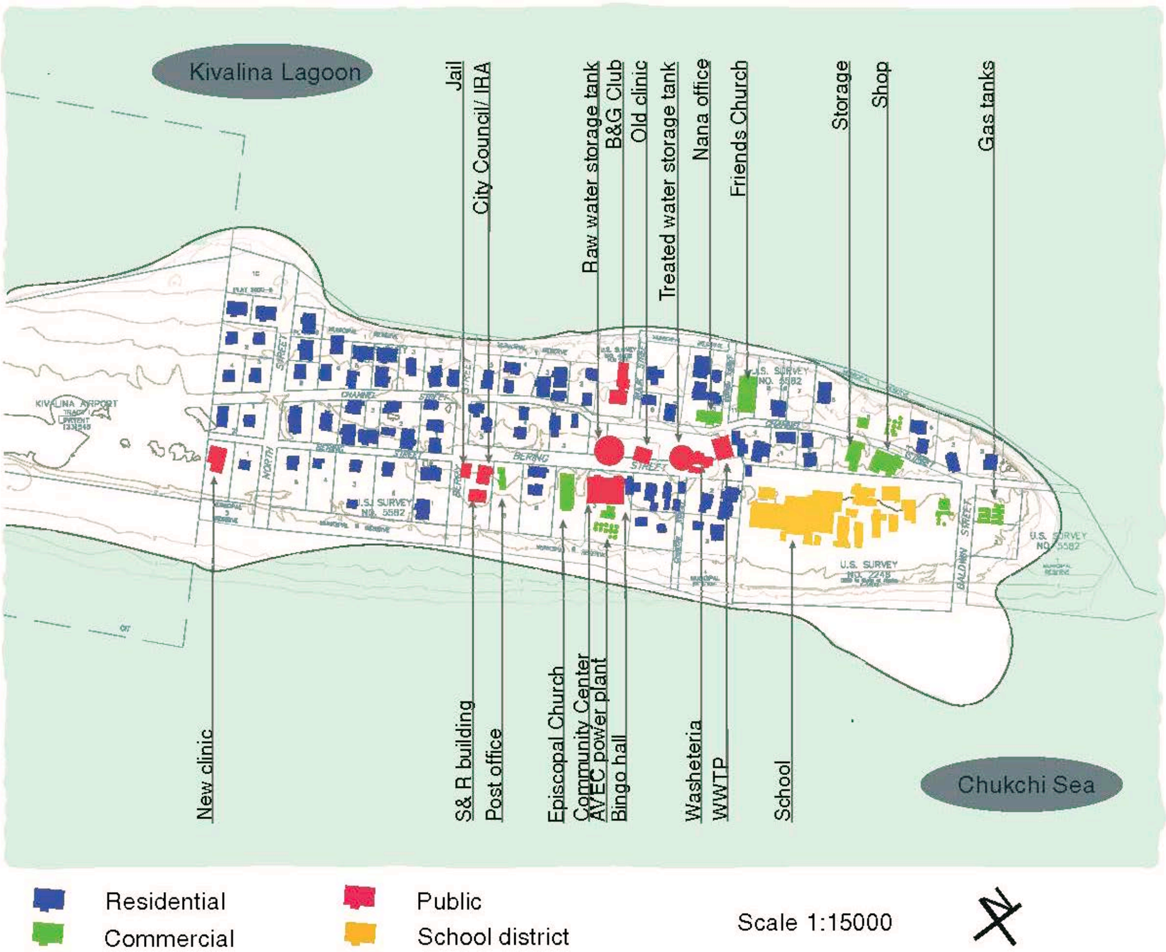

Figure 7: Kivalina building description

Altogether, there are 85 inhabited houses in Kivalina and 14 communal buildings including the water tanks, washeteria and wastewater treatment plant. The school campus including teachers housing was not included in the housing study. The wastewater treatment plant is not put and will not be put in operation. ANTHC (Alaska Native Tribal Health Consortium) initiated the construction of a new wastewater treatment plant in 2004 to connect the school and the washeteria. The system operation is based on a bio filter and UV-disinfection. Construction work started in 2008 and was completed um to 85 % in 2009. Still neither the washeteria nor the school is connected to this new wastewater treatment plant. The reason is the high operation cost of US$ 200.000 per year additionally to the current costs for the water supply system of US$ 180.000. These costs result in a monthly payment per household of US$ 196 for the wastewater treatment of the school and the washeteria. City officials expressed their concerns, that households in Kivalina are not able and are not willing to pay such a high amount.

As a second step, the residential buildings were subdivided into different housing types, which are shown in figure 8. Between 2000 and 2011 15 new houses funded by the Northwestern Inupiat Housing Authority (NIHA) were built in Kivalina. 25 houses were built in the 1970’s and 33 in the 1980’s according to the 2013 Alaska Housing Assessment (Wiltse et al., 2014). All housing units in Kivalina lack complete plumbing.

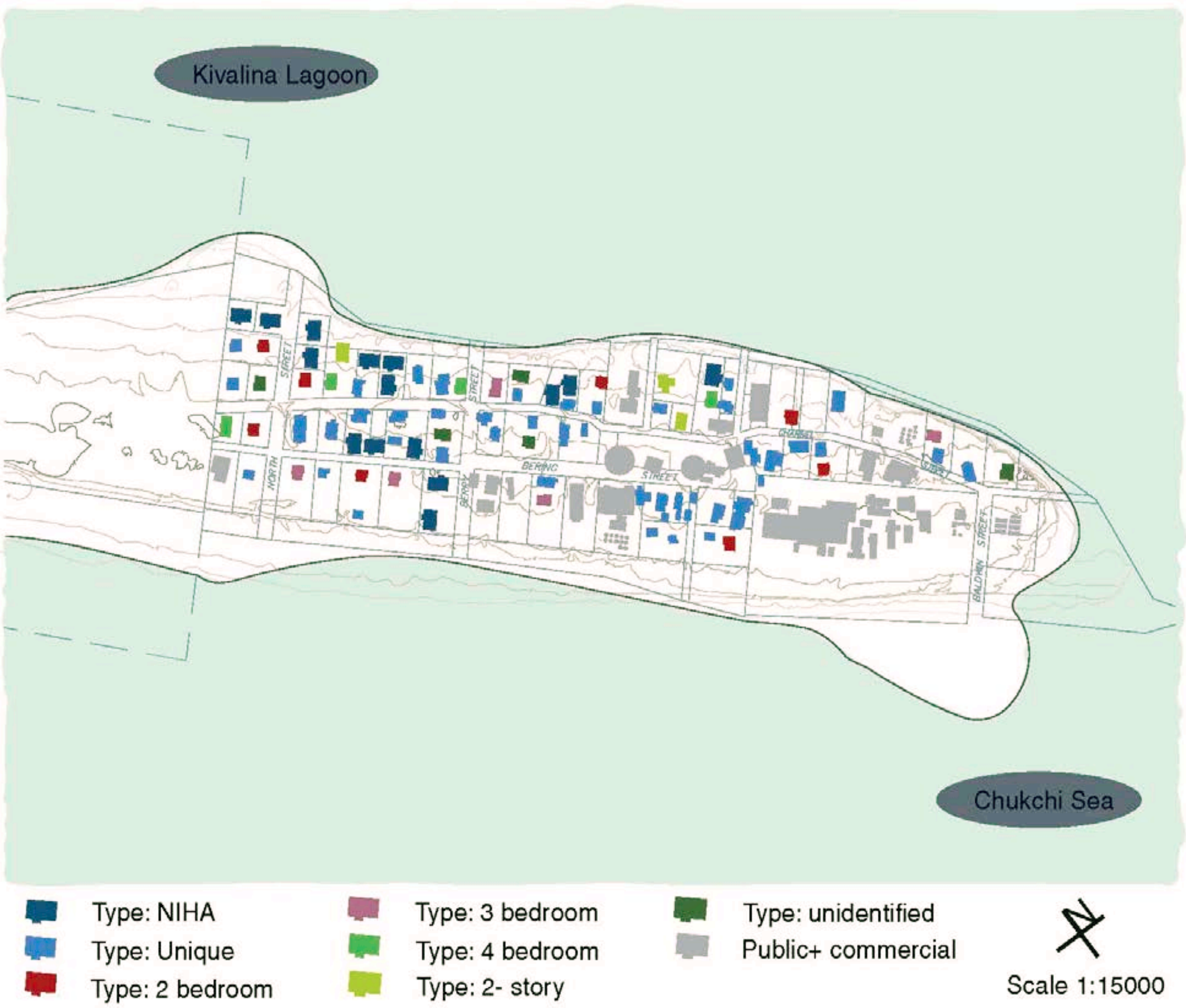

Figure 8: Kivalina building types

Figure 8 shows 45 unique building types. In Kivalina there are 8 2-bedrooms houses, 5 3-bedroom houses, 4 4-bedroom houses, 3 2-story houses. For 5 houses, the number of bedrooms could not be identified. All housing types except for the unique buildings and the 2-story buildings are built on piles to reduce the moisture in the house and to be able to adapt to the fluctuating snow depth. The height of the piles is 1.20 m (4 ft) which provides enough space for an under-floor collection system. The piling structure of the 2- 3- and 4-bedroom housing types were often modified which makes a detailed individual assessment of each house necessary for the installation of the collection box and the urine discharge pipe. The buildings study revealed that two different collection systems are necessary as half of the houses are built directly on the ground or don’t have enough space for an under-floor collection system. The fact that many houses have the same layout makes planning easier.

Figure 9 gives an impression on how the different housing types look like in Kivalina. The space around the house is used for additional storage space often a shipping container is used as storage compartment or an extra shed was built. Homes are accessed through gravel roads.

Figure 9: Pictures of the housing types from different directions.

The newest standardized housing type according to the Northwest Inupiat Housing Authority (NIHA) has a kitchen, a living room and 4 bedrooms as illustrated in the floor plan in figure 10. 15 houses of this type were mapped in the second field trip in September 2014. All rooms except for the bathroom and boiler room have windows and are accessible separately. A hallway is connecting the living room and kitchen to the bathroom and bedrooms. The master bedroom is bigger than the other bedrooms. At the end of the hallway is a fire exit located. The arctic entrance provides additional storage room and space for jackets and shoes.

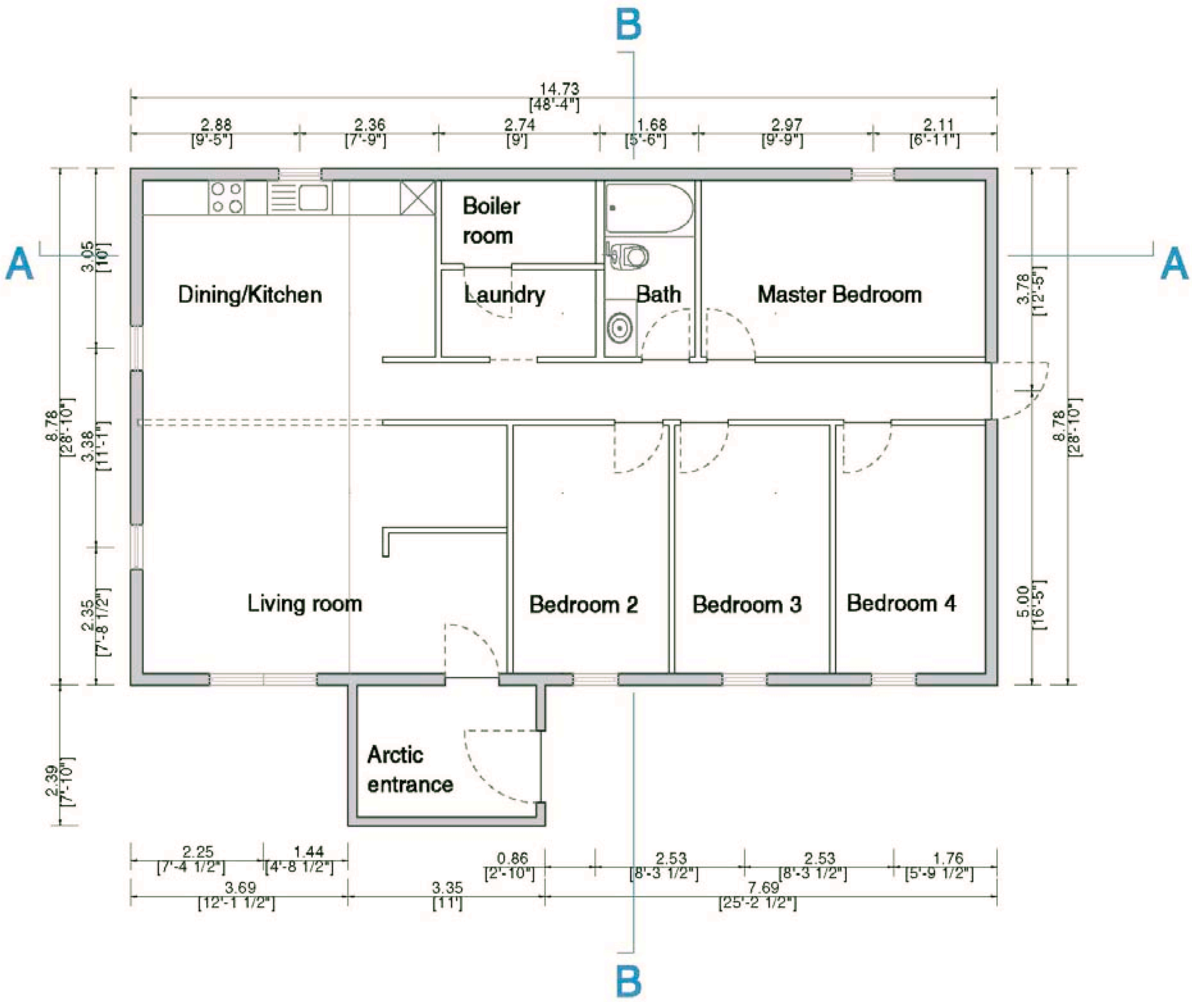

Figure 10: Floor-plan NIHA house

These houses have a fully plumbed and furnished kitchen and bathroom excluding a toilet, regardless the missing water supply. The bathroom is providing enough space for a separating toilet, which can only be placed as shown in figure 10 without rebuilding it. The whole wastewater of the house is discharged through the drain of the bathtub. The wastewater drainage is a non-insulated 7 cm (3 in) pipe which is not connected to any further drainage system. This drainage pipe can only be used in summer. In order to assure proper functioning and maintaining of the collection box the wastewater of the household also needs to be collected and discharged through the urine pipe. The location of the bathtub at the wall makes solid waste collection difficult. In the future, collaboration with the architects designing the houses and instructions about the realities in this part of the USA is mandatory. In older housing types and self-build types the bathroom is located next to an exterior wall and usually has no in-home plumbing.

5.2.2 Winterization Study

Wastewater handling in the Arctic and especially in Kivalina is a challenging task due to freezing temperatures in winter, flooding in spring, erosion, variable amount of water, a challenging transport situation, high costs of electricity and fuel as well as the settlement pattern. Additionally in most Artic villages permafrost represents a construction and operation challenge. Especially the big temperature differences and temperatures far below freezing point in winter are a challenging task in terms of storing the feces, freezing of the urine in pipes, treatment process, odor and the reuse of the end product.

Culturally and historically the Inupiaq of Kivalina are not farming, although it would be possible to some extend in the short summer period. Therefore the sustainable reuse of nutrients, especially of the urine, which also depends on the growth season and on the practiced agriculture, is restricted in Kivalina.

Commercially manufactured separating toilet systems are sold in Alaska mostly to non-native communities and for cottage homes mostly for seasonal use. There is little information available on installations in rural Alaska Native Villages and several features regarding collection, storage and treatment need to be adapted to the climatic conditions. The community demonstration project on composting toilets conducted by Selabo (2008) was used as an example project for this thesis. UDDTs are a critical subsystem of a fully functioning biochar sanitation system. In Kivalina UDDTs separate human solid waste from liquid waste, prior to the treatment of the human solid waste in the biochar reactor. Separation reduces the amount of human waste to be sanitized, dries fecal matter as much as possible, and lowers the risk for disease transmission. Most of the pathogenic bacteria, viruses, and parasites are excreted together with feces, whereas urine is far less pathogenic if not contaminated with feces. In addition, UDDT technology is responsive to the limited water and sewer infrastructure in Kivalina and addresses the need for technology solutions that are mobile and easily transportable to relocation sites. UDDTs use no water for flushing, do not require a piped sewage system or a reliable water supply, eliminate the need for informal human waste dumping, and can be easily retrofitted to current and future architectural conditions.

This part of the study aimed at exploring the following questions:

- Which systems are at risk of freezing, what damage will result if they do freeze and what can be done to protect those systems?
- How will the winter affect the maintenance of the facility?
- Is it possible to collect solid waste from all areas in town in winter?

The toilet design has three elements, which are vulnerable to frost damages: the ventilation, the urine pipe and the collection box are at special risk of being damaged or loosing functionality in winter.

Ventilation

According to information of Kivalina citizen’s, snow depth can be so high that houses, that are not located on piles, are covered with snow. Especially houses on the lagoon side are vulnerable to snowdrift. These snowdrifts are highly influenced by the wind speed and wind direction.

Figure 11 shows the wind direction and the percentage of time spent in each direction. The wind data was collected from the weather service WeatherSpark (2014). The northern and the north-eastern wind quadrant are the directions with the strongest and most frequent winds mainly in the winter months which verifies the information from the villagers of snow piles on the lagoon side.

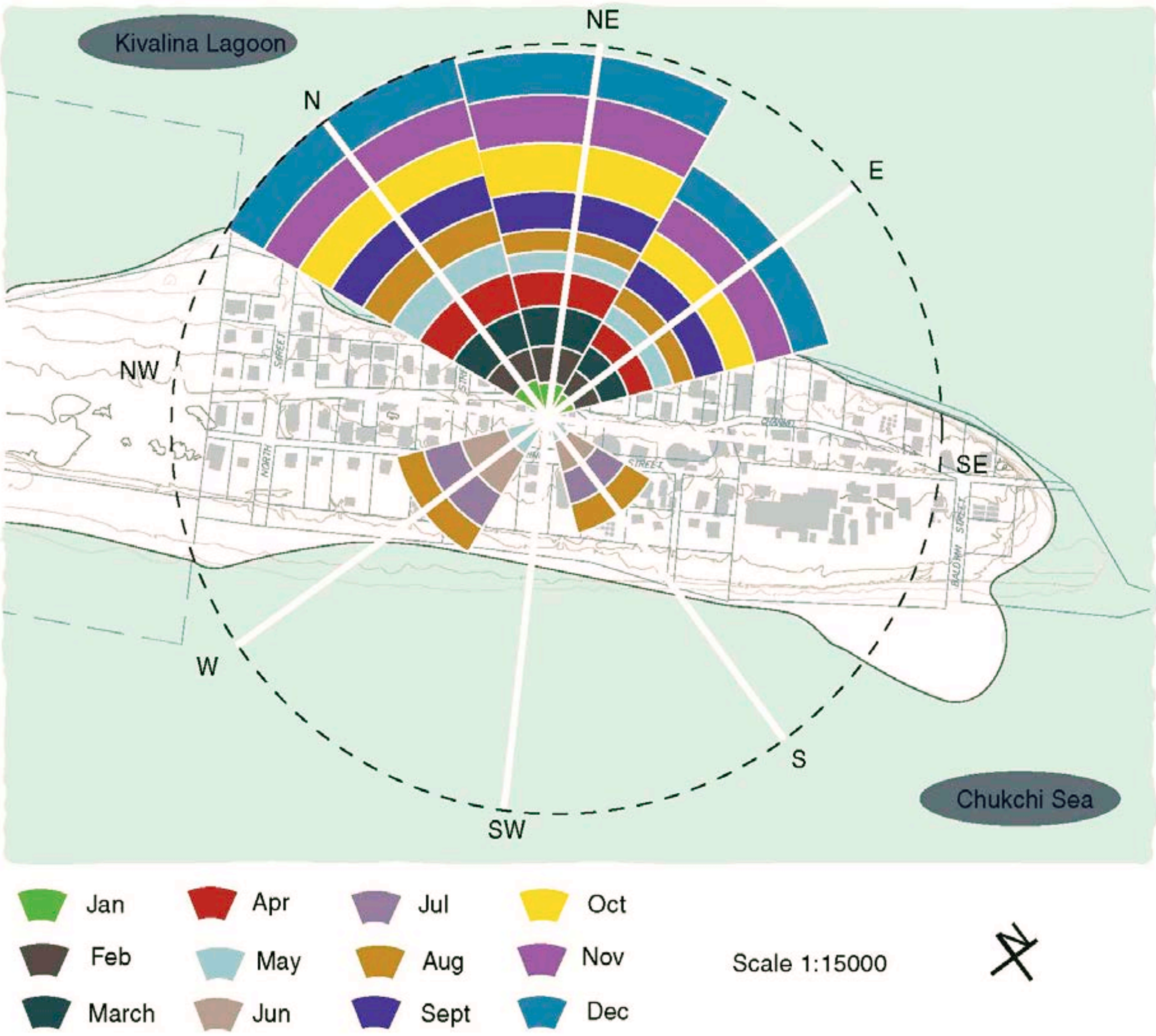

Figure 11: Wind rose of Kivalina

The toilet ventilation is at special risk of being influenced by the snow when not located at the roof. To protect the ventilation outlet of being clogged with snow, the ventilation pipe should be extended at least 50 cm (1.6 ft) beyond the roof height. If the ventilation is clogged by snow, odor from the toilet might occur. A suitable solution to prevent ventilation failure during strong winds in winter is a rotating vent cap. It keeps the odor from being blown back down the ventilation pipe and increases the rate of humid air that gets drawn through the pipe, which helps to dry out the feces.

Urine Pipe

A defined risk is the freezing of the urine either already in the pipe or in the underground where the urine will get disposed. According to Stintzing et al., (2007) the freezing point of urine depends on the concentration of ions. A urine container above ground will start to freeze from -5 °C (23 °F) or lower. When urine freezes the volume expands which should be considered in planning (Stintzing et al., 2007).

Based on information of the geotechnical studies by Lunsford, (1974), and RZA, (1986) brackish water at the depth of fife feet occurs in Kivalina. Geotechnical conditions can vary significantly within a specific area, thus the calculations of the rate of heat loss per unit length and design freeze up time were determined as proposed by (Smith, 1996 c). Table 5 lists all relevant parameters used for the above-mentioned calculations.

Table 5: Summary of needed parameters relevant for the winterization calculation of the urine pipe

Outer pipe radius	r_{po} = 17.5 mm
Inner pipe radius	r_{pi}= 16 mm
Insulation radius	r_I = 77.5 mm
Depth below surface	z_p= 1.5 m
Thermal conductivity of the pipe, (Smith, 1996 c)	k_p= 0.36 W/(m°C)
Thermal conductivity of the insulation, (Smith, 1996 c)	k_I= 0.023 W/(m°C)
Thermal conductivity of the ground, (Smith, 1996 c)	k_g= 2 W/(m°C)
Input urine temperature	T_{u1} =T_u= 37 °C
Temperature of the air	T_a = -45 °C
Freezing temperature	T_0 = -5 °C
Pipe length	l = 5 m
Specific volumetric heat capacity (Smith, 1996 c)	C = 4.19 kJ/(kg°C)
Volumetric flow rate	Q_v = 0.00002 m³/s
Constant, N	N= 1.12 W/(m7/4*°C5/4)
Constant, W	$\sqrt{0.56v} + 1$

The following calculations were conducted for above-ground pipes and for buried pipes. The urine pipe will go out of the wall directly into the ground. For houses on piles, a piping section will go above-ground before leading into the ground. The best way to minimize frost damage is to reduce the heat loss, which can be easily achieved by using insulated pipes. The heat loss of an uninsulated above-ground pipe and buried pipe was calculated to compare them to an insulated above-ground pipe and buried pipe (equation 1-14) to show the positive benefits of pipe insulation. Above-ground pipes must be designed to the lowest expected air temperatures (Smith, 1996 c).

Heat flow from an uninsulated above-ground pipe

Thermal resistance of the pipe, R_p

$$R_p=\frac{r_{po}-r_i}{(r_{po}+r_i)\pi\times k_p}= 0.04\ m°C/W \quad (1)$$

Near surface conduction thermal transfer coefficient, μ_{af}

$$\mu_{af}=N*(\frac{Tu-Ta}{rp})^{\wedge}0.25*W= 5.53\ W/m^2°CW \quad (2)$$

Thermal resistance of the air film, R_{af}

$$R_{af}=(2*\pi*r_p*\mu_a)^{-1}= 1.07\ m°C/W \quad (3)$$

Thermal resistance by conduction of an uninsulated above-ground pipe, R_c

$$R_{cau}=R_p+R_a= 1.11\ m°C/W \quad (4)$$

Rate of heat loss of the uninsulated above-ground pipe, q_c

$$q_{cau} =(T_u-T_a)/R_c= \underline{74.11\ W/m} \quad (5)$$

Heat flow from an insulated above-ground pipe

Thermal resistance of the insulation, R_I:

$$R_I = \frac{\ln\left(\frac{r_I}{r_{po}}\right)}{2\pi k_I} = 10.30\ m°C/W \quad (6)$$

Thermal resistance of the pipe, Rp:

$$R_p=\frac{r_{po}-r_i}{(r_{po}+r_i)\pi\times k_p}= 0.04\ m°C/W \quad (7)$$

Thermal resistance by conduction of the above-ground pipe R_{ca}:

$$R_{cai}=R_I+R_p= 10.34\ m°C/W \quad (8)$$

Rate of heat loss of the above-ground pipe q_{ca}:

$$q_{cai} =(T_u-T_a)/R_{ca}= \underline{7.93\ W/m} \quad (9)$$

Heat flow from an uninsulated buried pipe:

Thermal resistance of the ground, R_g

$$R_g=\frac{\operatorname{arccosh}(\frac{z_p}{r_I})}{2\pi*k_g}= 0.12\ m°C/W \quad (10)$$

Thermal resistance by conduction of an uninsulated buried pipe, R_{cbu}

$$R_{cbu}=R_{as}+R_p+R_g= 1.23\ m°C/W \quad (11)$$

Rate of heat loss of the uninsulated buried pipe q_{cbu}:

$$q_{cbu} =(T_u-T_a)/R_{cbu}= \underline{66.67\ W/m} \quad (12)$$

Heat flow from an insulated buried pipe

Thermal resistance by conduction of an insulated buried pipe, R_{cb}:

$$R_{cbi}=R_I+R_p+R_g= 10.46\ m°C/W \quad (13)$$

Rate of heat loss of an insulated buried pipe, q_{cb}:

$$q_{cbi}=(T_u-T_a)/R_{cbi}= \underline{7.84\ W/m} \quad (14)$$

The heat loss from the above-ground pipes is only slightly higher than the heat loss of the buried pipes both insulated and uninsulated. The heat loss from the insulated pipes is 10 % lower than from the uninsulated pipes. The Uninsulated above-ground pipe is the risk of freezing greatest.

Also the heat loss from a fluid flowing through a pipe is significant as shown in equation (15-18).

Heat loss and temperature drop in a fluid flowing through a pipe

Auxiliary quantity, G:

$$G =Q_v*C*R_l= 862.90\ m \quad (15)$$

Output urine temperature, T_{u2}:

$$T_{u2} =T_a+\left(T_{u1}-T_a\right)\times \exp\left(\frac{-l}{G}\right)= 36.53\ °C \quad (16)$$

Thermal resistance of Unit Length, R_f

$$R_f=-l\left(Q_v*C*\ln\left[\frac{T_{u2}-T_a}{T_{u1}-T_a}\right]\right)^{-1}= 10.30\ m°C/W \quad (17)$$

Heat loss rate of the fluid q_f:

$$q_f=\frac{G}{R_f}\times(T_{u1}-T_a)\times\left[1-\exp\left(\frac{-l}{G}\right)\right]= \underline{39.70\ W} \quad (18)$$

The calculations of the heat loss of a fluid flowing through a pipe shows, that it is much higher than the heat loss of the pipe with insulation and buried in the ground. The heat loss, q_f is less than the heat loss from an uninsulated pipe, above-ground or buried.

Design freeze-up times:

The design freeze-up time, t_f was calculated (equation19-22) to determine how much time to freezing for water in an insulated buried pipe will take to reach the freezing point of urine (-5°C). The design freeze-up time was calculated under no-flow conditions, the worst-case scenario. "*Pipe insulation is used to minimize energy required for heat tracing systems and to extend the time to freezing in the event of system failure*" (Buttle et al., 1999).

Design freeze-up time, t_{fau} for an uninsulated above-ground pipe

$$t_{fau} = \pi r_{pi}^2 \times R_{cau} \times C \times \ln\left(\frac{T_u - T_a}{T_o - T_a}\right) = \underline{0.74\ h} \quad (19)$$

Design freeze-up time, t_{fai} for an insulated above-ground pipe

$$t_{fai} = \pi r_{pi}^2 \times R_{cai} \times C \times \ln\left(\frac{T_u - T_a}{T_o - T_a}\right) = \underline{6.95\ h} \quad (20)$$

Design freeze-up time, t_{fbu} for an uninsulated buried pipe

$$t_{fbu} = \pi r_{pi}^2 \times R_{cau} \times C \times \ln\left(\frac{T_u - T_a}{T_o - T_a}\right) = \underline{0.83\ h} \quad (21)$$

Design freeze-up time, t_{fbu} for an insulated buried pipe

$$t_{fbi} = \pi r_{pi}^2 \times R_{cau} \times C \times \ln\left(\frac{T_u - T_a}{T_o - T_a}\right) = \underline{7.03\ h} \quad (22)$$

The urine is allowed to stand in the pipe without freezing for 6.95 h in an insulated above-ground pipe which is 6.21 h longer than in an uninsulated above pipe. This trend is also confirmed by the buried pipes. The buried pipes both uninsulated and insulated show a slightly longer time before freeze up. To minimize the risk of pipe material damage from freezing inside high density polyethylene was chosen as a suitable pipe material which still remains ductile at -60 °C, so they won't crack if water freezes in the pipes and survives the pressure of water expansion on freezing (Buttle et al., 1999).

According to the above calculations the risk that the urine is freezing in the chosen insulated pipes is very low due to the short pipe length leading directly vertically into the ground outside of the house. Still, the arctic climate is unpredictable. To assure that the toilets don't fail because of frozen urine pipes, heat trace lines will be additionally installed to the insulated pipes.

Feces Collection Box

The collection box for the houses with under-floor collection might not always be accessible in winter due to snowdrift and snowstorms. The collection container has to be sized in a way that using the toilet for a longer period due to winter storms does not affect the toilet use. Frozen feces on the dropping pipe have to be avoided. This risk can also be reduced with a well-scheduled collection plan. In Kivalina winter conditions, with temperatures below -40 °C (-40 °F), feces falling into the collection container may freeze before the pile has time to slump. The pit will not be filled efficiently, instead containing a frozen mound of excreta and void space (Buttle et al., 1999). It is not energy efficient and necessary to avoid the freezing of feces if winter conditions are taken into account. The planning of the system considers the freezing of feces.

5.3 Installation Details

5.3.1 General Information on the recommended UDDT

After researching potential UDDT technologies, the decision has been made to pilot the UDDT- model Villa 9210 from the company Separett in two different modes of installation to take into account the various architectural building units existing in Kivalina. The Villa 9210 was chosen for the following reasons:

- Odor reducing design
- No water required
- Easy installation
- Moderate investment and operation costs
- Reduces contact with pathogens
- Supplier is an Alaska-based company: spare parts easily available
- Reduces amount of waste volume to be hauled to dump site
- Attractive design
- Energy-efficient fan

To ensure adequate water content of the collected human solid waste suitable for the biochar reactor, UDDTs are the chosen technology. There are several apparent benefits changing the current sanitation system (honey bucket) to UDDTs. Reducing the need for handling and removing open deposits of human feces will decrease rates of waterborne illnesses and pollution of the environment with pathogens. The volume of human waste will be significantly reduced through separating the liquid from the solids. Additionally, the odor is minimized when the urine and feces are not mixed together reducing the need to add chemicals into the bucket.

The chosen UDDT can be modified to be suitable for the two different installation modes, the under-floor collection system and the in-home collection system. Figure 12 shows the Villa 9210 model.

Figure 12: UDDT model Villa 9210 (Eco Services Group, 2011)

In table 6 the aspects of installation, usage, operation and collection of both installation types are compared.

The installation of the under-floor collection type requires more effort and change of the building structure than the in-home collection type. The installation of the under-floor collection system requires outlets in the floor for the urine, the feces and additionally an outlet in the wall for the ventilation pipe, which could lead to heat loss through the feces outlet. The in-home collection system just needs an outlet for the urine waste pipe and one for the ventilation pipe, which also eliminates the thermal bridge from the relatively large feces opening. Through adaptations in the building structure and installation of counter flow heat exchanger, the negative effects of thermal bridges can be reduced. Also the installation of the toilet plus additional infrastructure is achieved quicker with the in-home collection system since no additional under-floor collection installations are needed.

Table 6: Comparison of two UDDT installation modes

	Under-floor collection	In-home collection
Cuts in the building substance	Ventilation, urine and feces outlet	Ventilation and urine outlet
Thermal bridge	Big thermal bridge through the feces outlet from the insulated box	Minimal thermal bridge through the ventilation pipe
Installation	Additional labor required for the soak away and the insulated box + cuts in the building substance	Additional labor required for the soak away, installation of the toilet in 2-3 h
Additional installation material needed (besides the UDDT)	All additional parts besides the toilet need to get ordered	Almost all parts are included
Design	Attractive design	Attractive design
Contact with the feces from the users	No contact	Possible contact while carrying out Double barrier protection (sealed bag and closed bucket) reduces this probability.
Costs for operation	Energy costs for ventilation and the use of heat trace, higher costs for collection	Energy costs for ventilation and the use of heat trace, lower costs for collection
Collection	Easy collection from outside	Collection either from the house or a storage container outside
Emptying period	Long period given the volume of the under-floor container, depending on the size of the container	Given container size 6 gal
Seasonal variations	Possible collection problems in the winter (snow, Ice)	Possible in-home collection in the winter

A very important feature to ensure the correct operation of the toilet is a child seat with the separating function to assure that the urine waste pipe is not clogged with solids. A child seat is included in the Villa 9210 for both installation types.

To reduce any possible contamination with pathogens, the contact with the solid waste container should be reduced to a minimum. The under-floor collection model collects the feces underneath the house in an insulated box with an opening that can be closed. Via the opening, trained waste collectors could replace the full bucket with an empty one; this would be a hygienic and comfortable solution for the toilet users who don’t have to handle contaminated feces anymore. The solid waste container in the Villa 9210 comes with compostable plastic bags and lid, which also helps to reduce the risk of contamination. The in-home collection system relies on the toilet user to close the full bucket with the lid and bring it outside the house ready for the trained staff to collect the human waste. For both models handling the waste container is easier and safer than handling honey buckets also because of the greatly reduced liquid in the bag. Extreme weather conditions especially in the winter are a challenging task for solid human waste collection. Collecting the containers from outside might be negatively affected by snowdrifts or ice. In-home collection could be guaranteed throughout the year.

The Alaska Village Electric Co-Op (AVEC) provides electricity to Kivalina via diesel generators, which makes electricity quite expensive, although the first 500 kWh are subsidized. The Villa 9210 needs 0.06 kWh/24h which would result in a monthly payment of US$ 1 per month for operating the ventilation. Therefore the issue of odor inside the house is not a limiting factor in both installation types. Possible odor nuisances might appear outside the house in a densely populated area like Kivalina. To minimize this problem the vent pipe will end 1 m (39 in) above the roofline. Warm air exhausting from the house will be more buoyant than the ambient air outside, reducing any odor risk outside.

Another important aspect is the emptying period of the solid waste container; an under-floor collection system allows variable container sizes, which can be adapted to the needs of the operation of the biochar reactor. The in-home collection provides less flexibility concerning the container size. The container volume of the Villa 9210 is 23 l (6 gal), which results in an emptying period of 25 days for an average family size in Kivalina of 4.4 people, not including toilet paper. This toilet model convinces with its attractive design, which is desired by the people in Kivalina. The urine will be drained in both systems via a soak away in a depth of 1.5 m (5 ft) which represents the freezing depth in Kivalina (Lunsford, 1974). Nitrate pollution of the groundwater is not regarded as a risk since it is salty and not used by the residents.

Altogether, both installation types will be well suited for Kivalina and satisfy the divers architectural, geographical and social needs. To assure project success the villagers are integrated into the decision process, regularly informed and communication channels established. The communication and engagement strategy supports the project and is the basis for a successful adaption of the new system.

5.3.2 Specific Information on the recommended UDDT

Following technical components are included in the Villa 9210 according to the producer (Eco Services Group, 2011):

- Pressure seat with view screen, to cover the solid waste
- Rotating container so that the feces are evenly distributed

- Two speed fan (electricity cost estimated at US$ 1 per month)
- Child seat
- Vent pipe ⌀75mm (3 in), vent grid, vent cowl, indoor vent flashing
- Connector pipe straight, connector pipe 90°
- 3 solid waste containers (23 l (6 gal)) and 2 lids
- 10 compostable waste bags
- 2 m (6.5 ft) long hose for urine waste ⌀32 mm (1.3 in)
- Silicon sealant compound
- Mounting screws
- Insect nets

The vent pipe that ships with the order of the Separett Villa 9210 is SDR35 and only 40 cm (1.3 ft) long, adaption to a commonly available 75 mm (3 in) SCH40 PVC pipe and fittings is necessary to guide the vent pipe out of the roof if necessary. To connect the two different vent pipes a waste valve seal type T1003-7VP 75 mm (3 in) is needed. The fan should operate continuously to keep the housing dry and to extend the lifetime of the fan. The venting pipe should go straight through the wall where possible. If this approach is not possible due to proximity to the house entrance or to where people gather, the venting pipe could go through the roof. Good seals need to be ensured. The Separett Villa toilet has a condensation collector which leads the condensation liquid into the urine pipe and does not need to be insulated.

Figure 13 shows the dimensions of the Separett Villa 9210. The included urine outlet is 2 m (6.56 ft) long and needs to be extended to 3 m (10 ft) preferably as a pipe. Under normal circumstances the urine waste does not freeze in the winter (freezing temperature at about -5 °C (23 °F)) if a slope of the entire length is ensured and at least a 50 mm (2 in) pipe is used outdoors. A steeper downward drop lessens the risk for deposit build-up of urine salts or ice. Still, we will insulate the piping sections that run outdoors and install heat trace lines to reduce the risk of toilet failure.

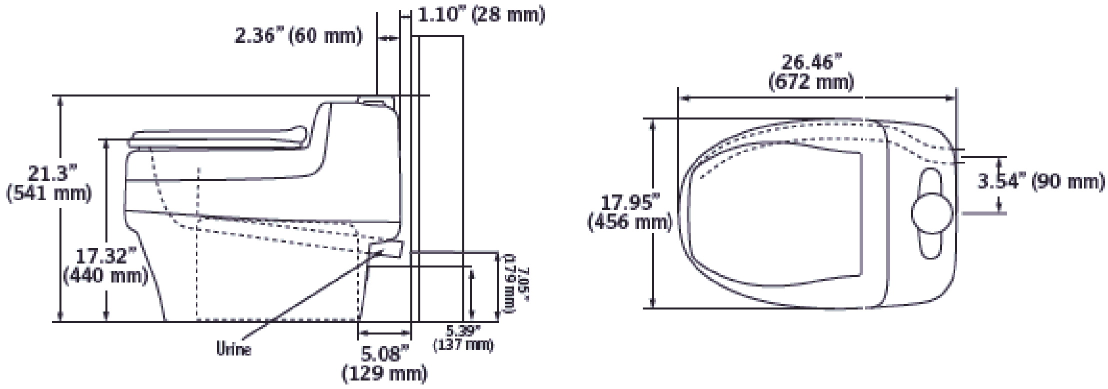

Figure 13: Installation dimensions (Eco Services Group, 2011)

The island is composed of primarily medium sand and locally sandy gravel until a depth of 1.5 m (5 ft), than the underground is composed of coarse gravel which represents also the freezing depth (Lunsford, 1974). For toilet installation, the urine outlet has to reach this gravel layer. At the same time clogging is prevented. To reduce the risk of urine salt deposit build-up in the urine outlet it is recommended to rinse the urine basin with a small cup of water after each use. As an alternative also a liquid drain unblocker can be used.

A big concern that was mentioned by the people in Kivalina was the possibility of having more flies and insects inside the house, which could carry germs from inside the toilet. The toilets are designed in a way that the collection container is inaccessible for flies and other insects. The continuous air stream during operation also keeps flies out of the toilet.

Table 7 shows the technical data of the chosen UDDT model.

Table 7: Technical data of the Separett Villa 9210 (Eco Services Group, 2011)

Material	Inner container	Voltage	Power consumption	Electrical connection	Noise level fan
Impact-resistant high-gloss polypropylene, recyclable	23 l (6 gal) Polypropylene	12 V	0.06 kWh/24h	Battery Cable or power adapter	<30 dB(A)

The Separett UDDTs depend not on room temperature, since there is no composting process inside the toilet and thus the UDDTs can also be placed in cold unheated rooms as long as the temperature doesn't drop below -5 C (23°F). The toilet can be installed personally by the home-owner, which takes about two to three hours.

5.3.3 Installation of the Collection Chamber

After the concept development of the under-floor collection system a pilot study was successfully realized. The aim of the laboratory trial was to test and to analyze the functioning of the under-floor collection segment based on the pulley principle. The model of the collection chamber was not built one-to one, only the functionality of the system was tested.

Figure 14 shows a cross section of the NIHA-house with a future under-floor collection system. The concept development focused on easy construction, low-tech and use of easily available and cheap materials. It was emphasized that the system will work even if the installation will not be realized precisely in Kivalina. Also the system needs to be arctic weather resistant.

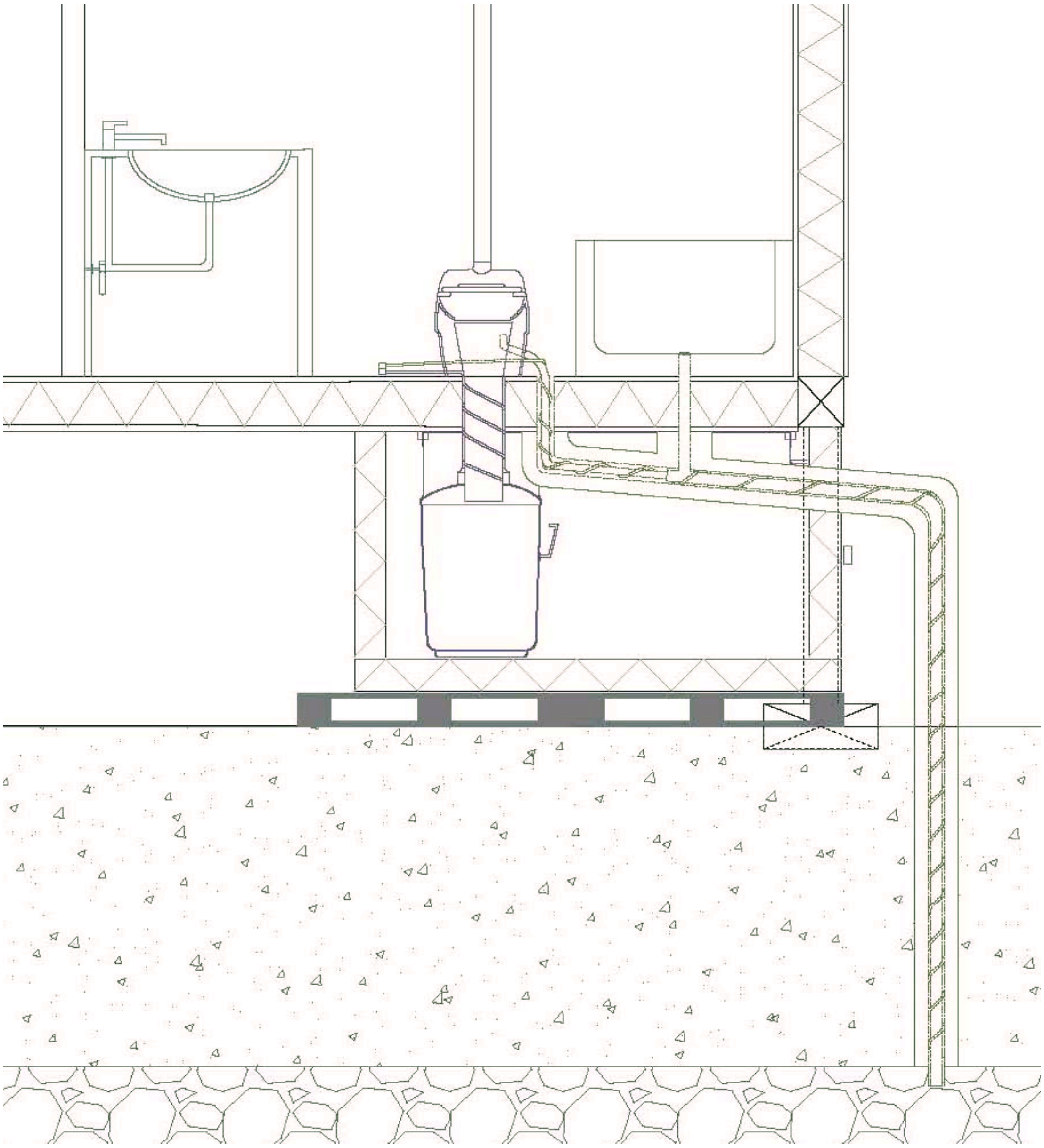

Figure 14: Installation of the under-floor collection system

For the trial two standard pipes available in every hardware store were used. Two pipes with different diameters were chosen to place them inside each other. The inner pipe is surrounded with a heating trace the outer pipe is fixed to the lid of the metal collection container. Everything has to be airtight; a felt is placed between the two pipes for airtight aspects. The collection container is enclosed by insulated SIP panels to protect it against wind and snow.

Figure 15 shows a model of the functional principle of the collection box. The container lid has to open automatically when the waste collector is opening the arctic box. This is achieved by ropes that are connected to the container lid and are also connected through rope winches with the door of the arctic box.

Figure 15: System model of the collection chamber

The wastewater outlet of the bathtub has to be connected to the urine pipe otherwise the wastewater of the whole household would be discharged directly out of the house on the ground. The collection container size was calculated by the amount of the produced wet matter per person and day and by the average household size. According to Shalabi, (2006) each person in North America on average produces 0.2 kg (7 oz) solid waste per day with a water content of 75 %. The U.S Census 2010 came to an average household size of 4.4 in Kivalina. Based on this data a 113 l (30 gal) container has a capacity of 130 days which is about 4 months. This calculation does not include toilet paper or other sanitary items thrown into the toilet, which will lead to a reduction of the available volume in the collection container of about 10 % assuming that the toilet paper absorbs moisture from the feces and therefor reducing its volume. The container capacity will get reduced to 110 days (3.6 month). This number is depending on the usage.

5.3.4 Pilot Installation at the Tribal Office

A small-scale pilot toilet trial in Kivalina was conducted to test the operability and function of the UDDT technology in Kivalina and appraise the comparability and compatibility of UDDTs alongside concurrent research of alternative sanitation technology systems by state and federal agencies and of the suitability of biochar sanitation systems for Arctic villages and for use in Kivalina specifically.

The first toilet is piloted in a public building to allow access to interested people. All possible public buildings were assessed under consideration of the following factors and summarized in table 8: Regular use, accessibility to the entire population, employed toilet facilitator, available space for the toilet, no in-home water supply, no connection to a septic tank and in-home collection.

Table 8: Pros and cons of the future location of a public separation toilet

	Tribal Council	City Council	S & R building	Store	Episcopal Church	Friend's Church	Nana Office	Washeteria
Regular use	x	x		x			x	x
Accessible to everyone			x	x				x
Employed staff	x	x		x				x
Available space	x	x	x				x	
No water and sewer connection	x	x	x	x	x	x	x	
In-home collection	x		x		x	x	x	

There is no public toilet available in Kivalina at this time; the use of the public UDDT would have to be advertised and communicated. According to the considered factors the best suitable public building is the Tribal Council.

During the field trip in September 2014, one in-home collection toilet was installed at the Tribal Office, accessible to the public as a “Show and Tell Toilet”. The trial is supervised by staff members who also agreed in teaching interested villagers about the toilet. Only locally available materials where used for installation, which was completed in two days.

Figure 16 shows pictures of the toilet installation process. The left top shows the bathroom of the Tribal Council before the toilet trial, the middle top picture shows the hole that was dug for the insulated urine pipe with brackish water at a depth of 1.7 m (5.5 ft). The pictures in the bottom show the finished toilet installation from inside and outside.

Figure 16: Toilet installation at the Tribal Council

It was considered to monitor the function of the pilot toilet with the help of Council members through filling out inspection sheets. It became clear, that the only possibility to monitor the toilet was through direct communication, performed by the project partner “Re-locate Kivalina” during additional field trips. This way also more open answers could get collected than through filling out forms. “Re-locate Kivalina” is in permanent contact with the city officials and council members in charge of the pilot toilet operation and maintenance.

The preliminary result collected by Re-locate Kivalina, (2015) can be summarized as followed:

- Overall positive opinion about the toilet
- Only had to change the bucket once yet (end of December)
- Toilet is mainly used to urinate
- One report of a dysfunction of the concealing view screen (poo on the flap)
- One report of odor problems in November- on a day with unusually very strong winds
- One report of freezing problems of the urine pipe on a day with -45°C (-50°F) – the heat trace was not plugged in
- Heat trace is regarded as fire hazard

One odor problem in the bathroom on a really windy day was reported with only 1/3 power available for the fan because of differences in capacity which got remedied with a battery and charger. A bigger rotating vent cap on top of the ventilation pipe will help to increase the drying potential of the feces and reduces the risk of odor during storm events.

Also one freezing incident at a temperature below -45 °C (-50 °F) was reported because the heat trace was not plugged in. A fire destroying the Kivalina store this winter contributed to great attentiveness about fire hazards and was the reason why the heat trace got plugged-out. Installing a thermostat to regulate the heat input will help to reduce fire danger, and the risk of frozen pipes.

The preliminary results showed that specific elements of the toilet are not robust enough. The mechanism of the concealing view screen broke as well as the plastic hooks to open the toilet seat. This result shows especially moving technical parts need to be improved and/or reduced before village-scale implementation.

5.4 Local Waste Management Economics

5.4.1 Current Honey Bucket Use Pattern

The current utility use pattern and the informality in the sanitation sector of the current sanitation system in Kivalina were determined by the honey bucket survey, which was co-developed by “Re-locate Kivalina”. The goal of this survey was to determine the time effort, costs and social pattern of the different sanitation utility steps (emptying, storage and transportation of the honey bucket waste from the household to the dump). Another goal of the survey was to collect information about the present informal waste collection system that includes transporting the waste or emptying honey buckets for a family member but also offering such services to supplement the income. Such information is highly valuable for the development of a new waste collection system, which will take over the existing structures. Based on experience from “Re-locate Kivalina”, young men are mostly in charge of the human waste disposal and were chosen as the relevant group of the inhabitants to be interviewed. The 15 interviewed households were chosen randomly by meeting young men between 16 and 25 in front of their usual gathering places, the store, school or post office.

The interviews always started with the following questions:

- Where is your house?
- How many persons live in your house?
- How are you related to the persons living in your house?
- Are the persons in the house living there the whole year or just over a certain time period?

The location of the house was shown by the interviewees on a simple map of Kivalina, which was digitized from a satellite image and supplemented in advance. The number of the household members is illustrated in figure 18. The number of people sharing a toilet is essential to calculate the filling rate of the collection container of the UDDT and the collection and exchange period of the containers. Two average household sizes were determined, one for households with less than 5 members and one for households with more than 5 members. For households with more than 5 members the average household size was 8.0 and for households with five or less members the average household size had 3.7 members. According to the Department of Labor and Workforce Development, (2010) the average household size in Kivalina includes 4.4 members. All of the interviewees were living either together with their family or extended family. Most of the household members were living during the whole year in the same house, in two cases household members are only periodically living in Kivalina due to an employment elsewhere.

To find out about the honey bucket emptying practices following questions were asked:

- Who empties the honey bucket in your house?
- How often does the honey bucket get emptied in your house?
- How many honey buckets are there in your house?
- Does your honey bucket get always emptied at the same time each day?

Table 9 shows the results of the question on who empties the honey bucket, on how many honey buckets there are in each house and if the honey bucket gets emptied always at the same time. The question on how often the honey bucket gets emptied in each house is answered in figure 17.

Table 9: Results of the questions regarding the emptying practices

Who empties the honey bucket in your house?	
Male member	93.33 %
Female member	6.66 %
How many honey buckets are there in your house?	
One	100.00 %
Does your honey bucket get always emptied at the same time each day?	
Yes	46.67 %
No	53.33 %

Handling of human waste is often accomplished by male family members; a 19 l (5 gal) bucket filled with mostly liquid is heavy to lift and to carry outside the house. The emptying period of the honey bucket depends on the number of household members and is on average for a household with >5 members every 1.1 days and in a household with <5 members every 1.6 days. The emptying periods are shown in figure 17. Every interviewed household had only one honey bucket. The most frequent emptying time of the honey bucket was the evening; often the answer was also that the honey bucket gets changed whenever it is full.

The next questions are related to the honey bucket use practices:

- Who uses or can use the honey bucket in your house?
- Do you use a potty for your toddlers?
- Where do you put the waste from the potty?
- What do you throw in your honey bucket?
- Do the men in your house urinate standing or sitting when using the honey bucket?
- Do you use the honey bucket at other people's houses?

Every asked household stated that they throw only toilet paper, sanitary products and pine-sol (cleaning product with scent) into the honey bucket. Also men indicated that they urinate standing, which highlights the need for the introduction and planning of waterless urinals.

Table 10 shows the results of the question on who can use the honey bucket, if toddlers use the honey bucket and if people use the honey bucket at other people's houses.

Table 10: Results of the questions regarding honey bucket use habits

Who uses or can use the honey bucket in your house?	
Family	53.33 %
Anybody	33.33 %
Family and friends	6.67 %
Other	6.67 %
Do you use a potty for your toddlers?	
Honey bucket	58.33 %
Potty	16.67 %
No toddler	25.00 %
Do you use the honey bucket at other people's houses?	
Yes	53.33 %
No	46.67 %

In 53.33 % of the interviewed households only the family used the honey bucket, 33.33 % stated that anybody who wants can use their honey bucket at home. Additionally, the nonexistence of public honey buckets in Kivalina confirms the result that people prefer using their own honey bucket. In individual cases people stated that they find honey buckets unhygienic and fear infections so that they prefer to use only their own.

More than half of the households (58.33 %) stated that their toddlers change directly from diapers to the honey bucket. Only 16.66 % of the toddlers use a potty. According to the interviewees the diapers get thrown into the normal trash and not into the honey bucket to prevent filling up. Considering the high numbers of children in Kivalina, this result represents a significant health risk. The proposed UDDT model Villa 9210 comes with a children’s toilet seat, which considers this trend. Diapers can be collected separately and can be combusted at the biochar reactor when available. 53.33 % of the interviewees indicated that they are using the honey bucket at other people’s houses mostly at family or friends houses and only if it is really urgent. 46.67 % prefer to use their own honey bucket.

Questions regarding the storage of the honey buckets:

- Where do you put the honey bucket waste that is waiting to be taken to the dump?
- How long do you store the honey bucket in front of the house until you bring it to the dump?

The honey bucket waste is always stored outside of the house mostly on the side of the entrance unprotected in boxes or totes. Care is taken that the wind doesn’t blow the smell to the porch and that the buckets don’t stay in the way.

The storage time of the honey bucket waste outside of the house in the summer is illustrated in figure 17. The storage time ranges from a few days to some weeks.

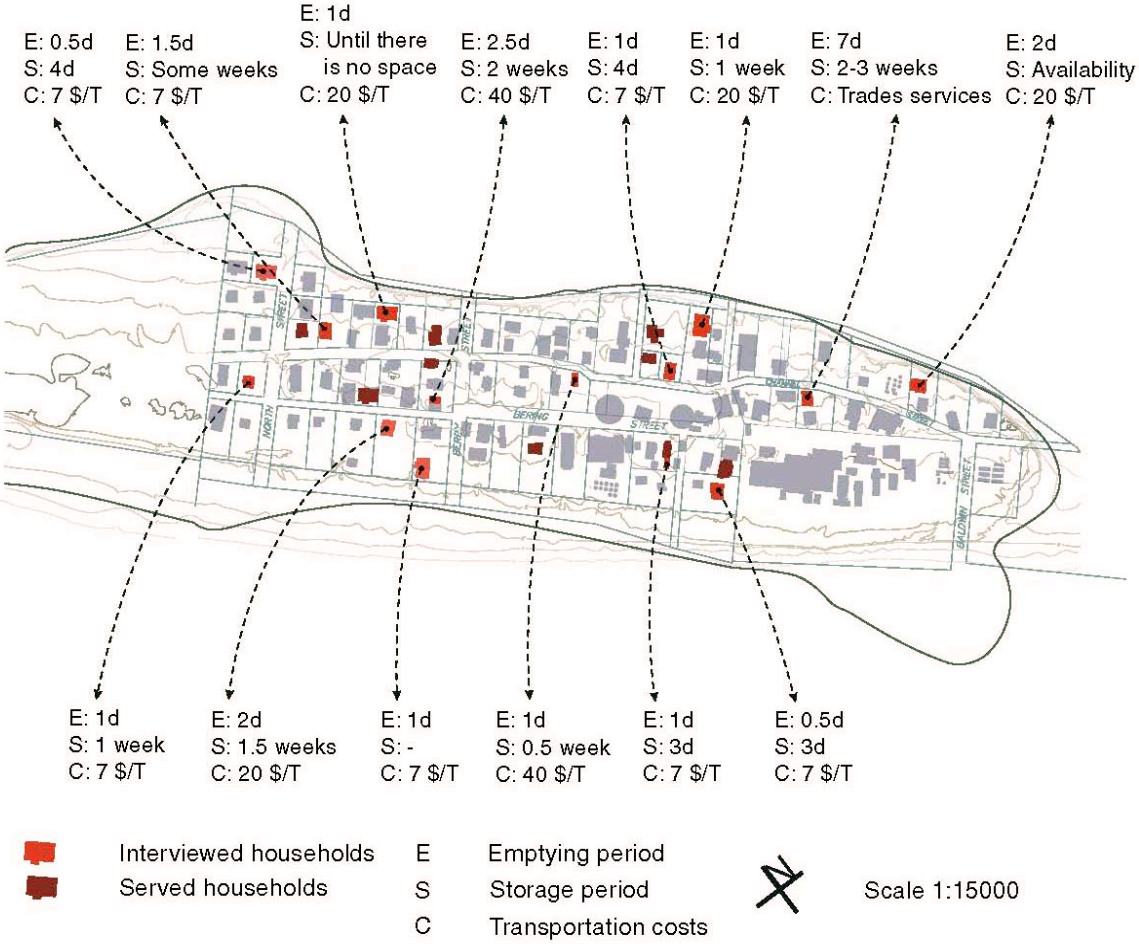

Figure 17: Illustration 1 of the honey bucket survey

In winter the honey bucket waste is stored in cardboard boxes which are dumped together with the frozen honey bucket waste. Dumping honey bucket waste is considered easier in winter when the human waste is frozen. Also some families reported that when the stored waste in winter is snowed in they wait until the snow is melting which significantly increases the storage time in winter and shows a problem to the community in spring. Unpleasant smell, increased health risk and related illnesses and unaesthetic appearance of the honey bucket piles are the cause of social tensions in spring.

Questions regarding the transportation of the honey bucket waste:

- Do you transport waste from your house to the dump?
- How do you transport the honey bucket waste to the dump?
- Do you transport waste from other people’s houses to the dump?
- Do you wear protective clothing (masks, and gloves) when you are handling honey bucket waste?
- Do you do other chores for your house?

Table 11 gives answers on the questions if the interviewee is transporting waste from his house to the dump, if he is wearing protective clothing when handling honey bucket waste and if he is doing other chores of the household.

Table 11: Results of the questions related to the transportation of the honey bucket waste

Do you transport waste from your house to the dump?	
Yes	54.54 %
No	45.46 %
Do you wear protective clothing when you are handling honey bucket waste?	
Yes	80.00 %
No	20.00 %
Do you do other chores of your house?	
Yes	100.00 %
No	0.00 %

It is common in Kivalina to bring the trash to the dump at the same time as the honey bucket waste. It mainly depends if the family has access to a transportation vehicle. If not a family member will step in or people will announce the chore on the local broadband network radio (VHF) and pay someone. Young men create supplementary income by transporting waste and honey bucket waste to the dump or they help out family members without transportation vehicle.

80 % of the interviewees are using a form of protection clothing, mainly rubber cloves when handling honey bucket waste. 20 % don't use any kind of protection cloth when handling honey bucket waste a high number which needs to get reduced in future. More public information and the offering of rubber cloves free of charge are necessary.

Every interviewing is also carrying out other chores of the house, like hauling water, getting fuel and taking out the trash and wastewater.

Figure 18 illustrates the number of members of the interviewed households and the availability of an own waste transportation vehicle (Y= transportation vehicle available, N= no transportation vehicle available). The arrows show which interviewed households is helping out mostly family related households with waste collection services in exchange for small favors.

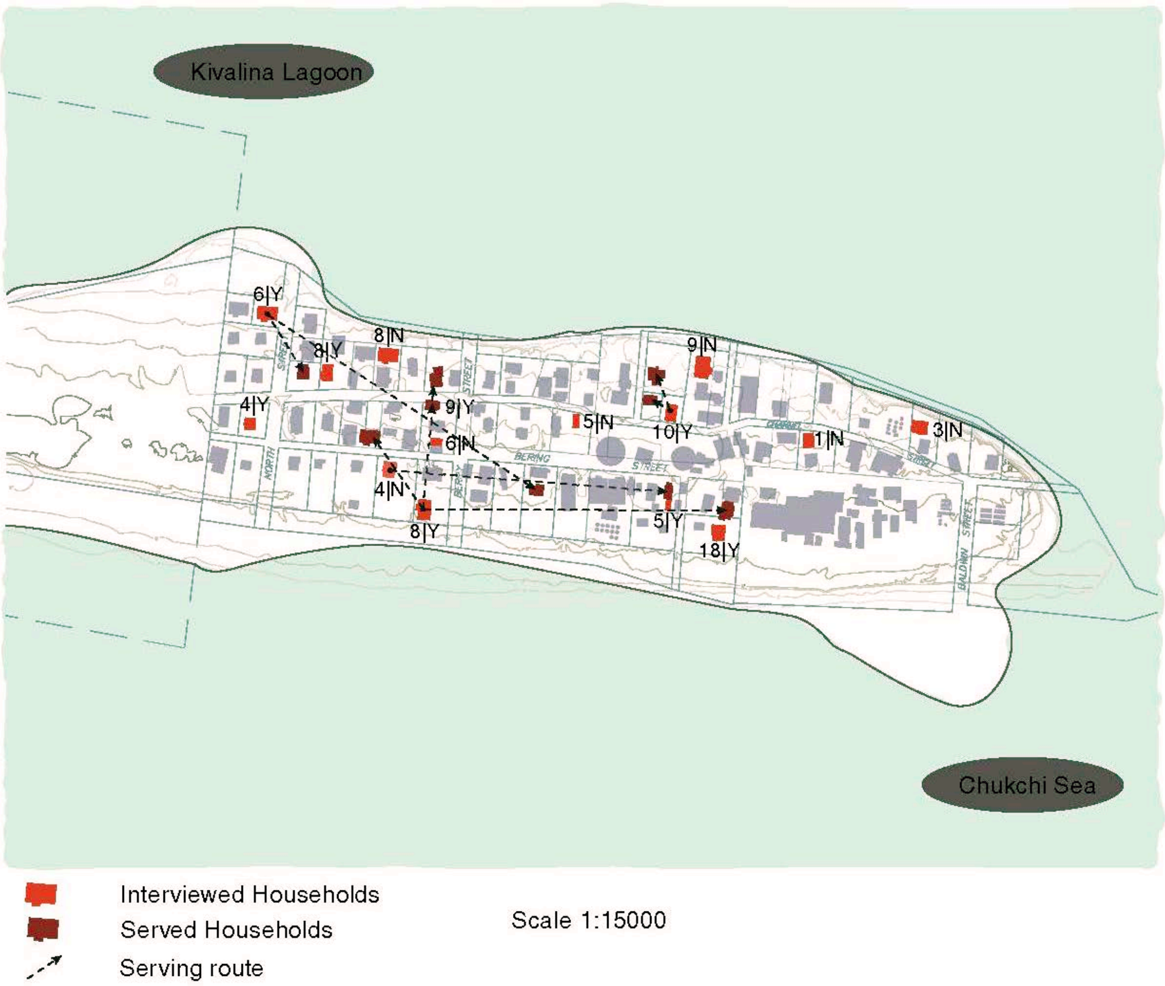

Figure 18: Illustration 2 of the honey bucket survey

According to an interview with the tribal administrator held by "Re-Locate Kivalina" on 21.4.2014 many young men don't dump the honey bucket at the designated areas at the open dump because of lack of education. This practice leads to an extension of the dump towards the village and to a health risk for people going to the dump.

5.5 Commercial Feasibility Study

The commercial feasibility of the project depends mainly on market research and analysis capabilities. Throughout the field trip we investigated if the specifications of the service meet the real needs of the community. A thorough analysis of all aspects of the project should provide an assessment of the profitability, risk, commercial aspects and integrate the expectation and needs of the community.

This chapter defines the design and intent of the provided service, and further it provides an estimated budget based on the best available information.

The commercial feasibility study was developed within specified boundary conditions. The total expenditures are divided in capital expenditures (CAPEX) and operational expenditures (OPEX). It is anticipated that the costs for sanitation infrastructure and installation (CAPEX) are funded by grants. Only the operational expenditures have to be borne by the community. Also the system is not supposed to make profit; the goal is to generate enough money to guarantee operation and maintenance. Table 12 and table 13 are summarizing the results of the commercial feasibility study.

Table 12: Results from the commercial feasibility study

Value proposition	
What is the value for the community?	Safe human waste and recycled waste collection, transport and disposal
Which community problems get solved?	Contamination of public and private ground Potential contamination and spread of pathogens Unpleasant appearance and smell
What services are offered to each customer?	Regular exchange and removal of human waste and recycled waste
Which needs of the community are met?	Human- and recycled waste collection and disposal
What are the required features?	Human waste collection should be affordable and safe Service guaranteed on a regular basis
Customer Segments	
Who benefits from the project?	The whole community: private→ households public→ offices, shops
Do the value propositions match their needs?	Yes
Channel	
How does the community wants to be reached?	Door-to-door service
How are they reached now?	Family relationships Informal self-disposal solutions Recycling program for cans and plastic bottles
How can the channel be integrated?	Rising of community awareness by highlighting an affordable and convenient system Through specially trained workers who are already involved in the informal waste economy
How is the channel integrated in household routines?	Analyzing household routines Basing it on the existing service but optimizing it in terms of environmental, economic and health aspects
Customer relationship	
What type of relationship does each customer segment expect to establish and maintain?	Maintenance and introduction of separating toilets (households) Binding of existing customers (administration), Stable sales for the shop workers in the informal waste sector
What relationships have been already established?	Introduction of separating toilets Practical trial
How are they integrated with the rest of the feasibility study?	Existing relationships are used to develop a business model that is based on existing structures

Table 13: Results from the commercial feasibility study (continued)

Key activities	
What key activities do the value propositions require?	Separation of the solid and liquid human waste Safe transportation of human waste in closed containers Affordable for everyone Creating jobs Reducing health hazards
What are the key issues to be communicated	Convincing households which have a cheap possibility to illegally dispose waste Creating jobs Communicating the benefits of separating toilet at household level at community meetings, open house events, information flyer...
What are potential revenue streams?	Monthly flat fee, or Fee for service: Exchanging human waste container, transporting human waste container to the biochar reactor
Key resources	
What key resources do the value propositions require?	Human and recycled waste Transportation vehicle Trained workers Gas Protective equipment
Distribution channel?	Trained worker, vehicle, gas, protective equipment
Key partners	
Who are the key partners?	Kivalina tribal and city administration Biochar reactor operator Kivalina shop Households
Who are the key suppliers?	Kivalina Tribal administration and city administration
Which key resources are acquired from partners?	Human waste (HH), recycled waste (HH), gas (shop), vehicle, protective equipment (shop)
Which key activities do partners perform?	Producing and collecting waste Helping promote and coordinate the project (administration) Selling and importing essential equipment (shop)
Revenue Streams	
What are the values that the customers are really willing to pay for?	Healthy life and community Sanitary way to dispose human waste
For what do they currently pay?	Informal waste disposal
How are they currently paying?	Payment depends on relationship and availability of transportation Cash per service
Cost structure	
What are the most important costs inherent in the business model?	Wages of the transporters
Which key activities are most expensive?	Collecting human waste and recycled waste

5.6 Financial Analysis

To analyze and to be able to compare the costs for OPEX and CAPEX of the separating toilet and the hauling system the results were calculated for 3 different options. Option 1-status quo is representing the current honey bucket system, option 2 stands for the in-home collection system and option 3 for the under-floor collection system.

The following data sources and assumptions were used to calculate the operational costs and the capital costs. The Kivalina community profile summarized in table 14 provides demographic analysis

Table 14: Statistical information about Kivalina (Department of Labor and Workforce Development, 2010)

Community profile	
Population	402
Average HH size	4.4
Average household size in owner-occupied housing units	4.7
Average household size in renter-occupied housing units	3.4
Housing	
Total HH	99
Occupied housing	85
Vacant housing	14
Owner occupied housing	64
Renter-occupied Housing	21
Economy	
Residence employed	167
Private	54
Local government	113
Median HH income per year	58,333
Per Capita Income per year	14,322
Unemployment insurance claimants	88
Persons in Poverty	107

5.6.1 Operational Expenditure (OPEX)

Operational expenses cover non-capital goods such as labor costs or energy costs. The OPEX for the 3 different toilet options, the hauling systems and the biochar reactor are summarized in this chapter. Assumed values were predicted conservatively as safety factor.

Toilet

The parameters affecting the cost components for operation of the two separating toilet designs and the honey bucket include spare parts (plastic bags, cleaning products) and electricity costs (ventilation, heating trace). The power cost equalization was not taken into account, therefore the electricity costs were calculated with a price of 0.55 $/kWh. Electricity costs of the toilet fan amounts to US$ 1 per household and month. It is assumed that the heating trace is used for 7 month a year, this is the period where the average minimum temperature is below -5 °C (23 °F) according to WeatherSpark, (2014). The electricity costs for the heating trace amounts to 10 $/month. The prices of the disinfectant and cleaner (pinesol) and the plastic bags needed for the operation of the honey bucket could be verified in the local shop, which is about double the standard price.

Table 15 is listing the costs for the whole village for all options divided into the category spare parts and electricity for a period of 5 years. Additionally the user fees per household and year were calculated. It is assumed that no externally paid labor is necessary to operate each toilet option on household level, which makes maintenance and operation cheap. Labor is one of the most expensive parameters in the operational costs. An inflation rate of 2.5 % per year was assumed. Table 16 shows the operational costs for the toilet per household and month.

Table 15: OPEX of the old and a new toilet system (US$)

Expenses (US$)	Option 1: Status quo						Option 2 + 3					
	2016	2017	2018	2019	2020	Total	2016	2017	2018	2019	2020	Total
Consumables	11,754	12.048	12.349	12.658	12.975	61.785	1,360	1,394	1,429	1,465	1,501	7,149
Repairs	0	0	0	0	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	6,059	6,210	6,366	6,525	6,688	31,847
Total	11,754	12.048	12.349	12.658	12.975	61,785	7,419	7,604	7,794	7,989	8,189	38,996

Table 16: Operational costs for the toilet per household, month and option (US$)

	Option 1	Option 2	Option 3
User fees per household and month (US$)	12	8	6

According to the total costs of the three options the costs per household and month could be calculated. Household which use honey buckets (option 1) have to spend US$ 12 per month for the operation. For option 2 households have to spend US$ 8 per month and for option 3 US$ 6 per month.

The electricity consumption is equal for option 2 and 3. The difference between option 2 and 3 results from the different amount of needed plastic bags and was taken into account in the calculation. In option 2 the plastic bag has to get changed every 2 weeks and in option 3 once a month. In comparison, option 1 has the highest usage of plastic bags. They have to get changed on average every day.

Option 1 has higher costs for consumables; since cleaning products (pinesol) are used and because of the more frequent emptying period of the honey bucket also more plastic bags are needed. The UDDT Villa 9210 has a 5 years guarantee so no additional costs for spare parts were included in the calculation.

In total the operational expenses of option 2 and 3 do not exceed the total costs of option 1. The electricity costs of option 2 and 3 do not push the total costs higher than the total costs of option 1.

In option 1, 100 % of the operational costs have to be spent on the factor spare parts (consumables and repairs), since honey buckets function without electricity. In option 2 and 3, 82 % of the total costs arise from electricity costs and only 18 % for spare parts.

This indicates a cost saving potential for option 2 and 3 if the electricity needed can be reduced. A possibility to decrease electricity needed for ventilation is to add biochar after each use to the feces collection container, which absorbs odor and moisture, besides other positive characteristics as states by Otterpohl, (2009). Installing thermostats to temperature regulate the heat trace line is optimizing the heat trace line operation and can also contribute to reduce the electricity consumption. This would increase the capital costs but would not affect negatively the operational costs per household.

Summary of the comparison of option 2 and 3 with option 1:

- Total reduction of expenses for the households of 37 %
- Reduction of expenses for spare parts of 88 %
- In comparison with option 1 costs arise for electricity
- Households have to spend 82 % less on spare parts
- User fees highest in option 1

Hauling System

Assumptions on operational expenses have been derived from the costs for the transportation vehicle composed of repair costs and fuel costs (consumables). The data for the repair costs and for the fuel costs are based on information gathered from Gentry, (2005). According to these information repair costs 1.86 $/h for a 4-wheeler and fuel costs of 6.94 $/h were estimated. The result is generated by multiplying the repair and fuel costs with the different storage times for option 1, 2 and 3. In option 2 the collection container gets changed twice a month and in option 3 it gets changed once a month. Honey buckets have to be emptied on average every day. An assumed salary of 25 $/h was taken into account for option 2 and 3.

Table 17 shows the operational expenses for all households for option 1 over a period of five years with an assumed inflation of 2.5 %. Additionally the user fees per household and year were calculated. It is assumed that no additional costs for storing the vehicles will arise, because existing infrastructure from the Tribal and City Councils can be used to reduce household expenses. The abbreviation HH stands for households.

Table 17: OPEX of the hauling system of the status quo

Expenses (US$)	Option 1: Status quo (85 HH)					
	2016	2017	2018	2019	2020	Total
Consumables	7,079	7,256	7,437	7,623	7,814	37,208
Repairs	1,897	1,945	1,993	2,043	2,094	9,972
Salaries	31,824	32,620	33,435	34,271	35,128	167,277
Total	40,800	41,820	42,866	43,937	45,036	214,458
User fees	533	547	560	574	589	2,803

The lowest share for the operational expenses in option 1 is the repair costs for the vehicle. The most expensive parameter is the salaries. An informal waste collector gets on average US$ 20 to transport one load of honey bucket waste to the open dump. Assuming he can serve 2 households per hour he gets 40 US$/h according to the gathered information from the local waste management economics. Costs for the fuel and repair costs were deducted from the salaries resulting in a salary of 31 US$/h. In option 1 the waste collectors gain most money but the individual gets less because of oversupply of labor. Households that get free waste collection at the moment have not been taken into account. After a period of five years all parameters influencing the operational expenses are US$ 214,458. The user fee per household including a payment default of 10 % is US$ 533 for the first year.

Table 18 shows the operational expenses for all 48 households suitable for option 2 of the hauling system over a period of five years. Additionally the user fees per household and year were calculated. The repair costs and the fuel costs (consumables) were calculated under the same estimations as in option 1. A payment default of 10 % and an inflation rate of 2.5 % were considered. The user fees were calculated over the period of one year like every other listed parameter.

Table 18: Hauling system cost analysis of option 2

Expenses (US $)	Option 2: In-home collection (48 HH)					
	2016	2017	2018	2019	2020	Total
Consumables	1,999	2,049	2,100	2,152	2,206	10,506
Repairs	536	549	563	577	591	2,816
Salaries	7,200	7,380	7,565	7,754	7,947	37,846
Total	9,734	9,978	10,227	10,483	10,745	51,167
User fees	225	231	237	243	249	1,184

Option 2 shows similarities with option 1. Again the salaries are the most expensive factor and the vehicle repair costs are the cheapest. It was estimated that four households per hour can be served assuming the biochar reactor will be located either in the village or very close to the village. On average the full collection container has to get changed and collected twice a month in option 2. Altogether salaries for collection will be US$ 37,846 over a period of five years. This pay and the work load is not sufficient for one full-time occupation. This implies that the waste collector will have to perform other tasks as well and the user fees have to get increased. To cover the costs for a full time job, the user fees would have to get tripled. The total costs over a period of five years are US$ 51,167. The user fee per household for the first year is US$ 225.

Table 19 shows the operational expenses of all 37 households suitable for option 3 of the hauling system over a period of 5 years with an estimated inflation of 2.5 % per year. The costs for the salaries, consumables and repairs, the total costs as well as the user fees were calculated. Additionally the user fees per household and year were calculated. The salaries were calculated similar to option 2. A payment default of 10 % was included into the calculation.

Table 19: Hauling system cost analysis of option 3

Expenses (US $)	Option 3: Under-floor collection (37 HH)					
	2016	2017	2018	2019	2020	Total
Consumables	770	790	809	830	850	4,049
Repairs	206	212	217	222	228	1,085
Salaries	2,775	2,844	2,915	2,988	3,063	14,586
Total	3,752	3,846	3,942	4,040	4,141	19,721
User fees	113	115	118	121	124	592

As for option 1 and 2 the repair costs are also for option 3 the lowest share of the operational costs and the costs for the salaries are the highest. Only the collection interval is with once a month less frequent. The money available for the payment of a worker is also not high enough for a full-time occupation in option 3. Only 48 households were included for the calculations for option 2 and 37 households for option 3. The addition of the user fees of option 2 and option 3 is increasing the work load for the waste collector. Employing 2 part time waste collectors is beneficial for the local life style in regard of hunting activities. Total costs of US$ 19,721 can be expected for option 3 over a period of five years. Costs per household amount to US$ 592 over a period of five years.

Table 20 compares the household fees per month for each option. Apparently households have to pay the most for hauling services in option 1 and the least in option 3 due to a high feces storage capacity.

Table 20: Operational costs for the toilet per household, month and option in US$

	Option 1	Option 2	Option 3
User fees per household and month (US$)	44	19	9

Table 21 shows the respective percentage of the parameters consumables, repairs, salaries and user fees affecting the operational costs of option 1, 2 and 3. All operational costs are covered by the user fees.

Table 21: Operational costs of the hauling system for all options as a % of total costs.

Cost as a % of total cost:	Option 1	Option 2	Option 3
Consumables	17	20	20
Repairs	5	6	6
Salaries	78	74	74

The proportion of the percentage of the fuel costs is slightly higher for option 2 and 3 than for option 1. The proportion of the salaries as a percentage of all parameters is slightly higher in option 1. All factors affecting the operational costs have the same percentage in option 2 and option 3.

Summary of the comparison of option 2 and 3 with option 1:

- Reduction of costs in all factors
- Higher cost reduction in option 3 than in option 2 in all factors
- Reduction in total costs by 76 % in option 2 and by 91 % in option 3
- Reduction of salaries by 77 % in option 2 and by 91 % in option 3
- Reduction of user fees by 58 % in option 2 and by 79 % in option 3
- Reduction of repair and fuel costs by 72 % in option 2 and by 89 % in option 3 due to reduced hauling distance and collection period
- 100 % of the operational costs are covered by the user fees

Biochar Reactor

The parameters affecting the operational costs of the biochar reactor include consumables & repairs and the salary of the reactor operator. It is assumed that a salary of 25 $/h can get paid for the biochar reactor operator. Fields of activities are the maintenance and operation of the biochar reactor.

Table 22 is summarizing various factors of the operational expenses of the biochar reactor. No additional costs for electricity will arise due to the self-supply of the reactor. The expenses of the spare parts are based on experiences with pilot reactors in India and Kenya. A payment default of 10 % was included in the calculation of the user fees. An annual inflation on 2.5 % was taken into account.

Table 22: Expenses of the operational costs of the biochar reactor

Expenses ($)	Biochar reactor					
	2016	2017	2018	2019	2020	Total
Consumables & repairs	10,000	10,300	10,609	10,927	11,255	53,091
Electricity costs	0	0	0	0	0	0
Salaries	48,000	49,200	50,430	51,691	52,983	252,304
Total	58,000	59,450	60,936	62,460	64,021	304,867
User fees	758	777	797	816	837	3,985

The salary of the biochar reactor is the salary of one full time or two half time employees at the biochar reactor. The total costs, which need to be paid by the households for operating and maintaining the biochar reactor, are US$ 304,867 over a period of five years. This can be achieved by user fees of US$ 3,985 per household and five years, including a payment default of 10 %.

The percentage of the individual parameters for operation of the biochar reactor indicates again the high influence of the salaries to the operational costs. 83 % of the total operational expenses are classified to the salary costs. Only 17 % can be classified to the repair costs. The missing electricity costs keep the operational costs low. User fees per month and household of US$ 63 arise.

Summary (OPEX)

Table 23 is summarizing the total operational costs of option 1, 2 and 3 including the hauling system, the toilet and the biochar reactor. The costs for option 2 and option 3 were additionally added to give comparable results with the same number of households (HH). Table 24 compares the total user fees per household and month. Option 2 and option 3 also include the user fee for the biochar reactor.

Table 23: Summary of the total operational costs in US$

	Summary of the total operational expenses (US$)					
	2016	2017	2018	2019	2020	Total
Option 1 (85 HH)	52,554	53,868	55,215	56,595	58,010	276,243
User fees	618	634	650	666	682	618
Option 2 (48 HH)	49,633	50,874	52,146	53,450	54,786	260,888
Option 3 (37 HH)	36,691	37,608	38,548	39,512	40,500	192,858
Option 2+3 (85 HH)	86,324	88,482	90,694	92,961	95,285	453,746
User fees	1016	1041	1067	1094	1121	1016

Table 24: Summary of the total operation costs per household and month in US$

	Total user fees per household and month (US$)
Option 1	56
Option 2	90
Option 3	78

In summary the user fees for the total operational costs per year including the biochar reactor are 61 % higher for option 2+3 as for option 1. Taking into account the fact that option 2 and 3 are also providing a human solid waste treatment system and shows as a whole a higher performance, justifies this higher value.

5.6.2 Capital Expenditure (CAPEX)

Toilet

The parameters affecting the capital cost components of option 2 and 3 are the proposed UDDT villa 9210 (Eco Services Group, 2011), additional technical components, installation costs and tool rental fees. Extra fees for the re-design of the product arise. Additional technical components needed for the UDDT installation are artic pipes, ventilation pipes, cleaning tools, AGM battery and charger, storage compartment for storage container + insulation, collection container and heating trace lines.

The following additional technical components per installation for the model Villa 9210 in-home collecting system (option 2) are required and summarized. The capital costs are summarized in table 25.

- Arctic pipes for urine discharge (per toilet: 3 m (10 ft) insulated HDPE Jacket | HDPE Pipe ⌀3 cm (1,25 in), 2* Insulated 90° Bend HDPE /HDPE Jacket, insulation thickness 7 cm (2.63 in)),
- Ventilation pipe (per toilet: 3 m (10 ft) PVC pipe ⌀ 7 cm (3 in))
- 12 V AGM battery (sealed lead acid battery, maintenance free) and a 12 V automatic constant current electronic charger
- Cleansing tools: cleaning brushes, small shovel, drain auger

The following additional technical components per installation for the model Villa 9210 under-floor collecting system (option 3) are required and summarized. The capital costs are summarized in table 25.

- Arctic pipes for urine discharge (per toilet: 3 m (10 ft) insulated HDPE Jacket | HDPE Pipe ⌀3 cm (1,25 in), 2* Insulated 90° Bend HDPE /HDPE Jacket)
- Storage compartment for storage container + insulation
- Hatch/opening for waste removal
- Insulated ventilation pipe (per toilet: 3 m (10 ft) PVC pipe ⌀7 cm (3 in))
- 12 V AGM battery (sealed lead acid battery, maintenance free) and a 12 V automatic constant current electronic charger
- Cleansing tools: cleaning brushes, small shovel, drain auger

Table 25: Capital expenses (US$) of the toilets for option1, 2 and 3

Expenses (US$)	Option 1 Status quo	Option 2 In-home collection	Option 3 Under-floor collection
Toilet	35	1,300	1,550
Additional technical components	15	400	1,100
Installation costs	0	500	1,000
Tool rental fees	0	100	100
Total per household	50	2,300	3,750
Households	85	48	37
Total CAPEX	4,250	110,400	138,750

In Kivalina it is possible to construct 37 under-floor collection systems and 48 in-home collection systems. The total costs for the under-floor collection units are US$ 138,750 resulting in costs per household of US$ 3750. The total costs for the in-home collection units are estimated to be US$ 110,400 and US$ 2,300 per household. As the least complex system, the honey bucket has the lowest capital expenses. The under-floor collection system is more expensive than the in-home collection system due to the additional construction unit under the house and changes on the toilet interface. The installation costs for option 3 are significantly higher than for option 2 resulting from changes in the building structure and a more complex construction. The costs per toilet include shipping to Kivalina. The local toilet supplier is the company “Lifewater Engineering” and is based in Fairbanks.

Table 26 shows the percentage of the individual factors influencing the capital investment of the 3 different options. The percentage of the toilet itself as a factor of the capital expenses is 50 % of the overall expenses which is the highest number compared to option 2 and option 3.

Table 26: Costs as a % of total cost- toilets for option 1, 2 and 3

Cost as a % of total cost:	Option 1 Status quo	Option 2 In-home collection	Option 3 Under-floor collection
Toilet	70	57	41
Additional technical components	30	17	29
Installation costs	0	22	27
Tool rental fees	0	4	3

The under-floor collection unit also has the highest percentage on the factor toilet but a significant amount of the total costs are shared by the additional components and the installation costs with 27 %. Option 2 is spending 59 % of the total capital costs on the toilet, 14 % on additional technical components and 23 % on installation costs.

These results show the huge cost differences of the current honey bucket system and the proposed systems. It is questionable if the honey bucket system can be compared with UDDTs but I consider it as important to show the cost differences. It is also obvious that the value for the community (comfort, health and environment) is much higher than the cost differences.

Summary of the comparison of option 2 and 3 with option 1:

- Increase of over 90 % of total costs, UDDT costs and costs for additional technical components for option 2 and option 3.

– Installation costs and toll rental fees are not required for option 1, resulting in an increase of 100 % for option 2 and option 3.

Hauling System

Capital expenses of the hauling system are expressed by the costs for the hauling vehicles.

Table 27 summarized the capital expenses which will have to be invested for the new hauling system. The costs for the vehicles are in conformity with the price of new vehicles of the types which are common in Kivalina.

Table 27: Expenses for the proposed hauling system

Expenses (US$)	
ATV	7,000
Trailer	1,500
Snowmobile	10,000
Working clothes	300
Total	18,800

The total costs for the needed vehicles and work clothes amount to US$ 18,800. It was estimated that only one hauling vehicle in summer and one in winter is needed, due to the fact that the hauling work load is only enough for one full time employee or 2 part time employees.

Biochar Reactor

According to the developer of the biochar reactor “The Climate Foundation” following expenses shown in table 28 can be assumed for the biochar reactor. Table 28 shows the costs of the different components of the biochar reactor.

Table 28: Capital expenses (US$) for the biochar reactor (Von Herzen, 2014)

Expenses (US$)	Biochar reactor
Dryer	15,000
Pyrolyzer	15,000
Combustor	10,000
Heat exchanger	10,000
Reactor total	50,000
Labor in construction, assembly testing, handling, GS&E	20,000
Shipping	3,000
Total	123,000

Summary (CAPEX)

Table 29 is summarizing the total capital costs for the hauling system, the toilet and the biochar reactor to provide the opportunity to compare option 1, 2 and 3. User fees were not calculated because it is assumed that the capital costs will be funded by grants. To enable correct comparison with the status quo total capital costs for option 2 and option 3 were added.

Table 29: Summary of the capital expenses in (US$)

	Total capital expenses (US$)
Option 1 (85 HH)	**4,250**
Option 2 (48 HH)	198,080
Option 3 (37 HH)	211,670
Option 2+3 (85 HH)	**409,750**

If the results are directly compared the fact that option 2 and option 3 provide a complete human waste management system has to be taken into account. The total capital expenditures per household are US$ 4,820. Compared with conventional wastewater treatment systems in Arctic villages where costs can exceed US$ 50,000 per connection (Schaefer and Bielak, 2006), the biochar sanitation system shows low total capital and operational costs . The fact that the treatment of the feces does not need additional energy is reducing the operational costs tremendously due to the fact of the high electricity prices in Kivalina. A factor that helps reducing the operational costs of the UDDTs is the waterless operation. Newer flush toilets need 6 l (1.6 gal) of water per flush. If it is to be assumed that 19 l (5 gal) of water costs in Kivalina US$ 0.25 and that 18 uses per household and day results in a water consumption of 106 l (28 gal) per day, a households in Kivalina would have to pay US$ 42 per month for flushing the toilet, disregarding the fact, that the increase of water consumption could not be handled by the current water supply system. Having a trained waste collector employed has the benefit for the villagers of having a contact person and a person in charge, if social or technical problems regarding the waste collection occur. In the current system no one is held responsible for not having dumped the honey buckets at the right place or for stored honey buckets representing a serious health hazard to the general public.

5.7 Biochar as a Product

Today, biochar is mostly used in agriculture as soil fertilizer. Biochar amendments have different effects on various soil types. Some general benefits according to Sohi et al. (2009) and Hestermann (2010):

- Rise of pH value caused by free bases
- Increased cation exchange capacity
- Increased soil surface area
- Improved water retention in sandy soils
- Minimized nutrient leaching losses
- Minimized groundwater contamination
- Long term availability of nutrients
- Pores for microorganisms and mycorrhiza
- Increased microbial activity
- Darker soil color, higher soil temperature
- Same yield with 10 % less fertilizer
- Provides micronutrients
- Less emission of non CO_2 greenhouse gases (under research)

The positive properties of biochar make it a valuable multi-purpose product where another application before it gets tilled into the soil is preferable and most likely to be used in Kivalina. Biochar is used in many different areas in industry and also has a chance in Kivalina to play a factor for economic development. Therefore alternative uses of biochar instead of in agriculture are listed in the following section.

5.7.1 Biochar as soil additive for soil remediation

At the open dump in Kivalina there is no controlled access and no maintained boundaries. The severe erosion and floods in Kivalina are affecting the stability of the dump (Martin, 2012). The open dump is contaminating the soil and water, promotes disease transmission, fire danger and potential injury of site visitors (Cointreau, 2006).

Biochar has the ability to improve and change soil properties. Amongst others biochar can increase the cation exchange capacity (CEC), soil pH (in acidic soils), soil buffering and the reduction of N leaching (Liang et al., 2006).

Biochar has a high capacity to absorb heavy metals and organic pollutants, reduce the bioavailability and leachability of heavy metals and organic pollutants in soil through adsorption and physicochemical reactions (Tang et al., 2013).

Organic toxic waste

Oil and grease damages aquatic organisms, plants and animals (Islam et al., 2013) and occur because the oil layer is decreasing the dissolved oxygen levels resulting in reduced biological activity. Additionally it is mutagenic and carcinogenic for human beings (Abd El-Gawad, 2014).

Table 30 shows the percentage of hazardous waste fractions estimated for the Northwest Territories (NWT). There are no numbers available from hazardous waste generation in Kivalina. It is assumed that the similar Arctic climate in the North and the low population provides comparable values for Kivalina resulting in a comparable lifestyle and numbers.

Table 30: Estimated quantities of hazardous wastes in NWT (Heeney and Heinke, 1991)

Hazardous wastes	Percent by weight
Oils and greases	70 %
Chemicals	9 %
Oil/ water mixtures	7 %
Household hazardous waste	5 %
Solvents, organic solutions, aqueous solutions with organics	5 %
Other hazardous wastes	4 %

The oil and grease fraction of hazardous waste is with 70 % the highest fraction as shown in table 30 and counts as organic contaminant. The remediation ability of biochar of organic contaminants works through surface adsorption, a surface interaction leading to adhesion of pollutant molecules to the biochar surface and partition (Tang et al., 2013). The ability of organic pollutant removal and the contribution of adsorption and partition is depending on the relative carbonized and non-carbonized fraction and surface and bulk properties of the biochar (Chen et al., 2008). These characteristics are depending on the pyrolysis temperature. Higher pyrolysis temperatures are leading to increased surface area and carbonized fraction (Tang et al., 2013). The sorption of organic contaminants to biochar is protecting them from microbial degradation and may increase their persistence in the environment (Beesley et al., 2011).

Heavy metals

The reduction of heavy metals and the immobilization in soils by adding soil amendments leads to a slower release rate with less impact on the environment, is decreasing the uptake by plants and is reducing the contamination of the surrounding water body (Tang et al., 2013). Biochar is effective by removing heavy metals from aqueous solution and soils. The study by Beesley and Marmiroli (2011) showed a reduction of the concentration of Cd (cadmium) and Zn (zinc) with 300- and 45- fold from an multi-element contaminated sediment-derived soil. Research (Peng et al., 2011 and Jiang et al., 2012) has shown that the negative charge on soil surface is increasing with the application of biochar, which increases the electrostatic attraction of the positively charged heavy metals. Jiang et al., (2012) also indicated that the presence of functional groups in the biochar is enhancing the formation of complexes between heavy metals and the functional groups.

The application of biochar is irreversible and, therefore, biochar should be free of toxic substances. Until now no systematic evaluation of all possible toxic substances has been made. Known toxic substances which can be found in biochar are polycyclic aromatic hydrocarbons (PAH) and dioxins. PAH generally are generated at temperatures higher than 700 °C but smaller amounts can emerge below this temperature. So far only one study reports on higher amounts of PAH in biochar but not at an environmental risk level (Sohi et al., 2009).

The quality of biochar products varies a lot, depending on feed stocks and processes. As not all pyrolysis products are suitable for soil amendment, quality management and proper selection of char sources are necessary.

5.7.2 Biochar for construction

Biochar is a highly porous material with an extremely low thermal conductivity resulting in excellent insulation properties and a high ability to absorb water to regulate humidity and to improve air quality (Schmidt, 2012).

According to the Journal for terrior-wine and biodiversity (2008) the biochar can be used as additive for plaster or for bricks and concrete elements at a ratio of up to 80 %.

Biochar-clay plaster

The biochar-clay plaster developed by the Ithaka Institute (Schmidt, 2013) contains a mixture of 50 % biochar, 30 % sand and 20 % clay. This mixture is suitable for conventional throw-on techniques which eliminate the need to import spray plastering tools to Kivalina. Using biochar pieces <25 mm (1 in) makes the plaster more resistant to cracks (Journal for terrior-wine and biodiversity, 2008). Following positive characteristics can be attributed to the biochar clay plaster according to the Journal for terrior-wine and biodiversity (2008):

- Regulation / buffering of humidity
- Insulation
- Noise protection
- Toxin binding (solutes, VOC)
- Blocking of high frequency radiation
- Low electrostatic charging of air
- Conservation of wood
- Reduction of dust
- Deodorizing
- Aesthetic
- Anti-bacteriological, fungicide (repellent)
- Air cleaning
- Increase of redox potential
- Emission of far-infrared radiation

This biochar clay plaster mixture is able to maintain humidity levels at 45-70 % which can prevent condensation on walls around thermal bridges and therefor reduces the risk of the formation of mold which is a common problem at many houses in Kivalina. Also problems potentially caused by dry room air like respiratory problems and allergies can be reduced (Schmidt, 2013). According to the Journal for terrior-wine and biodiversity (2008) already a biochar clay plaster layer of 2 cm (0.8 in) is improving the room's climate. To insulate outside walls as substitute for styrofoam a biochar clay plaster layer of 20 cm (7.9 in) is recommended by the Journal for terrior-wine and biodiversity (2008).

Using this technology is turning houses into long-term carbon sinks. After demolition of the houses, the biochar clay plaster can be used as compost supplement. It has to be tested if biochar out of fecal matter or out of different biomasses shows the same positive properties than the biochar tested by Schmidt (2013), used as building material.

Biochar bricks

Using biochar as building material is a rather new way of using biochar. First research on the properties of biochar used as building material and first developments and trials are conducted. The journal for terrior-wine and biodiversity (2008) published first promising results of their developed biochar bricks. The wet bulk densities below 1.2 g/cm^3 and a compressive strength of 20 N/mm^2 show that the product is meeting high expectations for the high requirements of a building material.

Biochar bricks can be used in Kivalina to build the under-floor feces collection chamber. Beneficial aspects are the regulation of the humidity, absorbing emission from the collection container and the temperature regulation through insulation. The light weight material makes it easy for installation and keeps the construction costs low. Biochar bricks show an alternative way to produce high quality building materials on-site.

5.7.3 Biochar in daily life

Biochar for odor reduction in UDDTs

Most of the pathogenic bacteria, viruses and parasites are excreted together with feces. Biochar increases the pH value which limits the growth of pathogenic micro-organisms (Hestermann, 2010). After every feces collection biochar particles can be added to the feces collection box to avoid offensive odor. One example which proves the odor reducing characteristics of biochar is Terra Preta Sanitation. According to Otterpohl (2009) and Hestermann (2010) there is no odor in the collection phase and even no ventilation is needed.

Feces need primary and secondary treatment to ensure safe integration into the biological cycle. Primary treatment occurs during collection and can be achieved by adding biochar to reduce the number of potential pathogens, to decrease the risk of odors and the risk of flies (Jönsson et al., 2004).

Biochar use as litter additive in livestock farming

Adding biochar in litter used for dog keeping in Kivalina could have many positive effects on the health of the dogs. Biochar prevents the development of odor through absorbing the urine by reducing the formation of fermentation gas and adsorption of ammonium salts. Further biochar reduces the formation and spread of disease causing organisms through the adsorption of microbial metabolites (Gerlach and Schmidt, 2012). Using Biochar first in animal keeping and afterwards as soil improver is increasing the positive characteristics of biochar and the optimal use of the product.

Energy production

The total amount of the produced renewable energy by the biochar reactor consists of syngas and biochar. Half of the carbon is released as syngas- used in the reactor to dry feces, the other half of the carbon is the produced biochar and can be used as additional energy source (Saddler-French, 2014).

According to in-home investigations only 3 % of houses in Kivalina have wood stoves and keep them for the case of emergency. This indicates that the produced biochar would be more likely used as heating source in camps. Biochar has a higher caloric value than wood, which means that less volume would need to be transported to the camp site.

6. Summary

An alternative sanitation system for the native village of Kivalina has been developed to eradicate the use of honey buckets associated with severe environmental and health risks. The proposed system is a biochar sanitation system composed of UDDTs, a human solid waste collection system, the controlled sanitation of the feces in the biochar reactor and to close the loop, possible uses of the produced biochar.

Planning Considerations

The research focus was put on planning considerations such as community layout, physical infrastructure and winterization issues. Focus was also put on the UDDTs, on installation details- UDDT, collection chamber and pilot installation. The local waste management economics consisting of the current honey bucket use pattern, a financial analysis and on various potential uses of the produced biochar was investigated.

The mapping of the community layout and the physical infrastructure during the field work in September 2014 gave relevant basic information to plan toilet installation for the specific situation in Kivalina. The mapping was conducted to capture water, sanitation, other project relevant features and different housing types. The information was collected through the measurement of the houses, drawing of floor plans and interviewing household members.

The most relevant results of the planning considerations are that 2 different installation modes- an in-home collection system and an under-floor collection system- are necessary in Kivalina. Further the number of households with under-floor collection (37 houses) and number of households suitable for in-home collection (48 houses) were identified. The generated floor plan gave the opportunity to plan a Kivalina specific installation. An important aspect of the project success was the identification of installation parts being exposed to freezing temperatures and the development of strategies to overcome frost damages.

Installation Details

The installation details consisted of the identification of a UDDT model suitable for the specific situation in Kivalina, the design of the collection chamber for the under-floor collection system and a pilot trial of the in-home collection system. The UDDT model was identified before the second field trip in September 2014 based on the information gathered in the first field trip in July 2013. The pilot toilet was installed in the second field trip and is continuously monitored by the project partner “Re-locate Kivalina”. All other installation details were created after the second field trip.

The UDDT model, Villa 9210 from the company Separett was chosen because of its odor reducing design, water-less operation, easy installation, reduction of the amount to be hauled to the dump site, attractive design and many other positive characteristics well suited for Kivalina. Furthermore the UDDT design can be adapted to an under-floor collection and an in-home collection model. The comparison of the two installation modes showed that both systems are well suited for Kivalina and satisfy the various architectural, geographical and social needs.

The final design of the collection chamber was kept simple with, as little as possible moving parts and with the requirement to be easy to maintain and to repair. The collection chamber cannot be operated without heat trace around the pipe which is connected to the collection container and the urine discharge pipe. A 113 l (30 gal) collection container was selected, which has a collection capacity of about 110 days. Furthermore the collection container is accessible from outside the house, which corresponds to the requirement of the villagers.

The pilot toilet installation was a success; minor adaptations like the addition of thermostats to regulate the heat input or using a self-regulating version in future will help to minimize fire danger, and the risk of frozen pipes. Installing a bigger rotating vent cap on top of the ventilation pipe will help to increase the drying potential of the feces and reduces the risk of odor during storm events.

Local Waste Management Economics

Information of the local waste management economics was gathered through interviewing male people in Kivalina around the age of 17-30 during the second field trip in September 2014. The goal was to get information about the current honey bucket use pattern. The asked questions were about emptying, storage and of the transportation of the honey bucket waste from the household to the dump. These interviews were also conducted to collect information about the important informal waste collection system that includes transporting the waste or emptying honey buckets for a family member but also offering such services to supplement the income.

The average price for the honey bucket transportation to the dump is US$ 20 per load. Households which have an own transportation vehicle only have to pay US$ 7 per load for the gas. The emptying period is 1.1 days for households with more than 5 members and in a household with less than 5 members the emptying period is every 1.6 days. In 93.33 % of the interviewed households male family members were in charge to change the full honey bucket. In summary the current system is socially not fair, wealthier families have to pay less than poorer families.

Financial Analysis

Financial analysis was conducted to be able to compare the proposed systems with the current honey bucket system and to know the expected operational costs. The operational costs and the capital costs for each system component (UDDT, waste collection system and the biochar reactor) were calculated after the second field trip on basis of the collected information.

The results of the OPEX (for toilets) show a total reduction of expenses for the households of 37 %, a reduction of expenses for spare parts of 88 % in comparison with the current system and households have to spend 82 % less on spare parts. In comparison with the current system cost arise for electricity.

The comparison of the OPEX (for waste collection) results for the current system with the proposed in-home and under-floor collection system shows a reduction of costs in all factors and a higher cost reduction in the under-floor collection system than in the in-home collection system in all factors. Further the results show a reduction in total costs by 57 % in the in-home collection system and by 79 % in the under-floor collection system, a reduction of salaries by 60 % in in-home collection system and by 80 % in the under-floor collection system and a reduction of repair and fuel costs by 50% in the in-home collection system and by 75 % in under-floor collection system due to reduced hauling distance and collection period.

The total capital expenses of option 2 and 3 are of course much higher than option 1 since they provide a complete human waste management system. Compared with conventional wastewater treatment systems, the biochar sanitation system (option 2 and option 3) causes with US$ 409.750 low total capital costs.

Biochar as a product

The properties of biochar were analysed to find appropriate uses of the biochar in Kivalina. Possible uses of the biochar in Kivalina are the use as soil additive for soil remediation, biochar for construction, biochar as litter additive in livestock farming and for energy production.

Biochar has the ability to absorb heavy metals and organic pollutants through reducing the bioavailability and leachability by increasing the cation exchange capacity (CEC), soil pH (in acidic soils) and soil buffering and can be used to reduce the contamination of the environment by the open dump.

Further biochar shows all positive characteristics of a good insulation material and can therefore be used as building material in form of biochar plaster and biochar bricks.

Most of the pathogenic bacteria, viruses and parasites are excreted together with feces. Biochar increases the pH value which limits the growth of pathogenic micro-organisms. After every feces collection biochar particles can be added to the feces collection box to avoid odor and to eliminate the need for ventilation. One example which proves the odor reducing characteristics of biochar is Terra Preta Sanitation.

Feces need primary and secondary treatment to ensure safe integration into the biological cycle. Primary treatment occurs during collection and can be achieved by adding biochar to reduce the number of potential pathogens, to decrease the risk of odors and the risk of flies (Jönsson et al., 2004).

Useful ways to use biochar in daily life were identified and include biochar use as litter additive in livestock farming, for energy production and for odor reduction in UDDTs.

7. Conclusion and outlook

Through developing a biochar sanitation system especially designed for the specific conditions in Kivalina numerous environmental benefits and climate change adaption can be provided. Compared to conventional wastewater treatment systems, the use of reuse-oriented sanitation systems is a suitable solution for Kivalina which is strongly dependent on the import of most products and resources.

The proposed biochar sanitation system also provides a numerous host of important community benefits to Kivalina. Less handling and reducing the open storage of human feces will decrease rates of waterborne illnesses, contamination of the aqueous and terrestrial habitat. Further it will decrease the need for additional village infrastructure and individual investments.

Environmental health hazards posed by the open dump can also be mitigated by the remediation ability of biochar at the dump, by reducing leakage into the lagoon and by filtering hazardous substances. As Kivalina's current location is threatened by the effects of climate change, planning biochar sanitation systems for a relocated village will ensure that possible new open dump sites will not expose the surrounding environment similarly as on the current location. Any amount of industrial waste that would be left behind, in the event that more static sanitation infrastructures were to be introduced, would be greatly reduced.

The current human waste disposal system is not economically and socially viable, desirable and environmentally sustainable. An officially organized and structured waste hauling system is cost effective for everyone and could be based on subsidizing the poorest 10 % in society. Social tensions between households because of honey bucket piles in front of the house will be greatly reduced.

User fees per household are higher for the biochar sanitation system, but compared to fees for a conventional wastewater treatment plant in Kivalina, costs are still very low and socially acceptable. The costs also include the treatment of the feces, which is not a factor for the current honey bucket system.

Biochar can help reverse rising CO_2 levels in the atmosphere, improve overall soil quality, and raise soil's water retention ability. Kivalina has a vibrant subsistence based economy and a biochar system will decrease contamination of plants and animals. Biochar characteristics vary with different biomass and pyrolysis conditions. Specific large-scale trials need to be conducted with the produced biochar before an operational scale remediation project at the Kivalina dump can be implemented. Biochar as product creates opportunities for new businesses and markets and helps to reduce the dependency on imported resources. In the future agricultural activities in Kivalina might be possible, as already small family gardens exist and benefit from the biochar as soil conditioner.

The result is a system that supports situational operation and maintenance systems as well as sustained participation and information sharing between experts, community members, and agency representatives. The promotion of biochar technology and its supporting infrastructure will serve as a model for other Arctic villages in North America.

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10. Curriculum Vitae

Theresa Theuretzbacher, BSC
Vienna, Austria 11.3.2015

EDUCATION

2013-2015 Master studies in Water Management and Environmental Engineering at the University of Natural Resources and Life Sciences, Vienna

2007-2013 Bachelor studies in Environmental Engineering at the University of Natural Resources and Life Sciences, Vienna

PROFESSIONAL EXPERIENCE

2013-2014 Institute for Water Management, Hydrology and Hydraulic Engineering (IWHW) at the University of Natural Resources and Life Sciences, Vienna

- Sediment balancing and bed level development of the river Obere Drau, land cover and impacts of hydropower plants on the bed load

2013 Center for Anti-Infective Agents supported by the FEMtech grant of the Federal Ministry for Transport, Innovation and Technology; 2 month internship

- Tracking of possible bacteriological infected herds of waste streams and elaborate measures to eliminate them

2012-2014 NGO Braveaurora

- Collaboration on the implementation of a solar powered water supply system in Guabuliga, Ghana

2012 Institute for Limnology, Austrian Academy of Science; 1 month internship

- Breeding and hatching of whitefish of the lake Traunsee, comparison of different measuring methods of water quality parameters

2010 Federal Ministry of Agriculture, Forestry, Environment and Water Management; 2 month internship

- Hydrographic Office: Internship

2007-2015 Eurotec, Vienna

- Administrative assistant

FUNDED RESEARCH PROJECTS

2015 US grant: The Alaska Water and Sewer Challenge

- Development of proposals for innovative and affordable water and sewer systems for homes in rural Alaska

2014 US grant: 2013-15 North American Partnership on Environmental Community Action Grant

- Improving Community-Scale Feces Waste Treatment (CSFWT) in Arctic North America

INTERNATIONAL EXPERIENCE

2013-2014 Kisangani, DR Congo

- Mapping the water supply, data analysis and developing proposals in collaboration with the University for Applied Arts, Vienna

2012-2013 Kivalina, AK, USA

- Mapping the water supply and sanitation, data analysis and developing proposals in collaboration with the University for Applied Arts, Vienna

2011-2012 Guabuliga, Ghana

- Mapping the water supply and community layout, data analysis and developing proposals in collaboration with the University for Applied Arts Vienna

CONFERENCES AND WORKSHOPS

2014 9th Vienna Anthropology Days, Department for Social and Cultural Anthropology of the University of Vienna; participated in developing and leading the workshop

- Socio-economic Aspects of Maintaining Technical Infrastructure in Architecture and Water Management

2013 First International Terra Preta Sanitation Conference, TUHH (Hamburg)

- Presentation of the bachelor thesis: Terra Preta like products on the German and Austrian Markets

2013 ELLS Scientific Student Conference, BOKU (Vienna)

- Poster presentation of the bachelor thesis: Terra Preta like products on the German and Austrian Markets

PUBLICATION

2014 Theuretzbacher T., Stranzl S., Smidt E., Langergraber G. (2014): Investigation on Terra Preta like products on the german-Austrian market. In: Bettendorf T., Wendland C., Otterpohl R. (Eds.). Terra Preta Sanitation- Proceedings of the 1st international conference on Terra Preta Sanitation, 29-31 August 2014, Hamburg, Germany.

AWARDS

2014 National Energy Globe Award Ghana

2012 International Bauhaus SOLAR AWARD 2012 for young talent (distinction)

IT-SPECIFIC SKILLS

MS Office, AutoCAD, ArcGIS, QGIS, HEC-RAS, SPSS, Rhinoceros, Adobe: Photoshop, Illustrator, In-Design, Flash

LANGUAGES

German (native language), English (fluent), French (school knowledge), Norwegian (basic)

SPECIAL EXPERIENCE

10 month foreign exchange in Palo Alto, CA, USA

11. Affirmation

I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Vienna, 12.03.2014, *Theresa Theuretzbacher,*