AN IMPACT ASSESSMENT OF CURRENT RURAL ALASKA VILLAGE SOLID WASTE MANAGEMENT SYSTEMS: A CASE STUDY

By

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Abstract

The purpose of this study is to examine the impacts of current and alternative solid waste management practices of two rural Alaskan villages. The EASETECH life-cycle assessment modeling tool was used to compare the current solid waste management systems for the remote villages of Kalskag and Fort Yukon across eight alternative scenarios. Annual waste generation and composition data for these two villages and data specific to processes and functions for each waste system were collected and used to modify templates within the EASETECH program to provide a life-cycle assessment for current and proposed waste management practices. The results indicate that integrated waste management practices for these remote villages may not be economically feasible or environmentally favorable. Waste management options, though limited for these remote villages, may benefit from minor system changes. These changes include transport services and burn practices that only slightly increase operating costs, but significantly reduce local social and environmental impacts. Local, accurate, and complete waste stream data could help support future management planning for the solid waste management systems of these rural villages.

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Chapter 1-Introduction

Solid waste management (SWM) is the process of handling, transporting, and disposing of residential, commercial, and demolition and construction waste for a given city, municipality, community, or village. Large scale solid waste management practices have evolved to include reuse, reduction, and recycling methodology that uses burial and incineration only after all recyclable or reusable materials have been removed. Solid waste management at any scale is based on the availability of resources and community priorities and must account for annual fluctuations in the heterogeneous waste stream. Resources and priorities may vastly differ in given communities. Alaska, for example, has a large land area with many small communities unconnected by a state road system that rely on local landfills to manage all waste produced. In most cases the waste stream consists primarily of various inorganic materials that are shipped into these communities, but that cannot be removed or recycled.

The focus of this thesis is to assess the impact of the current rural village solid waste management practices on the rural Alaska villages of Kalskag and Fort Yukon. The purpose of this study is to evaluate rural village solid waste management practices, for the two rural Alaska communities of Kalskag and Fort Yukon, and the related impacts on social and ecological services of these current SWM practices. In addition, I seek to quantify proposed impacts of the current solid waste management practices for the rural Alaskan villages of Kalskag and Fort Yukon, as well as to identify potential economically viable alternatives that mitigate harmful social and environmental impacts. The SWM practices and processes within these two remote communities may be not indicative of those used in other rural villages in Alaska. They do, however, provide an example of waste management practices that occur within many remote

Alaska communities. I provide an overview of SWM, current SWM within Alaska, and SWM practices of other circumpolar countries. SWM practices and methods used for addressing these systems are continually evolving and may be influenced by factors such as public priorities, environmental concerns, and social well-being.

SWM systems are influenced by a number of system drivers, including public health, environmental protection, resource conservation, institution and responsibility issues, various market forces, and public awareness (Wilson, 2007). Cultural significance as well as economic, social, and environmental impacts are major contributing factors that dictate how solid waste is being managed for a given community. Waste or trash implies a uselessness; however, the waste stream contains assorted materials that are still useful, such as non-renewable resources (aluminum, metals), organic matter (useful for composting), and other components that can be reused. Integrated solid waste management (ISWM) aims to decrease negative impacts to social-ecological services through a series of steps that minimize items to be burned or buried. Ultimately, all waste that is not recycled, reused, or reduced makes its way back into air, ground, and water mostly in the form of smoke, fumes, gas, or leachates. Some plastic items are highly resistant to breakdown, and pose a different set of risks to wildlife to which they become accessible. Health and environmental factors, community constraints, and multiple levels of policy drive solid waste management practices from large municipalities to small rural communities.

Public health concerns in the nineteenth century led to the emergence of solid waste collection systems that mitigated potential health hazards and remain to this day a key driver in the development of SWM systems. Environmental protection came to the forefront in the 1970s, with an initial focus on eliminating uncontrolled disposal, followed by the systematic tightening of technical standards (Wilson, 2007). Public health and environmental protection, along with climate change and diminishing non-renewable resources are some of the key drivers of SWM practices. Within the context of this study, the major drivers of SWM for remote Alaska communities are geography (seasonal variations), infrastructure, cultural influences, and economic constraints.

1.1 Introduction to Integrated Solid Waste Management Systems

The current SWM practices within most developed countries follow an integrated solid waste management (ISWM) approach. ISWM is comprised of four basic management strategies: source reduction, recycling and composting, combustion (waste-to-energy), and landfill (Tchobanoglous & Kreith, 2002). ISWM is based on a hierarchical top-down approach that moves from source reduction, recycling/composting, waste transformation, and finally to landfilling. Similarly, an interactive approach of reduction, combustion, recycling/composting, and landfilling is iterative and can be adjusted based on cost and benefits, providing a more thorough and collaborative approach. ISWM as a hierarchical or interactive approach aims to reduce the amount of waste burned or buried, in an attempt to mitigate negative environmental and social impacts.

The basis for managing solid waste relies on the accurate characterization of a given waste stream. The two main components of a waste characterization are amount and type of waste. An accurate waste stream characterization provides the foundation for decisions related to all SWM practices. The amount of waste informs spatial and temporal planning, while the type of waste dictates the treatment of that particular waste stream. Large cities and municipalities track this information in order to make informed decisions. For areas where space is limited, long term planning is required to avoid pollution of local resources and running out of landfill space. However, waste amounts and types in rural Alaska villages are not currently being tracked with any regularity or consistency, as indicated by the lack of accurate waste stream data.

ISWM strategies are implemented in order to manage waste while minimizing natural resource degradation and negative social impacts with the least possible cost. Without an accurate waste stream characterization, management practices are based on past practices and assumptions about the current waste stream. The basis for suitable waste management practices for a given community, borough, municipality, or city begins with information on the amount and type of waste being generated. Socioeconomic factors, climate, geography, and cultural influences will dictate these practices, but a characterized waste stream will help guide management decisions. The current controlling framework for most SWM practices is an ISWM hierarchy that aims to reduce, reuse, and recycle non-renewable resources, avoid human and environmental degradation, and decrease waste that is to be buried and/or incinerated and finally buried. Employing this waste hierarchy in Alaska and other remote arctic regions is challenging, due to lack of access to landfills with controls for handling hazardous waste, liners and covers that mitigate environmental degradation, and the limited ability to reuse, recover, and recondition recyclables.

There are three classes of landfills as defined by the Environmental Protection Agency (EPA) and are presented below, with additional delineation set by state entities that are designed to provide controls to mitigate social and environmental hazards. The EPA establishes standards for each landfill class, but each state can impose more stringent regulations and requirements. These standards require that landfills must reside out of wetlands and flood plains and that waste must be compacted and covered frequently to reduce odor and control litter, insects, and rodents.

Class I landfills must have compacted clay soil lining on the bottom and sides of the landfill. There must be ground water monitoring, and protection of groundwater and underlying soil from leachate release. Removal of leachate from the landfill for treatment and disposal is also required. Class I landfills are designated to accept hazardous waste, more than 20 tons daily of municipal solid waste (based on an annual average), and construction and demolition waste – all received waste will be incinerated or buried (Purpose, scope, and applicability; classes of MSWLF, 2002). These landfills typically serve large communities or municipalities, track waste entering the landfill, and employ an ISWM strategy that discourages burial and incineration. According to Doug Buteyn of the Alaska Department of Environmental Conservation (ADEC) waste division, there are nine class I landfills in Alaska and all of them are permitted (personal communication, February 12, 2016).

The requirements for Class II landfills are similar to those for Class I landfills, but limited to no more than 18,000 kg (daily) of solid waste, based on the annual average. Class II landfills are also restricted from receiving hazardous materials and may be unlined. There are 13 Class II landfills in Alaska, all of which are permitted (D. Buteyn, personal communication, February 12, 2016).

The local landfill, defined by the ADEC as a Class III landfill, represents the majority of the 200-plus landfills in Alaska and are allowable by a federal exemption (D. Buteyn, personal communication, February 12, 2016). A Class III landfill is not connected to a Class I landfill or is 80 km or more from a Class I landfill. The Class III landfill receives less than five tons daily of municipal solid waste, which is based on the annual average of waste received by the landfill (ADEC, 2002). The Alaska Class III landfill is permitted by the ADEC. These landfills are required by the Alaska DEC to be permitted and as of July 2015 123 of 187 Class III community landfills held permits (D. Buteyn, personal communication, February 12, 2016). These unmonitored, uncontained landfills lack the necessary precautions for protecting human health and the environment; thus, the rural Alaskan landfills permitted or not, are (Figure 1.1 & 1.2) negatively affecting local natural resources and human health.

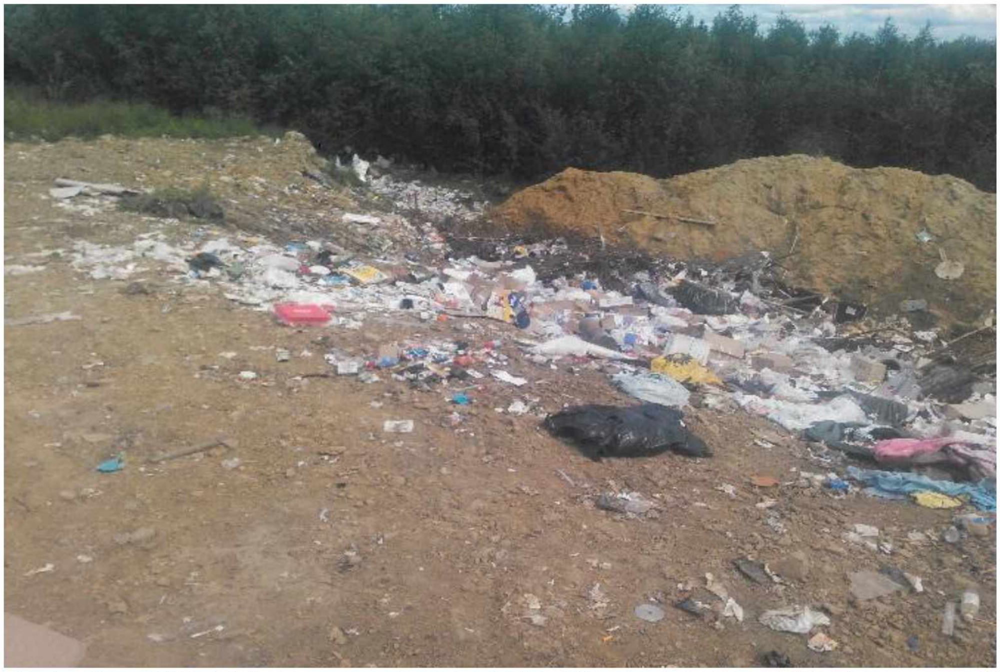


Figure 1.1 Ruby Landfill. This picture taken in 2014, illustrates uncontained waste and litter being moved out of the local landfill and into bordering natural resources.

Figure 1.2 Fort Yukon Landfill. A burning pile of trash captured in 2014. Open burning practices and uncontained waste are indicative of conditions found throughout many rural village landfills.

1.2 Solid Waste Management in Alaska

SWM in Alaska and other arctic areas faces several unique challenges, including harsh climate and inaccessibility. The 2013 U.S. Census Bureau (ADEC, 2010) estimates the population of Alaska as 736,399, with more than half of the population concentrated within the city centers of Anchorage (301,134), Fairbanks North Star Borough (99,632), the Matanuska-Susitna Borough (96,074) and Juneau City and Borough (33,064) (The Alaska Department of Labor and Workforce Development's Research and Analysis Section, 2015).

In 2014, the Anchorage area, which contains approximately 41% of the state's population, produced roughly 210,000,000 kg of solid waste, of which almost 30,000 kg were reused and just over 3,000,000 kg were recycled or composted (Anchorage landfill, 2015). This equates to a recycling rate of approximately 2%, and a waste generation of 1.95 kg per person per day. The Anchorage landfill serves the Anchorage municipal area, Eagle River, and Girdwood. In Anchorage, there is a gas to energy facility that uses gases produced from the landfill to generate utilities for Joint Base Elmendorf Richardson (Anchorage landfill, 2015). In terms of operating under an ISWM regime and reusable material recovery, Anchorage is well below the reported U.S. national average of a 34% recycling rate and a 13% rate of organic materials being composted (Table 1.1) (EPA, 2013).

The Fairbanks North Star Borough (FNSB) and the surrounding Fairbanks area represents the second largest population center in Alaska. The FNSB landfill is 252 acres, with 14 transfer sites serving the city of Fairbanks, the North Pole, the University of Alaska – Fairbanks, and several surrounding communities (FNSB, 2014). The FNSB landfill accepted roughly 95,000,000 kg of waste in 2014, with about 3,000,000 kg being recycled or composted, representing approximately a 3% recycling rate (Jordan, 2014). The transfer sites (stations) function as a processing site that receive trash and reusable materials as a temporary holding facility en-route to the local landfill. They have a designated area for trash and provide a separate area for items considered reusable that can be dropped and picked up by members of the community. They are emptied daily, and the remaining waste is removed and transferred to the local landfill. The average waste generation per capita was 2.95 kg per person per day. The FNSB does offer waste-to-energy options for flammable liquids, fuels, oily water, and used oil, to provide heat and energy for onsite space heaters. The oily water is used to power a boiler. The used oil is recycled and reused as heating oil.

Fairbanks has a recycling rate of approximately 3.3% according to reported recyclables received by Green Star and the annual report from the Fairbanks North Star Borough end of year fiscal report (FNSB, 2014; A. Cyr, personal communication, August 31, 2015). Green Star of Interior Alaska is a local nonprofit serving the Fairbanks North Star Borough and encourages reuse of materials, waste reduction, and increased recycling within the Fairbanks area. The recycling options utilized by the Fairbanks area are:

- Paper is shipped to the lower 48 and recycled, or to K&K Recycling Inc. (located in Fairbanks) and burned in an electrical generator.
- Plastic only clear soda bottles, and milk and laundry detergent type jugs can be recycled in town.

- Metals such as aluminum, copper, brass, steel, etc., go to C&R Pipe in Fairbanks, Alaska. If the aluminum is sorted by “clean” aluminum (cans) and “"dirty” aluminum (foil or other kind), the company provides compensation for the metal.
- Glass may be crushed and used in road paint and mixed with asphalt
- Household electronics (batteries, computers, TVs, wire, any electronics, etc.) may be taken to Green Star and then backhauled to Seattle, for a fee. (A. Cyr, personal communication, August 31, 2015).

Table 1.1. Solid Waste Statistics for Waste Generation. Recycled waste is expressed in kg and % of total waste, and total kg of waste landfilled for one year. The U.S. totals are for 2012, rural Alaska was 2010, Fairbanks and Anchorage were for the fiscal year of 2014 and the Greenland data was for 2013. All units are expressed in kg (x1000) (FNSB, 2014; Anchorage Landfill Gas to Energy Project, 2014).
*Calculated from the estimated rural village population of 238,000 and a waste generation of 2.3 kg/per person/per day (Van Haaren, Themelis, & Goldstein, 2010).
**Based on little to no record of recycling occurring.
Total tons have been adjusted to reflect recycled materials that did not go into the landfill.

	Total kg	**Recycled (kg)**	**Landfilled (kg)**
U.S. Totals	228,000,000	79,000	122,000
Alaska	583	24	554
Rural Alaska	*150	Not reported	**Not reported
Fairbanks	99	3	96
Anchorage	294	3.3	290
Mat-Su Valley	76	1540	75
Greenland	66	Negligible	66

In Alaska, even the large municipalities of Anchorage and Fairbanks lack an ISWM approach that emphasizes source recycling and reduction of total waste entering the landfill, as evidenced by their low recycling rates (Table 1.1). SWM practices utilized in the contiguous United States may not be practical for communities within the Arctic region, due to remote locales, limited access, long transport distances to recycling facilities, and monetary constraints. The result of these factors may negate the benefits of recycling for these remote communities.

Alaska occupies a large geographical areas characterized by many small communities separated by ice, water, and impassable terrain. A major challenge for these rural isolated communities is management of solid waste. Little information and even less formal research in journals is available with regard to these rural landfills and their impacts related to their management. The 2011 Eisted and Christiansen characterization for Greenland and the 2006 Daniel Lung waste characterization for the village of Kalskag, Alaska represent the only known relevant waste stream analysis available. They represent the solid waste management challenges of isolated communities without access to Class I landfills, and access limited to plane, barge, or boat.

The Greenland solid waste characterization study reflects the challenges to a large country (1.3 million square km) with a very small population (56,000 inhabitants) scattered in remote settlements and coastal towns (World Fact Book North America, 2014). A waste characterization was carried out in Sisimiut, the second largest town in Greenland, with approximately 5,400 inhabitants about 10% of the Greenland's population and considered characteristic of a typical town in Greenland (Eisted & Christiansen, 2011). The sampled waste stream represented about 15% of the weekly waste collected in Sisimiut. The small waste quantities (less than 5 tons/day), long transport distances that are limited to boat or plane, and the harsh arctic climate result in most waste being buried in the local landfill or incinerated. These landfills and small-scale incinerators offer little to no environmental protection (Eisted &

Christiansen, 2011). Greenland lacks a major road system connecting villages, disposes of waste mainly by burning or burial, and has limited options for recycling; these challenges are shared by most rural Alaska communities.

The SWM practices for remote Alaska communities rely on the local landfill as both a place for their trash and as a resource for reusable materials. Rural or remote villages in Alaska, within the context of this study, refers to those villages off the road and state highway system, accessible by plane, boat, or barge, with a predominately Alaska Native population. In my thesis, I focus on two rural villages located in the Southwest and Interior Alaska. Both communities operate in a mixed economy system that includes subsistence practices of fishing and hunting with community sharing of subsistence harvests, and income from wage work (Goldsmith, 2007). Many rural Alaska villages were often established as seasonal hunting and camping areas and located in areas that were never intended for anything more than short-term, special purpose hunting and collecting activities (Hall, Gerlach, & Blackman, 1985). Kalskag was a seasonal fish camp (Alaska Department of Commerce, Community, and Economic Development [ADCCED], 2015), while Fort Yukon was a Canadian outpost in Russian territory (ADCCED, 2015). Both communities established a school and post office. Dependence on resources generated outside of these remote villages (e.g., automobiles, snow machines, appliances, electronics, food, and fuel) and travel to and from these villages requires both capital and access to transport by barge, boat, or plane. As outside goods enter the villages, the packaging contributes to the waste stream and the eventual product end of life requires a place for disposal. Separation of large appliances, automobiles, and removal of harmful materials is determined by the local landfill managers and community priorities. When separation of harmful materials (i.e., paint, oil, fuel, anti-freeze, etc.) does occur, landfills serve as short-term solutions for storage and not disposal. Rural Alaska villages rely on local landfills for disposal of all waste (Gilbreath & Kass, 2006).

The average number of landfills per state in the United States is 38; Alaska has more than 240, indicating more local, less centralized landfill sites (Van Haaren, Themelis, & Goldstein, 2010). Current regulations prohibit the dumping of human waste and open burning (Figure 1.1) within rural landfills. However, according to a personal communication with the Rural Alaska Community Action Program (RurAL CAP) coordinator, and personal observations, both practices are a regular occurrence within rural village landfills (T. Jacobs, personal communication, May 14, 2014).

Two options for SWM exist for rural communities: 1) burning of waste, and 2) burning and burial of waste. Burning and burial methods vary from one village to the next. Some village landfills may rely on a large hole, a shallow pit, or simply pile trash on top of other trash. Burning practices also differ in each village and the extent of degradation is highly variable. Village landfills typically consist of a hole or pile where residents dump and often burn their waste (T. Jacobs, personal communication, May 14, 2014). Recycling, reuse, and reduction options within these remote villages are limited or non-existent. However, discarded items, such as wood, wire, screws, and other reusable items are recovered by community members in need of these items. This provides a method of material reduction and reuse, however, these individuals are exposed to noxious fumes from open burning (Figure 1.1), vectors of disease from human waste, and other dangers inherent to the landfills (Shirley, 2011).

The current solid waste management systems of many rural Alaska communities are necessary for these communities, but pose a risk to human health and supporting natural resources. Proximity of these villages to natural resources such as forests, berries, fish, and moose, enabling a subsistence way of life. The local landfill usually borders resources and may risk diminishing their value through resource degradation and contamination. The establishment of these communities usually have centered on a school or church and were not settled in locales with access as a priority. These villages were often established as seasonal hunting and camping areas, and located in areas that were never intended for anything more than short-term, special purpose hunting and collecting activities (Hall, Gerlach, & Blackman, 1985). Thus, these communities have become established without supporting infrastructure, such as state-connected road systems, access to major healthcare, affordable fuel, and Class I landfills with recycling and source separation options. These remote villages rely on spring and summer transport of goods and services imported by planes, boats, and barges. These imported items may include clothes, automobiles, food, computers, appliances, and medications, as well as non-essential items. An extensive bush pilot system provides most of these rural villages with service once a week and in some cases multiple times a week. Large freight, mail, food, medical supplies, and other goods are transported on these planes. With an inflow of goods and supplies from outside the village and little option for removal of discarded materials, the local landfill has within the last twenty years seen a growing waste stream. The modern Alaska Native subsistence hunter and fisher are more dependent upon manufactured boats, motors, and all-terrain vehicles, than the subsistence hunter and fisher 20 years ago (Nuttall, 2001; Nuttall et al., 2004).

Rural or remote Alaskan villages, often referred to bush villages, are those villages dependent on urban centers for goods and services, via planes and barges (Loring & Gerlach, 2009). Local food procurement (of wild food sources) is unable to meet the needs of most rural Alaskan households, necessitating the purchase of imported foods at the village store or during costly trips to urban city centers (Reed, 1995; Loring & Gerlach, 2009). This shift from local foods to imported foods includes packaging, such as cardboard, plastic, and glass. In addition, vehicles used for subsistence hunting have contributed to an increased waste stream as they are brought into the villages and operated until beyond repair. Technology such as televisions and computers have rapidly changed and improved and these items also enter the village, and older versions become obsolete finding their way into the local landfill. Barges, boats, and air transportation bring in food, snow machines, televisions, computers, and laptops. However, few options exist for recycling non-renewable resources or for disposal of hazardous materials within these communities. Recycling options and removal of hazardous materials are currently limited to backhaul programs. Funding for these programs is largely based on state and federal grants and barge operators that are willing to transport these items to major city centers willing to provide compensation. This current model for recycling seems an unlikely long term sustainable solution, however no feasible alternative is available.

Backhaul efforts have stalled as these grant funds were intended to support a temporary solution while communities created long term backhaul solutions locally funded or funded through community partnerships. Other recycling options available for these communities are local bush plane operators willing to transport aluminum cans to larger city centers when cargo space is available. Local bush plane companies (i.e. Warbelow’s and Wright Air), if returning empty and properly packaged will transport aluminum cans out of village(s) (Fort Yukon, Ruby, Galena, and Beaver) (Wright Air Pilot Boots, personal communication, May, 2014). These cans are then flown to major cities like Anchorage and Fairbanks and then transported to facilities with recycling capabilities. Beyond backhaul programs and aluminum flown out by bush pilots, few, if any, options for recycling exist within these rural landfills. In some villages, waste may be separated by degree of size, with household waste and small items within the main landfill and cars, appliances, old snow machines, and four-wheelers in a separate area or outside the confines of the landfill.

1.3 Rural Alaska Village Economics

The remote villages of Alaska have a mixed cash subsistence economy where members subsist in these communities using a combined cash/subsistence strategies dependent on allocation of payment and/or seasonal employment and dependence on adequate renewable resources (Dubbs, 1992). In Alaska, most products of subsistence practices do not enter the market economy. Rather, subsistence products are directly consumed by the harvesting household, given away, or exchanged (Goldsmith, 2007). Additionally, capital is required for subsistence practices for which expensive boats, motors, and all-terrain vehicles are required for hunting and fishing. These items all require cash to purchase and ship to these villages and to pay for fuel, hunting supplies, and maintenance (Einarsson, Nymand, Nilsson, & Young, 2004). Cash economies within the rural Alaskan village remain limited in many of these communities.

The cash economies emerge primarily as the result of resource-extraction, e.g., mining. However, such economic gain has been temporary, and in many places cash dependency and environmental contamination, not long-term economic development, are the only legacies (Aarsæther, Riabova, & Bærenholdt, 2004; Birger, Kruse, Duhaime, Abryutina, 2007). Time spent in wage work may conflict with time that otherwise would be spent harvesting subsistence resources. Along with this mixed economy is an "informal" economy, in remote places, which is undocumented in official statistics (Poppel & Kruse, 2009). Families and neighbors may trade services, share goods, or make cash payments not reported to the IRS (Poppel & Kruse, 2009). Such activities outside the standard market economy go on nationwide, but are especially important in remote rural Alaska, where both cash and local businesses are scarce (Goldsmith, 2007). Income generation within these rural villages is highly dependent on government employment, and according to 2010 census data, 45% and 35% of Kalskag and Fort Yukon (Figure 1.3) residents, respectively, held state or local government jobs. Along with government employment, natural resources play a major role within the context of the rural village economy.

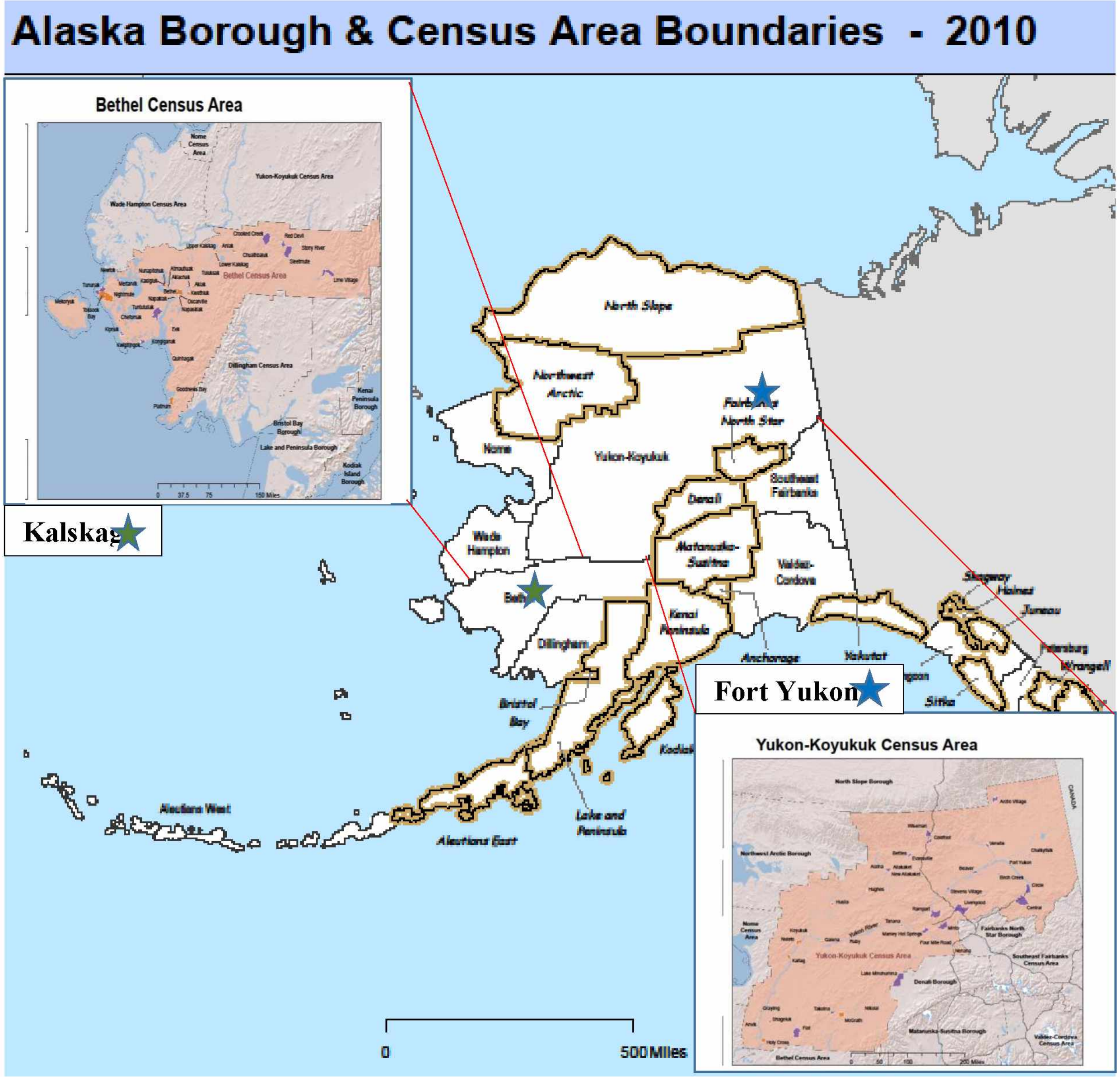


Figure 1.3. Alaska Borough and Census Area. A map of Alaska and the Bethel and Yukon-Koyukuk census areas. Kalskag is located in the southwest region of Alaska and is located on the north bank of the Kuskokwim River. Fort Yukon in that order located in the Arctic Circle and interior Alaska at the confluence of the Porcupine and Yukon Rivers. Source: U.S. Census (Alaska Department of Labor and Workforce Development, 2010).

Most of the natural resource wealth of Alaska originates in the remote or rural parts of the state, with oil extraction contributing to a large piece of the economic input. Mining extraction of other natural resources and commercial fishing are valued at billions of dollars. However, very little of this money enters these rural Alaskan villages. By traditional standards of economic measurement, the economy of the region lags behind the rest of Alaska. For example, in 2002, the combined personal income in remote rural Alaska was $1.462 billion and in the Kenai Peninsula Borough was $1.532 billion, which translates to $24,366 and $30,212 per capita for remote rural Alaska and the Kenai Peninsula Borough, respectively (Goldsmith, 2007). For the most part, individuals survive in these communities by a combined cash generation-subsistence, which is dependent on transfer payments and/or seasonal employment, as well as sufficient renewable resources (Dubbs, n.d.). The Alaska Permanent Fund Dividend (PFD) has provided an annual income to all Alaskan residents annually at an average of more than $1000 over the last twenty years. Opportunities for monetary income generation are largely those related to local government agencies, schools, state employment, the PFD, and jobs related to fishing or hunting activities.

In 2003, state and federal grants, Medicare payments, social security, and procurement totaled $868 million of income in these remote rural economies. Outside of natural resources production, federal government funds provide the economic base for these rural Alaska economies. Lack of employment opportunities contribute to out-migration, along with better access to specialized medical care, higher education, and technical training available in urban city centers (Goldsmith, 2007). The lack of economic opportunities within these remote Alaska villages limit the monetary resources available for improvements to these local landfills.

Current SWM systems and their projected impacts, modelling, and system changes pose an economic challenge for these rural Alaska communities. Solid waste management practices within these rural Alaskan villages exist out of necessity and with current economic constraints, improvements are only as important as each community deems them. Schools, supporting subsistence practices, infrastructure improvements (e.g., roads and public works water, sewer, and local food production) and SWM systems, are subject to community priorities. There is very little incentive to improve this “free” system that is the local landfill, with limited economic resources, a major motivator for change to the current system is a quantitative assessment of the impacts to local social and economic resources. This requires local waste characterization data of waste stream amount and type in order to use these modelling programs.

1.4 Rural Alaska Landfills

There are a variety of strategies and practices employed for the rural Alaska village landfill. These strategies or management practices are dictated by local agencies or governments and are based upon local involvement and community priorities. The village of Fort Yukon offers weekly trash curbside pickup (personal observation). The trash is picked up and taken to the local landfill in five or six flatbed truck loads and dumped onto the existing pile. This pile is frequently set on fire, trash is scattered by birds, and a partial fence does very little to keep trash within the landfill boundary. The city pushes the pile further into the landfill and on occasion into a pit. This landfill is not fenced in and there are no restrictions to access or monitoring of waste being dumped into the landfill. In Fort Yukon, containment of waste, enforcement of open burning, and landfill maintenance are not regular practices. The Fort Yukon waste management challenges stem from isolation, lack of recycling options, and limited monetary resources dedicated to solid waste management.

The small village of Ruby, also situated on the banks of the Yukon River, has a fenced area around a small pit where waste is dumped, but wind blows waste, such as plastic and paper, into and over the fence (Figure 1.2). The community participated in a cleanup of the landfill in August 2014, but I visited the landfill less than a year later in 2015 and the conditions appeared worse than they were prior to the initial cleanup. I have visited the landfills for the rural Alaska villages of Ruby, Fort Yukon, Stevens Village, Beaver, Birch Creek (all within the Yukon-Koyukuk census area) between May of 2014 and August of 2015. These landfills differ slightly through management practices, burning practices, and degrees of local interest. Other observations from site visits include unused hoppers (used to condense waste in compact boxes) for recycling, non-operational burn boxes, and whole areas developed as a new landfill, that are below the water line and therefore unsuitable for use. These landfills border local resources, are within two miles of the village, and receive waste daily from a variety of delivery vehicles all of which contribute to human and natural resource degradation.

Adjacent natural resources and human health are being affected by litter, leachates (entering ground and surface water), smoke, and noxious fumes exiting the local landfill. These rural Alaska village landfills are negatively affecting quality of life with negative impacts to air, water, and subsistence practices (Zender, Sebalo, & Gilbreath, 2003). I have visited the Interior rural Alaska villages of Ruby, Fort Yukon, Beaver, Stevens Village and the condition of those landfills seem to mirror the conditions described by Zender et al. (2003). The rural village landfills I have visited and researched all operate under a basic system where all materials are burned or buried at little to no monetary cost. The average rural Alaska village landfills, including those I visited, have very little regulation enforcement, monitoring, or controls for mitigating impacts on bordering social-ecological services. Maintenance or management of these landfills is done either when conditions are poor enough to require maintenance or on an annual basis per permitting requirements. Maintenance and operations within these landfills are usually managed and funded by local tribal or city governing entities. The controlling entity will employ several members of the community for the annual maintenance and cleanup or one or two individuals as regular employees for landfill waste management operations. Open burning, the dumping of hazardous materials, and improper containment for debris and leachates contribute to health and environmental degradation. The extent of these impacts on local social and ecological system services is unknown, but the importance of these resources warrants local action to monitor and establish impacts of local waste management practices.

1.5 Thesis Problem and Statement

Very little research and general information about solid waste management and the impacts of current waste management practices for rural Alaska are available. Out of 200 rural Alaska villages, there is only one formal waste characterization (Lung, 2006) of waste and a second unpublished waste stream characterization (performed for this study). With these two community waste characterizations the intent is to assess the current waste management practices and their projected impacts. This case study aims to highlight the need for further investigation of current solid waste management practices for more remote Alaska communities. In order to evaluate current and estimated impacts of SWM for these two rural communities, I applied the life cycle assessment (LCA) methodology using the EASETECH modeling program. EASETECH (Environmental Assessment System for Environmental Technologies), an LCA modeling tool developed by Denmark Technical University. The LCA methodology uses the life cycle impact assessment (LCIA) to categorize and quantify the proposed impacts of the current solid waste management system(s) on water, air, soil and human health. The International Organization for Standardization (ISO) and the Society of Environmental Toxicology and Chemistry (SETAC) provided the framework and standardization used in my study, (ICCA, 2006a) which was intended as an assessment tool rather than to inform management decisions. This dataset is not large enough to represent conditions for the whole of the 200 remote Alaska communities, however these two community landfills may be very similar to conditions found throughout rural Alaska. I used a systems modelling approach, LCA methodology, and the EASETECH modelling program to achieve the goals and objectives of this study. Further description of the EASETECH model is discussed in Chapter 3.

I examined the proposed impacts of current solid waste management practices on environmental quality (air, water, and soil) and human health for these two communities. This was accomplished using nine scenarios representing the current system(s) and alternatives moving up the waste hierarchy where recycling and source reduction decrease the total amount of waste being burned or landfilled. Therefore, in this study I address the question:

> What changes to remote village solid waste management systems can be made in order to manage the local waste stream within the community landfill with minimal degradation of supporting natural resources, and in an affordable manner?

1.6 Thesis Outline

Chapter 1 "Introduction" Chapter one introduces solid waste management broadly and specifically within rural/remote Alaska communities. The purpose of this study is to assess current solid waste management systems within two rural Alaska villages in order to establish possible alternatives with fewer negative impacts than those incurred by the current system.

Chapter 2 "Case Study" An introduction to two rural Alaskan villages and their solid waste management practices. The waste characterization methods and results are included in this chapter.

Chapter 3 "Systems Modelling and Life-Cycle Assessment Methodology" the EASETECH program and life-cycle assessment approach to solid waste management systems. Includes methods and results of the life-cycle assessment of the rural Alaskan villages of Kalskag and Fort Yukon.

Chapter 4 "Synthesis and Conclusion" the synthesis of results, conclusion, and discussion of rural village solid waste management and associated impacts.

Chapter 2-Case Study

2.1 Kalskag and Fort Yukon Solid Waste Characterization

The Alaskan villages of Kalskag and Fort Yukon were used as a case study in order to compare waste stream characteristics and evaluate their SWM practices. The rural Alaskan village of Kalskag is the site of the only complete and published waste characterization for any rural Alaska village. The Lung (2006) waste characterization of the Kalskag waste stream in 2006 will be used to represent one data set for the rural Alaskan landfill assessment. I used the Kalskag study as a template in order to perform a second similar waste characterization of the Fort Yukon waste stream during the summer of 2014 and in the spring of 2015. The combined characterization data for Kalskag and Fort Yukon were used to carry out the impact assessment of current solid waste management practices for the these two remote Alaskan villages. The scope of this study is limited to these two villages; however, the SWM practices, conditions, and waste characteristics may be similar to those found in other rural Alaskan villages. Kalskag and Fort Yukon are subsistence-based river communities accessible by barge, boat, or plane. These two communities are similar in size and less than 800 km from the major city centers of Anchorage and Fairbanks, respectively.

2.2 The Rural Villages of Kalskag and Fort Yukon

The village of Kalskag is located in the southwestern portion of Alaska. The population of Upper and Lower Kalskag, according to the ADCCED (2015a), was estimated to be 512, with 231 people in Upper Kalskag (ADCCED, 2015a) and 281 people in Lower Kalskag (ADCCED, 2015b). The two Kalskag villages, Upper Kalskag and Lower Kalskag are located on the Kuskokwim River and will be referred to as Kalskag. The shared solid waste management facilities are located in Lower Kalskag, 3.2 km downriver from Upper Kalskag. Subsistence activities are an important component of the community culture. The shared SWM facility is approximately 5 km down an unpaved road that connects Lower Kalskag to Upper Kalskag. In a phone interview with a member of the Kalskag tribal council, Crim Evan reported that there is no burn box and that no active burn or incineration of waste within the Kalskag landfill is currently taking place (C. Evan, personal communication, May, 2015). Waste is brought to the landfill directly by individual households, businesses, schools, and local government organizations using a variety of vehicles that include snow machines, four-wheelers, cars, and trucks (C. Evan, personal communication, May, 2015). The waste is thrown into a pile and buried as needed. Landfill operations and maintenance are provided when necessary, but currently the tribal council is without heavy equipment for upkeep and maintenance of the landfill (C. Evan, personal communication, May, 2015). The Kalskag village landfill is operated by the local tribal government at little to no cost and minimum maintenance and unsupervised open dumping is allowed.

Fort Yukon is located in the interior of Alaska, approximately 230 km northeast of Fairbanks, at the confluence of the Yukon and Porcupine Rivers. It has approximately 576 residents (ADCCED, 2015c). Unlike Kalskag, Fort Yukon provides weekly curbside pickup and delivery to the local landfill. The current waste management practices within Fort Yukon include curbside pickup and delivery to the local landfill provided by the city of Fort Yukon. The collected waste stream is dumped into piles and as deemed necessary, waste is pushed into a pit and buried. Large appliances and vehicles are collected separately for the backhaul program when in operation. I visited the village of Fort Yukon six times over 2014 to 2015 and have witnessed the landfill burning and/or smoldering during each visit. Curbside pickup lowers the overall traffic to the landfill; however, community members frequently visit the landfill for waste disposal. The landfill is open to the community and dumping and burning occur unsupervised. In order to perform an impact assessment of these two landfills, I assessed waste stream characteristics such as the annual amount and types of waste for the villages of Fort Yukon and used the Lung report (2006) for Kalskag.

2.3 Waste Stream Characterization Methods

I obtained the generated waste amount and types for Kalskag from a study conducted by Daniel Lung through University of Alaska Fairbanks and Cooperative Extension Service in 2006 (Lung, 2006). The study provided a waste stream assessment for the combined villages of Upper and Lower Kalskag (Lung, 2006). The purpose of Lung's study was to (1) improve estimates of waste generation and waste composition, (2) to raise awareness of issues related to open dumping, and (3) support efforts to seek long-term solutions to reduce waste and increase recycling (Lung, 2006). The characterization was used to estimate the amount and type of waste generated by the community of Kalskag. For a six month period, waste was collected from 24 homes, three schools, and six business-administration offices (annual characteristics were extrapolated) (Lung, 2006). The collected waste was weighed, sorted, categorized (11 categories), and recorded, and the percentage and amount of each waste type was deduced from the waste stream characterization.

I visited the community of Fort Yukon over a two-year period during which I estimated annual waste composition and quantity from a waste collection period of six total weeks. For three weeks in August 2014 and three weeks in May 2015, the city maintenance staff collected waste once a week and separated the waste stream for characterization purposes. The City of Fort Yukon hauls an average of five truckloads of 400 to 500 bags of trash weekly to the local landfill. A total of six weeks of waste was used to estimate annual generation and types of waste for the community of Fort Yukon.

The collected waste was piled separately from the existing landfill waste. I sorted the waste into eight categories. Business waste, school waste, and household waste were all collected and gathered in one large survey area. The pile of waste was further separated into the following 10 categories; diapers/sanitary products, food waste, cardboard, paper, newspaper, office paper, food cans, other, plastic bottles/containers, and aluminum. The other category represents random items such as bed frames, bike frames, and miscellaneous items that did not fit in any of the nine categories. The pile was sorted and each category was collected in 40 gallon trash bags and weighed. Items that were too large for the bag were weighed individually and included in the appropriate category. The total number of bags collected each week was counted and a total number of bags was then calculated for the two three week collection periods (August, 2014 and May, 2015). The pile was sorted, separated, weighed, and the number of assessed bags was used to estimate the weight and percentage of the whole of the collected pile (Figure 2.1). Approximately 6% of the total three-week collection was assessed, characterized, and used to estimate a daily waste stream generation for the village of Fort Yukon.

Figure 2.1. Fort Yukon Waste Characterization. Collection of Fort Yukon waste stream. Waste was sorted, separated, categorized, and weighed.

2.4 Waste Stream Characterization Results

The waste characterization conducted on the waste stream in Kalskag the reported an estimated 46,200 kg of total waste produced and estimated per capita waste generation of 0.5 kilogram/person/day for a six-month period in 2006 (Lung, 2006). Households generated an estimated 36,287 kg of waste, schools 7,167 kg, and the combined business/office buildings 2,812 kg (Lung, 2006). I used the 0.5 kilogram/person/day that Lung calculated for the survey period to extrapolate the total annual estimated waste stream, which resulted in an estimated annual total weight of 84,368 kg/year. For the Kalskag characterization the waste was sorted into 16 categories and then combined into 11 sorted categories representative of the community's waste stream (Table 2.1).

Table 2.1. Fort Yukon and Kalskag Waste Fractions. The original material percentages of waste for Fort Yukon and Kalskag. The Fort Yukon waste fractions were collected the summer of 2014 and spring 2015. The Kalskag material fractions come from the Lung waste characterization study completed in 2006.

Fort Yukon-Material Fraction	**%**	**Kalskag-Material Fraction**	**%**
Aluminum cans	13.5	Aluminum cans	3.4
Plastic	17	Plastic	10
Diapers, sanitary towels	17.5	Diapers	12.4
Food waste	11	Food waste	14
Cardboard	10.5	Cardboard	6.3
Newsprint	8.5	Newspaper	1.2
Office paper	8.5	Other paper products	19.2
Food cans (tin/steel)	3.5	Other metal products	5.3
Other (misc., clothes, gloves)	7.5	Other trash	13
Plastic bottles	2.5	Glass	2.5
		Bathroom Medical waste	12.6
Total	100	Total	100

A total of 37.5 bags were weighed and sorted, representing about 6% of the total of the three-week period. This was used to extrapolate an estimated annual waste generation for Fort Yukon, 2014 and 2015 waste characterization estimated .10 kg/person/day and 17,237 kg of waste per year. In total, 1,456 bags were collected in August 2014, and 1,441 bags were collected in March of 2015. An average of 483 bags per week of waste was calculated from the six-week collection period. There were ten sorted categories that included food waste (organic waste), office paper, newsprint, plastic, aluminum cans, glass, non-aluminum cans, cardboard, other, and diapers/sanitary towels (Table 2.1). All waste was treated equally and no distinction between household, businesses, or schools was made.

While there is a nine-year gap between the Kalskag waste characterization and the characterization that I conducted for Fort Yukon, there was no reason to expect major changes over time in the distribution of waste across the various categories. The methods used to determine the waste characterization varied to some extent and may have contributed to the differences of estimated amounts and types of waste of each characterization. For the purpose and scope of this study, the two data sets appeared to be adequate and comparable, but the total estimated waste generated for Fort Yukon was much lower than Kalskag.

Chapter 3-Evaluation of Rural Alaska Waste Management Systems

3.1 Systems Modelling Approach and Life-Cycle Assessment

Computer modelling or system dynamics approaches are described as the use of computer models to assess a complex processes, diagnose problems through experimental methods, and study the behavior of these models over a given period of time (Caulfield & Maj, 2001). In this study LCA models are used to evaluate complex systems such as solid waste management systems, using quantitative data to estimate outcomes based on inputs, outputs, and system boundaries LCA models are useful tools that provide an evaluation of systems dynamics, are cost effective, and utilize existing data to determine the feasibility of changes to the system and proposed impact to local resources. Inputs to the system include materials entering the landfill, energy (expressed as fuel consumption) required for transport of waste to the landfill, and costs associated with these activities. Outputs of the system include materials exiting the landfill for recycling or reuse (i.e. glass used for road repurposing), energy required for recycling transport and processes, profits and expenses, and emissions from all processes (Figure 3.1). Internal processes are those actions occurring as functions within the system such as operations (burning and separating materials), maintenance (i.e. maintaining vehicles used internally and moving and burying of waste), processing (separating materials such as oil, antifreeze, harmful materials or recyclables) , receiving (waste entering and associated processes), etc. (Figure 3.1; EPA, 2006).

The program inputs include waste generation estimated from the waste characterization, all collection, separation, and transportation processes occurring before entering the landfill. Examples of quantitative data includes waste generation in quantity and amount, emissions data for transportation of waste into and out of the system, and percentages of materials burned, buried, or recycled. The system boundaries for this particular assessment were limited to waste generation transport and handling of waste to and from the landfill and all internal processes occurring within the landfill. The outcomes are the results of the life cycle impact assessment (LCIA) calculated for each scenario based on the all system process required for handling, processing, disposing, and recycling of the waste stream for a given case study. All operations within the landfill including handling, waste treatment options, maintenance and operations are system process included in the assessment. When available data specific to the study area should be used, generic options contained within the program may be used. Outputs to the system include materials transferred to recycling centers, required transport processes and any activities occurring downstream from the landfill as a result of managing the given waste stream.

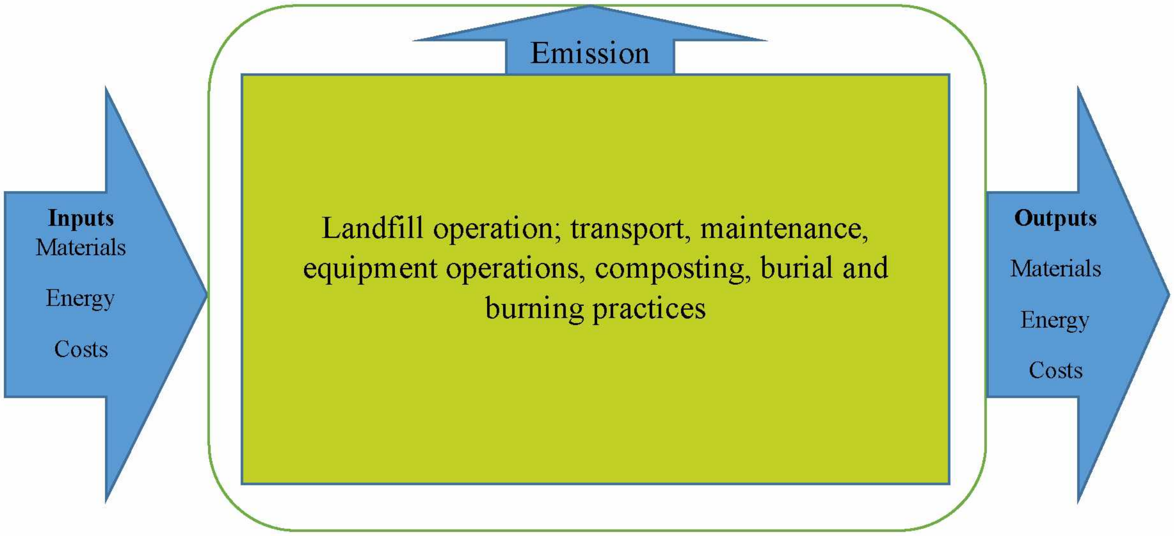


Figure 3.1. Conceptual Model of Solid Waste Management Systems. Arrows indicate flow of materials into and out of the primary system represented by the local landfill. Inputs include the waste stream, transport to the landfill, and energy and economic costs associated with those activities. Outputs are those materials exiting in the landfill for recycling, composting purposes, and the energy and costs associated with those activities. The emissions arrow indicates the release of gases, leachates, and any other materials (smoke, hazardous waste, human waste) moving from inside the landfill into supporting ecological services. The green outline represents the primary system and the emissions occurring from the primary system, with inputs and outputs as a result of functions occurring outside this primary system.

LCA "is a straightforward methodology for assessing all the environmental impacts of a product (or service), from 'cradle to grave," i.e., from the initial extraction and processing of raw materials to final disposal" (Ayres, 1995, p. 199). Ideally, a life-cycle analysis is composed of an inventory of resource inputs and waste outputs for each stage of the waste system, as well as an assessment of risk associated with each of the inputs and outputs (Tchobanoglous & Kreith, 2002). Model inputs include waste characterization data specific to Kalskag and Fort Yukon mainly waste generated and waste types. Other data inputs included specific transport related including estimated fuel usage and emissions related to transportation of waste materials into, within, and out of the landfill. The internal processes of the model is the LCIA, where gathered data has been entered into each inventory template and the EASETECH model provides the environmental assessment using the 12 impact categories. (EPA, 2006). The model performs an impact assessment using as much real data as the user can gather and enter into the templates that represent all associated processes.

One of the most critical components in performing an accurate LCA is establishing reliable inventory data. These data include accurate waste generation for waste type and amount, along with all the associated processes that include transport, treatment, and handling of the waste stream. Generating site-specific monitoring data for all substances known to cause adverse health and environmental impacts is prohibitively expensive, and in many cases not even feasible. This leads to existing data gaps relating to processes and emissions into the environment and gaps of data and knowledge (i.e., epistemic uncertainty) that lend to an underestimation of overall impacts of the modelled systems (Huijbregts et al., 2001; Pennington et al., 2004). The integrity of the LCA depends largely on the utilization of currently available operation, emission data, and assumptions made to fill data gaps (Huijbregts et al., 2001; Björklund, 2002; Reap, Roman, Duncan, & Bras, 2008; Yoshida, Christensen, & Scheutz, 2013).

Life-cycle assessment methodology effectively began with the oil crisis in the 1970s and was used to analyze waste transportation and lower fuel usage and transportation costs (Pires, Martinho, & Chang, 2011). Since then, LCA methodology has evolved to increase efficiency, lower costs, and minimize negative human and environmental impacts (International Council of Chemical Associations [ICCA], 2006a). Over the last 30 years, the LCA methodology and framework have become a major tool for quantifying the environmental impacts of products and systems. Detailed guidelines such as the International Reference Life-Cycle Data System (ILCD, 2012) Handbook and ISO standards (ICCA, 2006b) have been developed to guide the users of the LCA methodology. The European Platform for Life Cycle Assessment (EPLCA) and other organizations facilitate the actual modelling of more than 50 models available to help practitioners with their LCA projects, allowing them to meet the demand for more complex modelling (Hilty, Aebischer, & Rizzoli, 2014). With the emphasis on modeling and LCA methodology, general models appropriate for modelling different products and systems and models designed for specific system analysis have emerged (Hilty et al., 2014). Within the scope of this study the "cradle" is defined as the point of exit or delivery of waste from households, businesses, and schools, and the "grave" as the final disposal of waste by burial and/or incineration.

3.2 The EASETECH Model

LCA modeling programs vary in complexity, usability, cost, and availability. In this study, I used EASETECH to compare the current solid waste management practices and their environmental and human health impacts in two rural Alaskan villages. The EASETECH modelling program has been used widely for scenario generation and systems modelling. For example, the EASETECH program was used to assess the environmental impacts of the processes associated with mining old landfills for energy recovery and prevention of groundwater contamination (Jain et al., 2014). Similarly a study conducted in China used the EASETECH program and LCA methodology to assess the impacts of the internal operations construction and operations of a municipal solid waste landfills (Yang et al., 2014). Both of these cases illustrate the use of EASETECH as an LCA tool for assessing solid waste management and landfill processes.

The EASETECH model has a database that includes recovery, treatment, and disposal options, as well as external processes. EASETECH is a comparatively easy program to use and thorough enough to provide detailed analysis of solid waste management systems. Minor technical issues with EASETECH include system crashes as more sub compartments are added and external databases are needed as system complexity increases. The model contains a large catalog of processes, but when building a system specific to real world conditions, it becomes necessary to import data representative of the study site.

EASETECH allows the user to follow resource use and recovery as well as environmental emissions associated with environmental management in a life-cycle context (Clavreul, Baumeister, Christensen, & Damgaard, 2014). A Life-Cycle Impact Assessment (LCIA) uses the LCA methodology to convert the life cycle inventory impact categories in order to evaluate human health and environmental impacts (ILCD, 2012; Clavreul et al., 2014). Three main elements make up an LCIA: characterization, normalization, and weighting (Yang et al., 2014). The characterization refers to the amount and type of waste of the given waste stream and uses an internal catalog of collected impacts associated with each waste category. Normalization occurs internally as an LCIA option within the EASETECH program where values are assigned to substances used to calculate projected impacts (Table 3.2). Weighting of data for LCA studies is the assigning of values for each impact category that are representative of local and regional standards. Weighting was not included due to insufficient standards and data at local and regional levels for the state of Alaska.

The input into the EASETECH model is the waste quantity and composition data measured in Fort Yukon and Kalskag (Table 2.1, Figure 3.2). The EASETECH model then uses these data to estimate emissions and resource consumption (Table 3.1) for each specified waste management scenario based upon model default processes Denmark Technical University (DTU, 2014). The model accounts for emissions associated with the waste composition and quantity that is burned, buried, or recycled. For example for a burn scenario, the EASETECH model uses the user-assigned burned fraction to calculate the air, ash, and water emissions associated with the process of burning an assigned proportion of the waste stream. The unburned materials and ash were assumed to be included in the buried materials. Because the landfills in both Fort Yukon and Kalskag were unlined, an additional model assumption was that infiltration and exfiltration processes were occurring (DTU, 2014). The local landfill emissions were assumed to impact only local and regional resources, whereas recycling processes including transport and material recycling were assumed to impact global emissions (Table 3.1). Annual maintenance and consistent burning practices were assumed to occur at both landfills. In Fort Yukon, it was assumed that individual transport of waste materials to the landfill was not occurring.

Table 3.1 Impact Category Descriptions. The description for each impact category, the area of impact, resources effected, and the substances, chemicals, and elements used to measure each impact category. Descriptions for the impact categories were provided in the International Life Data System Handbook and substances were listed in the “documanual” for the EASETECH program.

Impact categories	**Area of impact and resources impacted**	**Substances released and used to characterize each impact category**
1. Climate or global warming refers to polar snow and ice melt, soil moisture loss, longer seasons, forest loss/change, and change in wind and ocean patterns. Addresses the effect of increasing temperature in the lower atmosphere and is characterized by the buildup of greenhouse gases such as CO_2, CH_4 N_2O and CFCs.	Global-air	➢ Carbon dioxide(CO_2) ➢ Methane (CH_4) ➢ Nitrous Oxide (N_2O) ➢ Chlorofluorocarbon (CFCs) ➢ Hydro-chlorofluorocarbon (HCFCs) ➢ Halons ➢ Carbon Monoxide (CO)
2. Stratospheric ozone depletion-The stratosphere is responsible for the absorption of UV radiation, and the reduction of ozone concentration has the potential to have a serious effects on life. On the surface of the earth the potential for depletion of stratospheric ozone is quantified by using ozone depletion potentials for substances having the same effect as CFCs.*	Global-air	➢ Chlorofluorocarbon (CFCs) ➢ Hydro-chlorofluorocarbon (HCFCs) ➢ Tetra-chloromethane ➢ 1,1,1-trichloroethane
3. Photochemical ozone formation reflects the relative effect of the total emissions of volatile organic compounds (VOCs) and oxides of nitrogen (NOX) commonly referred to as “smog,” decreased visibility, eye irritation, respiratory tract and lung irritation, and vegetation damage.	Local-air	➢ Nitrogen oxides (NOx) ➢ Volatile organic compounds (VOCs) ➢ Carbon monoxide (CO)
4. Terrestrial acidification is caused by releases of protons in the terrestrial or aquatic ecosystems, building corrosion, water body acidification, vegetation effects, and soil effects. In certain areas, acidification leads to increased mobility of heavy metals and aluminum.*	Global, regional, and local-water	➢ Sulfur dioxide (SO_2) ➢ Sulfur trioxide (SO_3) ➢ Nitrogen oxides (NOx) ➢ Hydrogen chloride (HCL) ➢ Nitric acid (HNO_3) ➢ Sulfuric acid H_2SO_4) ➢ Hydrogen fluoride (HF) ➢ Hydrogen sulfide (H_2S) ➢ Ammonia (NH_3)
5. Terrestrial eutrophication –“an enrichment of the aquatic (coastal and marine) environment, with nutrient salts leading to an increased production of plankton, and algae. In time this leads to a reduction in the water quality and in the value of the exploitation, which occurs in the area”.	Regional, local-water	➢ Nitrogen oxides (NOx) ➢ Ammonia (NH_3) ➢ Phosphorus in the form of phosphates (P) ➢ Nitrogen in the form of nitrates(N)

Table 3.1.Continued

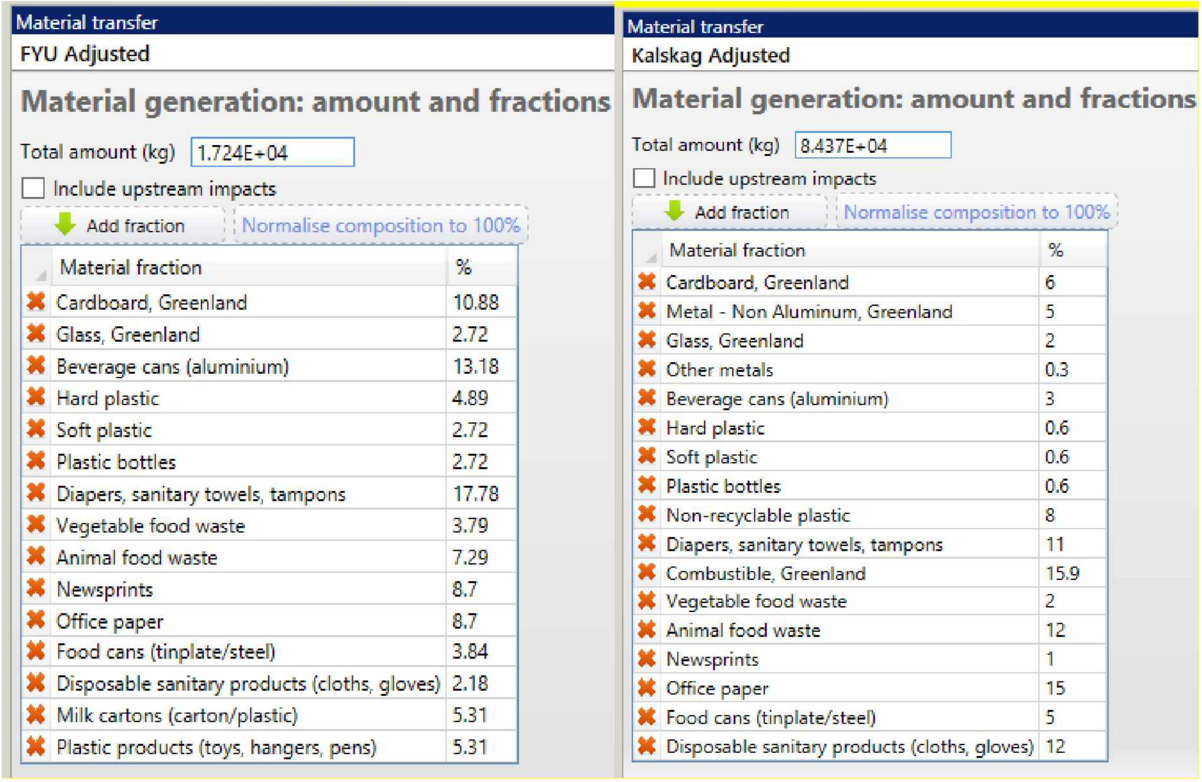
6. Freshwater eutrophication- “an enrichment of the aquatic lakes, river, reservoirs) environment with nutrient salts leading to an increased production of plankton and algae. In time this leads to a reduction in the water quality and in the value of the exploitation, which occurs in the area”.	Local-water	Kg P-eq./personal equivalent/year
7. Depletion of abiotic resources-(elements) encompasses both non-renewable and renewable abiotic resources, but here it will be only those non-renewable resources such as elements i.e., ore, copper, silver, etc. The decrease of unique natural configurations of elements in resources in the natural environment (Vervoer, van Verkeer., & voor het Vervoer., 2002).	Global, regional, and local-natural resource depletion	➢ MJ/personal equivalent/year 1 kg/kWh
8. Human toxicity cancer effect represent carcinogenic effects, toxicity to the reproductive system/teratogenic effects, and neurotoxicity. This is then combined with an effect factor characterizing the potential risks linked to the toxic intakes. Measured by morbidity and mortality.	Global, regional, and local-human	➢ Comparative toxic unit for humans with carcinogenic effects *based on a dose-response and comparative response based on exposure
9. Human toxicity non-cancer effect is the acute toxicity, irritation/corrosive effects, allergenic effects, irreversible damage/organ damage, and genotoxicity from exposure. This is then combined with an effect factor characterizing the potential risks linked to the toxic intakes. Measured by morbidity or mortality.	Local-human	➢ Comparative toxic unit for humans with non-carcinogenic effects *based on a dose-response and comparative response based on exposure.
10. Freshwater ecotoxicity effects as acute and chronic toxicity on different species in the freshwater aquatic environment. Ecotoxicological effects are changes in the state or dynamics of an organism, or at other levels of biological organization, resulting from exposure to a chemical. (Van Leeuwen, 1995) In terms of toxicological effects, these levels may include the subcellular level, the cellular level, tissues, individuals, populations, communities and ecosystems, and finally, landscapes.	Global, regional, and local-water	➢ Organotin compounds ➢ Metals ➢ Organic substances ➢ Pesticides
11. Depletion of abiotic resources-fossils is the decrease of unique natural configurations of elements in resources in the natural environment (Vervoer, van Verkeer., & voor het Vervoer., 2002). This typically relates to energy consumption of fossils, crude oil, gas, and renewable energies.	Global, regional, and local-natural resource depletion	➢ Kg Sb-eq./personal equivalent/year

Table 3.1.Continued

12. Particulate matter-also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA, 2014).	Local-air	➢ Ozone ➢ Particulate Matter (PM) ➢ Carbon Monoxide(CO) ➢ Nitrogen Oxides (NOx) ➢ Sulfur Dioxide (SO_2) Lead

These twelve impact categories (Table 3.1) are grouped into human toxicity, water, air, and resource depletion. Within solid waste management systems, the primary system is that which occurs within the confines of the landfill. The secondary system involves the downstream processes that happen outside of the landfill. These primary system functions are; the operation, maintenance, burial, burning, and recycling of organic materials including compost and are limited to the village landfill. The secondary system is made up of the upstream and downstream processes related to transport to and from the landfill and materials recycling. The secondary or compensatory system is composed of materials being recycled (e.g., of glass, paper, plastic, and aluminum), that require transport and processing outside the village landfill. Within the EASETECH model, these two systems are analyzed as a whole, but in the discussion the primary and secondary systems are discussed separately.

The EASETECH program requires each waste category with a material fraction (Figure 3.2) (percentage of waste stream) and a total waste generated annually; for this study, the Kalskag and Fort Yukon characterization data was used (Table 2.1). The components that make up the complex system of handling, transporting, and ultimately the final disposal of municipal solid waste were evaluated. This evaluation was used to assess the current waste management practices, alternative waste management systems (through scenario generation), and associated impacts of the rural Alaskan village landfill. This assessment included an inventory of all processes associated with the current rural village solid waste management system and scenario generation of alternative systems and their projected impacts.



FYU Adjusted

Material generation: amount and fractions

Total amount (kg) 1.724E+04

☐ Include upstream impacts

Material fraction	%
Cardboard, Greenland	10.88
Glass, Greenland	2.72
Beverage cans (aluminium)	13.18
Hard plastic	4.89
Soft plastic	2.72
Plastic bottles	2.72
Diapers, sanitary towels, tampons	17.78
Vegetable food waste	3.79
Animal food waste	7.29
Newsprints	8.7
Office paper	8.7
Food cans (tinplate/steel)	3.84
Disposable sanitary products (cloths, gloves)	2.18
Milk cartons (carton/plastic)	5.31
Plastic products (toys, hangers, pens)	5.31

Kalskag Adjusted

Material generation: amount and fractions

Total amount (kg) 8.437E+04

☐ Include upstream impacts

Material fraction	%
Cardboard, Greenland	6
Metal - Non Aluminum, Greenland	5
Glass, Greenland	2
Other metals	0.3
Beverage cans (aluminium)	3
Hard plastic	0.6
Soft plastic	0.6
Plastic bottles	0.6
Non-recyclable plastic	8
Diapers, sanitary towels, tampons	11
Combustible, Greenland	15.9
Vegetable food waste	2
Animal food waste	12
Newsprints	1
Office paper	15
Food cans (tinplate/steel)	5
Disposable sanitary products (cloths, gloves)	12

Figure 3.2. Material Generation EASETECH Model. The screen shot of the EASETECH material generation compartments showing annual waste generation in kg and the percentage for each type of waste. These percentages have been adjusted from the original material percentages (Table 2.1) and broken down further for more comprehensive analysis within the EASETECH program. The compartment is labeled and adjusted to indicate that the material fractions have been further broken down into sub categories i.e., paper to newspaper and office paper and plastic into hard, soft, and bottles. FYU=Fort Yukon.

With modelling systems and analysis, the results are only as good as the data used. For this study, waste characterization data, emissions data for burn methods, and data averages for auto and transport were used to increase the accuracy of these compartments. Models are tools to guide decisions and are only part of an iterative process that involves monitoring, evaluation, and adjustment based on actual outcomes. Results based on generic data, data averages, and incomplete data must be reviewed accordingly and updated as real data are made available. Using the best available data, it was my intent to evaluate and compare the current system to eight alternative scenarios for estimated environmental impacts and the cost/benefits of these alternatives.

3.3 Impact Categories

I performed a normalized LCA for this study. Normalization is used to express impact indicator data in a way that can be compared among impact categories (Table 3.2). This procedure normalizes the indicator results by dividing by a selected reference value (Clavreul et al., 2014). The normalization factors used in my impact assessment come from the normalized impacts ILCD handbook (ILCD, 2012), these are contained within the EASETECH model and used to parameterize production/consumption using EU regional data (Blok et al., 2013), and may not be representative of conditions found within Alaska. Characterization factors (Table 3.2) are represented by a substance (or substances) used as a measure for each impact category (ILCD, 2012) and occur as an internal process within the EASTECH program. For example, the measure for the climate change category is measured by the greenhouse gases released into the atmosphere and calculated within the program from reports and studies done for all processes and products included within the model (Stranddorf, Hoffmann, & Schmidt, 2005). The EASETECH model contains 6 options for the life-cycle impact assessment. The ILCD-recommended impact assessment option was used for this study because it was the most up to date option. The 12 impact categories with local, regional, and global areas of impact were included within the LCIA (Table 3.2).

Table 3.2. Impact Categories, Normalization, and Methods of Measurement. Impact categories, normalization factor, areas of protection, and the characterization factor for the substances are detailed. The chemicals, and elements used to measure each impact category are listed. Normalized factors come from the output of characterization models made available to practitioners in literature and databases, as well as available LCA support tools (ILCD handbook, 2012). The normalization factors used within this study were the reference factors included within the EASETECH ILCD LCA (Blok et al., 2013), which came from the International Life Cycle Data system. *Multiple substances and various values.

Impact category	**Normalization Factor**	**Areas of protection**	**Substance measured & characterization factor**
Climate change	8096	Air	1 kg CO_2 & 1 kg Chloroform,
Stratospheric ozone depletion	.00414	Air	1 kg Chlorofluorocarbon (CFCs) .07 Hydro-chlorofluorocarbon (HCFCs) 1.14 kg Tetra-chloromethane 1 kg -trichloroethane 4.9 kg Bromochlorodifluoro-Halon 11.5 Bromotrifluoro-Halon
Photochemical ozone formation	56.7	Air	1 kg Nitrogen oxides (NOx) 1 kg Volatile organic compounds (VOCs) .04561 kg Carbon monoxide (CO) * kg Hydrocarbons and GHG
Terrestrial acidification	49.6	Water	3.02 kg Ammonia .74 kg NO_x 1.31 kg Sulfur dioxide 1.05 kg Sulfur trioxide
Terrestrial eutrophication	115	Water	3.16 kg Nitrates 4.26 kg NO_x 13.5 kg Ammonia
Freshwater eutrophication	.62	Water	1.35 kg Nitrogen oxides (NOx) 3.64 kg Ammonia ($NH_{3)}$ 32.03 Phosphorus in the form of phosphates (P) .59 kg Nitrogen in the form of nitrates(N) 2.38 kg Cyanide 2.82 kg Dinitrogen monoxide
Depletion of abiotic resources-mineral	.0343	Natural resource depletion	List of mineral resources in kg (e.g. Iron, Ore, Aluminum, etc.)reflected in the amount consumed for total processes within the waste system
Depletion of abiotic resources-fossil	62,400	Natural resource depletion	List of energy related resources in kg (e.g. coal, crude oil, diesel fuel) reflected in the amount consumed for total processes within the waste system
Human toxicity-cancer	.0000542	Human health, via air, soil, & water	List of chemicals, compounds, elements and substances in kg with deleterious and carcinogenic responses to humans via soil, water, and air from process emissions within the waste management system
Human toxicity-non cancer	.00110	Human health, via air, soil, & water	List of chemicals, compounds, elements and substances in kg with deleterious and non-carcinogenic responses to humans via soil, water, and air from process emissions within the waste management system
Freshwater ecotoxicity	665	Water	List of chemicals, compounds, elements and substances in kg with deleterious responses to freshwater ecosystems from process emissions within the waste management system
Particulate matter	2.76	Air	.6 kg Particulates, >2.5um, and <10um

Several impact categories list more than twenty substances (Table 3.2). The characterization factors (Table 3.2) are associated with a common reference, such as the impacts expressed as a personal equivalent (PE) annually in the proposed geographic location. This facilitates comparisons across impact categories and/or areas of protection (ILCD, 2012). The normalized factors reflect a global context because local and regional information was not available.

Uncertainty in terms of life-cycle assessment methodology refers to factors used to model systems using best available, generic, or incomplete data, thus making it necessary model systems with a variety of assumptions. Several factors, such as incomplete data and unknown variables, contribute to uncertainty and required the use of assumed values in order to fill in the data gaps present within this study. The 12 impact categories presented here represent estimated impacts on environmental resources and human health and are a proxy of proposed impacts. Further data collection is necessary to fill data gaps before the LCA methodology can be used to alter management decisions.

Each of the 12 impact categories as defined within the EASETECH program are characterized by the production or consumption of certain substances (Table 3.2). These 12 categories of the impact assessment comparing these two rural Alaskan village waste stream and waste management systems were evaluated for their current practices and the proposed alternatives. The 12 impact categories were evaluated using nine progressive scenarios comparing the two different village waste management practices in order to determine the current impacts and proposed alternatives and their impacts (Table 3.3). The following section introduces waste management options and technologies used in scenario progression which a representative of an increased integrated waste management scheme. Two such options include waste to energy (WTE) incineration that provides energy from heat emissions from the combustible portion of the waste stream and composted organic waste, intended for application on local garden or agricultural lands.

Table 3.3.Scenario Descriptions Cost/Benefit Summary. Table provides description of each scenario. Recycling rates were based on proposed material significance and possible impact effects of landfilling, burning, and recycling. Table continues to the following page.
*Glass (60%), paper (50%), plastic (80%), and aluminum (90%) recycled. Scenario Cost Analysis is based estimated costs
of facility operations, wages for workers, and costs associated with all landfill related practices.
**Minimum burned or buried, waste to energy systems and composting of organic waste.
*** Burying does not include the residuals buried from open burn.

Scenario	Scenario description	System cost/benefit
1. Current System	Scenario one is most representative of what is happening within the villages of Kalskag and Fort Yukon. The system is a 20/80 burn to bury scenario. This system was modelled burying 80% of waste, along with an estimated 60% residues (of the burned 20%) left from the open burn.	Minimum cost for equipment maintenance, transport and site maintenance. Fort Yukon with two employees at eight hours/week $12/hour. Push pile, once a month and bury annually. Kalskag site maintenance twice a year
2. 50% open burn 50% bury	Scenario two degradation rate of about 15% and all the remaining residues being buried. This scenario is very similar to scenario 1, due to a very low degradation rate and all remaining waste landfilled.	Same as scenario one, employee hours, fuel costs, site maintenance and a slight increase in land use of waste landfilled. Abiotic resource use and water impacts were half that of scenario one and the air impacts increased with higher burn rate.
3. 50% burn box 50% bury	Scenario three degradation rate of 60%. This burn box burns at a higher heat in order to minimize toxic fumes and smoke into the local air stream.	Cost for burn box (divided by estimated 10 years of use), cleaning, maintenance, and operations of burn box added to scenario three. Increased degradation rate and landfill space savings of nearly 25%.Abiotic resource use, air, and water impacts increased, but insignificant with increased burn load, but better efficiency and lower emissions.
4. Recycle* 50% open burn 50% buried	Scenario four is the recycling of 60% glass, 50% paper, 80% plastic, and 90% aluminum. The remaining waste was a 50% burn (5/20/15/60-fly/water/degrade/residuals) and 50% bury with an open burn. *fly ash, water as leachate, degradation rate, and residual waste	Wages, maintenance, and operations slightly higher than scenario one, but lower than scenario three without burn box costs. 50% landfill space savings from recycling and increased burn to bury ratio. Abiotic resource, air, and water impacts significantly higher due to long transport distances and smelting process for aluminum.
5. Recycle* and all remaining buried	Scenario five is the recycling of 60% glass, 50% paper, 80% plastic, and 90% aluminum. The remaining was all landfilled.	Wages, maintenance, and operations slightly higher than scenario one, but lower than scenario three without burn box costs. Landfill space increased from scenario four due to all non-recycled waste buried.

Table 3.3.Continued

6. Recycle* with 50% burned (burn box) and 50% buried	Scenario six is the recycling of 60% glass, 50% paper, 80% plastic, and 90% aluminum. The remaining split 50% burn box (5/10/60/25-fly/water/degrade/residuals) and 50% bury.	Half burn half bury with higher degradation rate and recycling result in a 40% land use savings. Abiotic resource use and air impacts same as scenario four and five. Water impacts slightly lower due to more efficient degradation of waste lowered leachates.
7. Recycle*, 50% burned, 50% buried, and 80 organic waste composted	Scenario seven is 60% glass, 50% paper, 80% plastic, and 90% aluminum recycling. A 50% burn box (5/10/60/25-fly/water/degrade/residuals) 50% bury and composting of 80% organic waste.	Wages, operation, and maintenance increase due to addition of composting to the system. Land saving also increased with the subtraction of 80% organic waste. All other categories incur insignificant changes.
8. Recycle*, 80% WTE and 20% bury	Scenario eight is recycling of 60% glass and 90% aluminum. 80% organic waste to compost. 80% remaining waste to a waste energy facility and 20% to the local landfill.	With the addition of the waste to energy facility wages, maintenance, and operations are over one 1.5 million dollars a year (cost of facility divided by 25 years). Land saving are more than 80%. The energy production from the WTE facility could offset the large monetary increase of the system.
9. Recycling excluding aluminum, 80% organic waste to compost, 80% to WTE and 20% buried.	Scenario nine is recycling 60% glass, 50% paper, and 80% plastic. 80% organic waste composted. No recycling of aluminum or any metals. All remaining materials are incinerated in a waste to energy facility and all residuals and non-combustibles buried in the landfill.	With the addition of the waste to energy facility wages, maintenance, and operations, costs are over one 1.5 million dollars a year (cost of facility divided by 25 years). Abiotic resource use, air, and water impacts are significantly lower than scenarios four through eight with the subtraction of recycling aluminum. And land saving are close to 90% with only 20% of waste buried.

3.4 Materials and Methods

The 12 impact categories characterize projected human health, abiotic resource depletion, and soil, water, and air effects from the modelled solid waste management system scenarios. The impact categories were separated into four groups; 1) human toxicity cancer and non-cancer, 2) water impacts (four), 3) air impacts (four), and 4) depletion of abiotic resources (two). These human and environmental health indicators were assessed using the ILCD LCIA function within the EASETECH program. The nine scenarios for each village projected deleterious environmental and human health effects with contributing substances and processes detailed within the EASETECH program. The cost in dollars were estimated for systems and processes for each scenario, with the current system as the baseline (Table 3.4). Estimated costs of improvements were based on an estimated average cost per process, these were generic estimates and may not reflect increased costs reflected for remote Alaska villages. WTE costs were based on the technology available in the EASTECH program and the total cost was estimated for a 25 year span.

Table 3.4. System Scenario Cost Breakdown. Scenario cost breakdown in dollars (estimated cost for wages, landfill maintenance, and operations) and land use (calculated as km^2). Facility equipment and WTE costs were calculated averaging the facility cost divided by estimated years of use (25 years). The distances and fuel consumptions to the recycling location were estimated. *Scenario four through seven recycling rates were; glass (60%), paper (50%), and plastic (80%). **Rates for glass and plastic same as Scenarios four through seven, but all other combustibles were used for incineration in the WTE template.

Scenario description	Fort Yukon cost in dollars	Fort Yukon estimated land use	Kalskag cost in dollars	Kalskag estimated land use
1. Current system	$9,984.00	.16 km^2	$720.00	.70 km^2
2. 50% open burn 50% bury	9,984.00	.16 km^2	$720.00	.70 km^2
3. 50% burn box 50% bury	$14,343	.13km^2	$4,152.00	.53 km^2
4. Recycle* 50% open burn 50% buried	$10,982	.08 km^2	$792.00	.42 km^2
5. Recycle* and all remaining buried	$10,982.00	.12 km^2	$792.00	.54 km^2
6. Recycle* with 50% burned (burn box) and 50% buried	$13,727.00	.07 km^2	$990.00	.34 km^2
7. Recycle**, 50% burned, 50% buried, and 80 organic waste composted	$22,219.00	.069 km^2	$4,386.00	.30 km^2
8. Recycle*, 80% to WTE and 20% bury	$1,772,219.00	.024 km^2	$1,755,106.00	.11 km^2
9. Mixed recycling without Aluminum, 80% organic waste to compost, 80% to WTE and 20% buried.	$1,772,218.00	.011 km^2	$1,755,106.00	.048 km^2

I detail each scenario in the following section, each figure and chart that follows employs each of these scenarios. Scenario one (S1) represents the current system within the rural villages of FYU and Kalskag. Scenario two (S2) represents a 50/50 split of burn bury (using open burn) system. Scenario three (S3) represents a 50/50 burn bury (using a burn box). Recycling was included in scenarios four through nine. Scenario four (S4) includes a 50/50 burn bury (open burn) with the recycling of 60% glass, 50% paper, 80% plastic and 90% aluminum. Scenario five (S5) is an all bury of all non-recycled materials (same recycled materials as scenario four). Scenario six (S6) is a 50/50 burn bury split (using burn box) and the recycling of 60% glass, 50% paper, 80% plastic, and 90% aluminum. Scenario seven (S7) is a 50/50 burn bury (burn box) same recycling as previous scenario and the addition of composting 80% organic matter. Scenario eight (S8) represents is and 20/80 bury burn, using a WTE incinerator, 90% aluminum and 60% glass recycled, and 80% organic matter composted. The scenario nine (S9) includes WTE (incineration of all combustibles for energy production), composting of organic matter (80%), recycling of glass (60%), paper (50%), plastic (80%), and all remaining (non-combustible) materials were buried. I modelled S9 as a preferred ISWM system and I assumed S9 as an optimized system, but not all human and environmental impacts were mitigated. S9 employs a mixed method recycling system that excludes the recycling of aluminum due to the higher emissions resulting from the re-melting process. Recycling rates of 60, 50, 80, and 90 for glass, paper, plastic, and aluminum respectively were used in this study, these rates reflect a higher rate per material as compared to the national average (EPA, 2013) and was intended to justify the long transport distances.

System scenario costs were based on estimated costs of the current system established by averaging average fuel costs for these two villages, travel distance for waste stream delivery to the landfill, and wages for waste management staff. Each consecutive scenario was based on changes to the current system including cost of increased travel distances for recycling of materials, increased wages for waste management staff, and improvements to waste management technology (i.e. WTE incinerators and composting operations; Table 3.5).

The two impacts used to represent human health were human toxicity-cancer and human toxicity non-cancer. They represent the exposure to harmful substances, chemicals, or elements with cancer and non-cancer toxic effects. Non-cancer potential or effects would include allergic reaction, respiratory (asthma), or other deleterious response, but without carcinogenic effects. The four water impacts to freshwater and terrestrial bodies were measured by ecotoxicity or eutrophication effects. There are four air impact categories used to measure emissions with potential negative environmental and human effects. The air impact categories accounted for both global and local effects. The category used to measure resource depletion were abiotic resource depletion of mineral (extraction) or fossil fuel (non-renewable energies) used within various processes of the waste management system. Land use was evaluated by estimating current land (expressed in km^2) use by the waste stream and amount of land saved by materials recycling and incineration for S4-S9. This was estimated from the average amount of space needed per waste stream category that is removed from the landfill that is alternatively recycled or incinerated. The waste generation for Fort Yukon and Kalskag was estimated from the characterization data presented in the methods section. The data for the 12 impact categories were grouped based on abiotic resource depletion (Figure 3.4) air (Figure 3.5), water (Figure

3.6), and human cancer and non-cancer potentials (Figure 3.7). The Fort Yukon and Kalskag waste streams differed in compositions and thus effects on the three grouped categories had different results.

Within the EASETECH program are templates contained within the catalog that represent practices, processes, and emissions of the rural village solid waste management system (Figure 3.3). The solid waste management systems are created within the EASETECH model using templates represented by different compartments. Each template represents material generation (waste stream), transport, processes (within the landfill), emissions, and the processes ending at the final destination of individual materials being recycled (e.g., glass, paper, aluminum, and plastic) (Table 3.5). These templates are used to construct each scenario moving from the current system ending in mixed method recycling system.

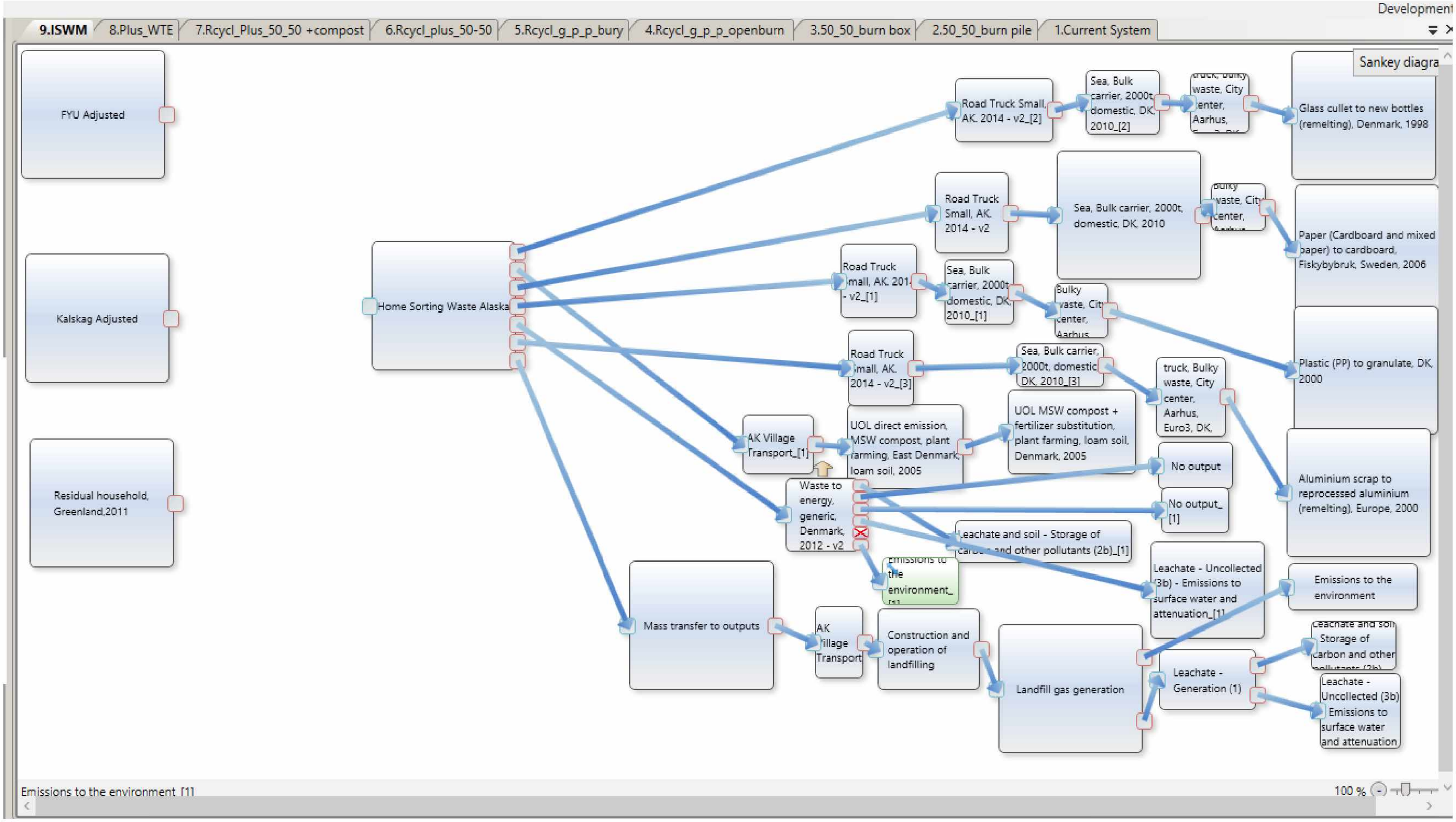


Figure 3.3.EASETECH Templates and Processes. Image represents templates of system process within the model. Each box represents a system process (i.e., transport, mass transfer, incineration, and burial) within the model catalog and internal process that can be customized and represent the solid waste management system(s) for Kalskag and Fort Yukon. Arrows indicate the flow of waste to labeled method of treatment. Nine scenarios were generated for the waste stream and practices of Kalskag and Fort Yukon, each with different processes, handling, and methods. Source EASETECH “documanual” (DTU, 2014).

The Ecoinvent Database is a 3rd party database that provides documented processes and associated emissions data specific for customizing processes for waste management systems like EASETECH. I extracted the transport emissions data that I used to model waste transport processes in the two villages from this database. The transportation compartments for representing movement of waste to the landfill were modelled differently for the two villages. This was in order to represent the actual conditions of Fort Yukon, which has curbside pickup of waste, and Kalskag, which, like most Alaska villages, individuals transport all waste per household using various transport mechanisms. This may result in waste falling off various methods of transportation and/or being dumped in places other than the local landfill. I modified the model transport compartment within the EASETECH program using combined emissions data to simulate the average of emissions and fuel consumption for small trucks, snow machines, and four-wheelers, combined, to represent the transport for waste delivery processes for Kalskag. This modified transport compartment was used throughout all nine scenarios for Kalskag. I modelled the Fort Yukon waste transport systems emissions data using a small ten-ton truck transport compartment; the Ecoinvent Database provided the data to modify the EASETECH catalog. The Ecoinvent Database was also used to modify all associated recycling processes within the EASETECH catalog, which included transport systems, aluminum recycling, and waste to energy (WTE) processes.

I used the Kalskag and Fort Yukon characterization data, LCA methodology, and EASETECH model to assess current solid waste management practices and their projected impacts. Multiple sources were used to modify the process catalogs within the model in order to create SWM systems characteristic of the actual conditions for these two village landfills.

Modified data adjusted within the EASETECH catalog included burn emissions for open burn practices and burn emissions using burn boxes. Open burning tends to burn slower, with minimal degradation and produces heavy fumes over many hours as the fire smolders out. Alternatively, custom-made burn boxes are designed to burn at higher temperatures with greater degradation rates and shorter warm-up and cool-down periods, thus preventing long periods of heavy smoke and fume production. Several sources were used to provide emissions data for open burn waste and Polychlorinated dibenzodioxins/furans (*PCDD/F)* emissions from uncontrolled, domestic waste burning, and emissions of organic air toxics from open burning (Lutes & Kariher, 1996; Lemieux, 1997; Gullett, et al., 1999; Lemieux, Lutes, & Santoianni, 2002).

Table 3.5.EASETECH Templates. Templates within the EASETECH program with a description and data source. *All templates have exchanges of elements/energy and external processes that contribute to material processes within the whole of the system and are included in the life-cycle impact (Clavreul et al., 2014).

Template	Catalog processes	Data source
Material generation	Includes compositions of household waste expressed as amount in kg generated annually and percentage of each waste type totaling 100% of waste stream	This information came from the Kalskag report and FYU collection.
Collection/transportation	Includes processes of collection of waste and includes both collection vehicles, road trucks with different sizes given in ton, transportation at sea and rail transportation.	Used a combination of data to represent village transport, barge transport to city centers. Modified compartments to represent actual data.
Biological treatment	Includes three kind of biological treatment methods: 1) composting, 2) anaerobic digestion, and 3) combined aerobic-anaerobic treatment.	Used model data for composting processes.
Landfills	Includes both complete processes of landfills Sub processes are divided into the subcategories "Construction and Operation," "Gas processes," and "Leachate processes."	Used a combination of model data and data collected for representing actual conditions.
Material Recycling	Includes recycling processes of four major material categories: Paper, Plastics, Glass, and Metal.	Used model processes.
Thermal treatment	Includes one overall waste incineration process, as well as two sub processes, which can be used to build a waste incineration plant.	Used model processes.
Material utilization	Includes use of compost in gardens and in soil manufacturing, from both green and garden waste. The processes have different substitution profiles, if any.	Used model processes.

The purpose of the scenario analysis was to evaluate different levels in a progression starting from the current system and ending in an ISWM mixed method recycling system with decreased environmental and human health impacts. Nine scenarios were used to describe the current system and eight alternatives (Table 3.3) with projected impacts for each. Scenario one is representative of the current systems of solid waste management for the villages of Kalskag and Fort Yukon. Scenarios one through three did not include materials recycling, scenarios four through nine included recycling. However, scenario nine did not include the recycling of aluminum. All recycling scenarios included estimated distances to the major city centers of Fairbanks and Anchorage and then larger city centers with recycling centers, I assumed Seattle as the closest. Scenario two through eight followed a progression from the current system to an integrated solid waste management approach that favors reduction, recycling, and reuse of materials over landfill and incineration. Scenario nine is a mixed method recycling system without aluminum recycling.

Within the EASETECH program as part of the LCIA are a list of substances and processes responsible for emissions or depletion for each of the 12 impact categories. S1-S3 had processes limited to transportation processes, internal landfill maintenance/operations, burn, and bury practices. S4-S9 had the same processes as S1-S3, but additional processes such as transportation for recycled materials, recycling, WTE operations, and composting. Each of these processes contributed to emissions of substances to air, water, and soil. Additionally, substances consumed attributed to natural resource depletion and human health degradation upon exposure to measured substances. The major contributing processed have been summarized within the results section for each of the nine scenarios. The total of these emissions were represented as a final sum as one number for each impact category and represented in Figure 3.4-3.7 of the results section.

I grouped the impact categories based on similarities of each system and major changes that affect the SWM system emissions and associated impacts. Scenarios one through three represented the current system. In scenario two burning methods, amounts, and buried waste have been changed to 50% burn and 50% bury. Scenario three is 50% burn and 50% bury using a burn box. Scenarios four through eight are grouped together due to the addition of recycling to the system along with variations in burning amounts, methods, and buried waste. Scenario nine, as noted, is represented as a mixed methods recycling system without aluminum recycling and has been compared separately. Along with each scenario grouping, the impact categories are arranged as follows; 1. Abiotic resource depletion-categories 7 and 11 (Figure 3.4). 2. Air impacts-categories 1-3 and 12 (Figure 3.5). 3. Water impacts-categories 4-6 and 10 (Figure 3.6). 4. Human Toxicity-categories 8 and 9 (Figure 3.7).

3.5 Results

The nine solid waste management scenarios examined in this study resulted in similar patterns across all impact categories. Waste management S4-S8, tended to result in impacts that were several orders of magnitude higher than those in S1, S2, S3, and S9. Moreover, the same waste management scenarios had larger impacts on abiotic resources depletion, air, water, and human health in Kalskag compared to Fort Yukon.

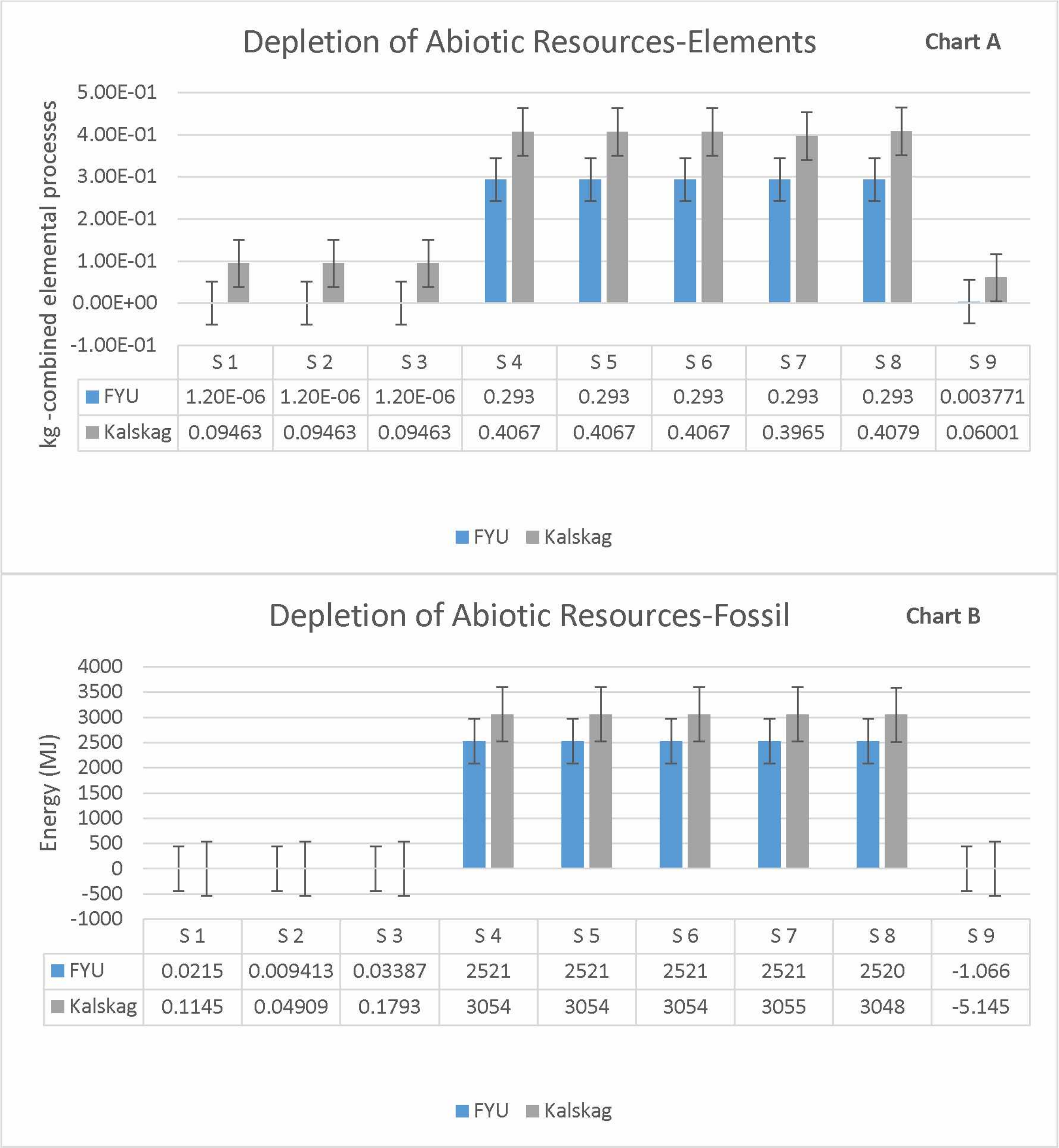
A greater quantity of abiotic resources were depleted as a result of SWM S4-S8, in comparison to S1, S2, S3, and S9 (Figure 3.4). The processes exchange tab within the EASETECH program indicated the transport and recycling processes contributed to the higher depletion of both abiotic impact categories in S4-S8. Abiotic resource depletion was higher in Kalskag than in Fort Yukon regardless of the scenario (Figure 3.4).

The nine SWM scenarios produced similar patterns of emissions across the four air impact categories (Figure 3.5). Air emissions in scenarios S1, S2, S3, and S9 were negligible in comparison to the magnitude of emissions that were produced in scenarios S4-S8 (Figure 3.5). As a function of the LCIA within the EASETECH program the processes exchange tab indicated these higher emissions can be attributed to transport and processes associated with recycling. Emissions of all gases and particulate matter were higher in Kalskag than in Fort Yukon regardless of the scenario (Figure 3.5).

The nine SWM scenarios resulted in similar patterns in water quality across the four impact categories (Figure 3.6). SWM scenarios S4-S8 were more deleterious to water quality than SWM scenarios S1, S2, S3, and S9 (Figure 3.6). The processes exchange tab within the EASETECH details which processes contributed to the higher negative impacts in S4-S8, indicating the transport and processes related to recycling (aluminum specifically) were the main contributors. The same SWM scenarios produced more influx of deleterious substances to water in Kalskag than in Fort Yukon (Figure 3.6).

The nine SWM scenarios resulted in similar patterns of impacts on human health indices in both impact categories (Figure 3.7). SWM S4-S8 resulted in greater production of carcinogenic and non-carcinogenic substances than S1, S2, S3, and S9 (Figure3.7). This was indicated by processes exchange tab within the EASETECH program and was attributed to the transport and processes associated with recycling. Regardless of the SWM scenario, more carcinogenic and non-carcinogenic toxins were produced in Kalskag compared to Fort Yukon (Figure3.7), this is likely a result of Kalskag having a larger waste stream.

For scenarios S1-S3 the transport of waste stream, burning practices, landfill operations, and leachates from buried materials were the four highest contributing process with deleterious effects on human health and natural resources. For S4-S6 the aluminum re-melting, transport processes (both for waste to landfill and materials to recycling centers), landfill operations, and incineration practices were the major contributing processes affecting human health and natural resources. S7-S8 included all the same processes associated with S5-S6, but also included composting and WTE processes. S9 had all process associated with S4-S8, but without process associated with aluminum recycling.



	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
■ FYU	1.20E-06	1.20E-06	1.20E-06	0.293	0.293	0.293	0.293	0.293	0.003771
■ Kalskag	0.09463	0.09463	0.09463	0.4067	0.4067	0.4067	0.3965	0.4079	0.06001

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
■ FYU	0.0215	0.009413	0.03387	2521	2521	2521	2521	2520	-1.066
■ Kalskag	0.1145	0.04909	0.1793	3054	3054	3054	3055	3048	-5.145

Figure 3.4.Abiotic Resource Depletion. Elements and fossil fuels consumption over nine scenarios. Lower numbers indicate lower adverse impacts. Chart A: depletion of abiotic resources-elements measured by elemental consumption of the system per year, Chart B: depletion of abiotic resources fossil fuels measured by the total fuels consumed by the system per year in terms of energy. The intervals represent the confidence interval of standard errors. S1 through S9 represent scenario 1 to nine. The intervals represent the confidence interval of standard errors. FYU=Fort Yukon

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
■ FYU	-0.3349	0.1589	0.4919	2799	2799	2799	2799	2794	4.162
■ Kalskag	45.54	47.8	49.12	3201	3201	3201	3192	3185	51.4

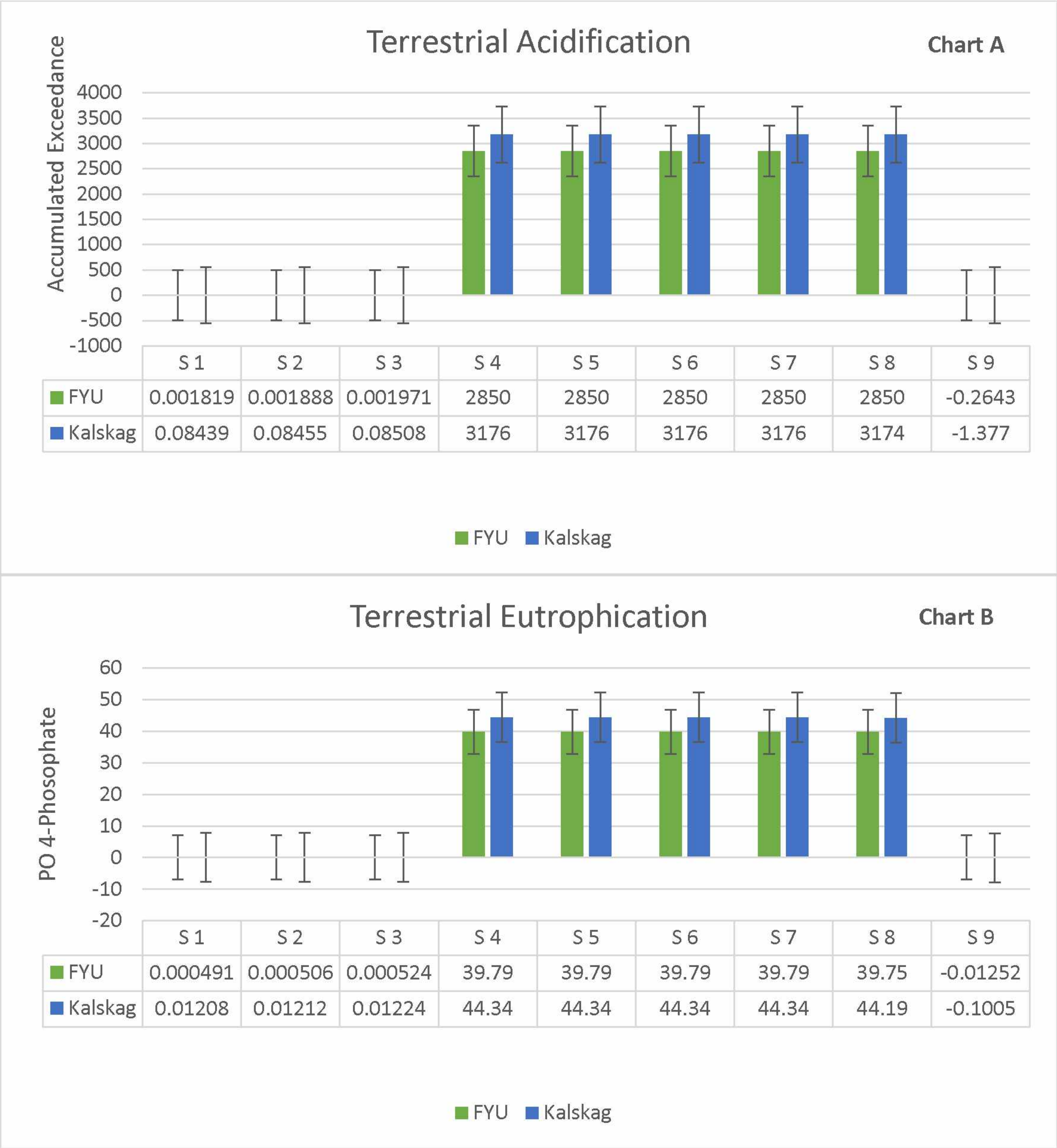
	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
■ FYU	8.13E-07	8.57E-07	9.09E-07	102.9	102.9	102.9	102.9	102.9	-0.0028
■ Kalskag	0.001739	0.001739	0.001739	114.7	114.7	114.7	114.7	114.7	-0.0022

Figure 3.5. Air Impact Categories. Scenario 1-9. Chart A: climate change/global warming measured by kg of CO_2 released per kg of waste. Chart B: stratospheric ozone depletion as kg of CFC's released per kg of waste. Chart C: particulate matter measured as kg PM 2.5 released per kg of waste. Chart D: photochemical ozone formation measured by 1 kg of NO_x and VOC per kg of waste and .0456 kg CO per kg of waste. The intervals represent the confidence interval of standard errors. FYU=Fort Yukon

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟦 FYU	0.000357	0.000387	0.000422	1274	1274	1274	1274	1274	-0.1266
🟧 Kalskag	0.1443	0.1444	0.1446	1419	1419	1419	1419	1418	-0.5201

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟦 FYU	0.04758	0.1146	0.003176	478.9	478.8	478.8	478.9	478.7	-0.07705
🟧 Kalskag	2.896	3.224	2.679	536.2	535.7	535.7	535.5	534.9	0.5377

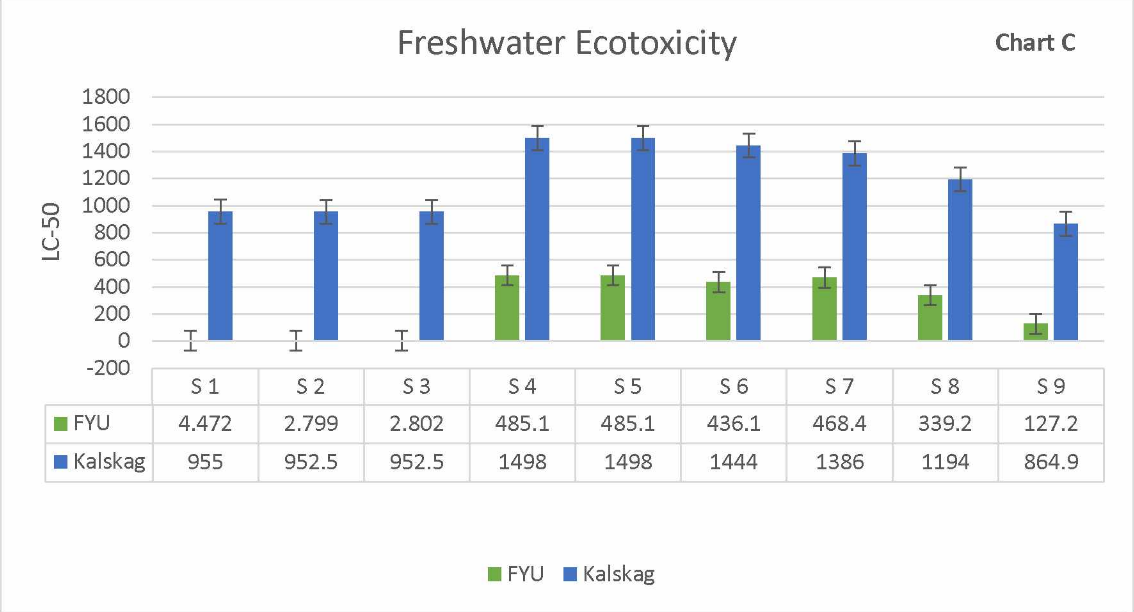
Figure 3.5.Continued



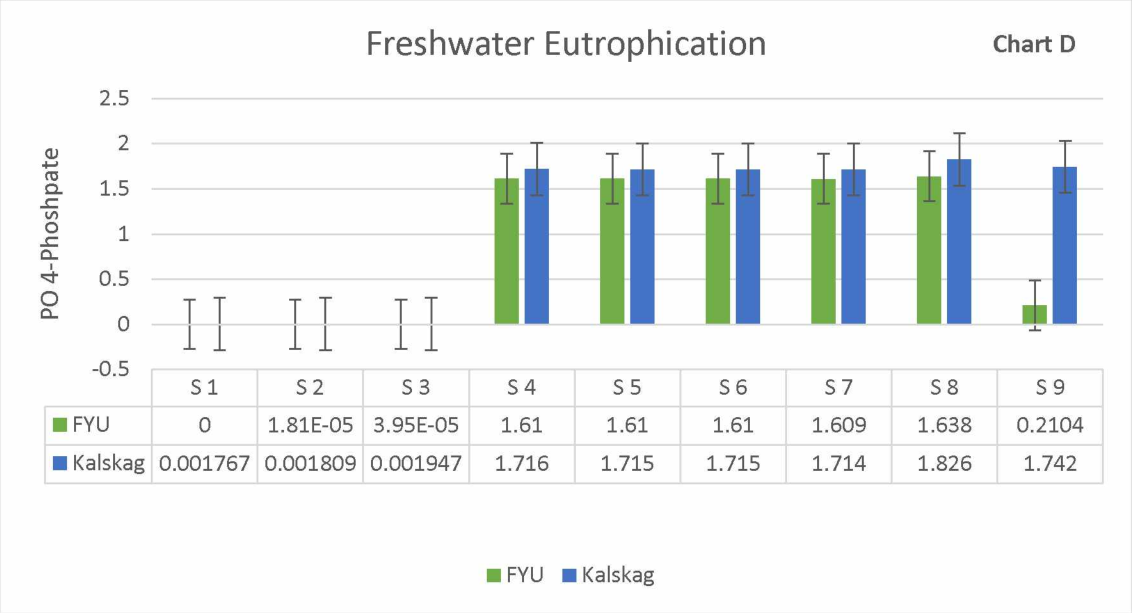
	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟩 FYU	0.001819	0.001888	0.001971	2850	2850	2850	2850	2850	-0.2643
🟦 Kalskag	0.08439	0.08455	0.08508	3176	3176	3176	3176	3174	-1.377

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟩 FYU	0.000491	0.000506	0.000524	39.79	39.79	39.79	39.79	39.75	-0.01252
🟦 Kalskag	0.01208	0.01212	0.01224	44.34	44.34	44.34	44.34	44.19	-0.1005

Figure 3.6. Water Impact Categories. Scenarios 1-9. For the substances used to measure Chart A through Chart D refer to table 3.2. The intervals represent the confidence interval of standard errors. FYU=Fort Yukon

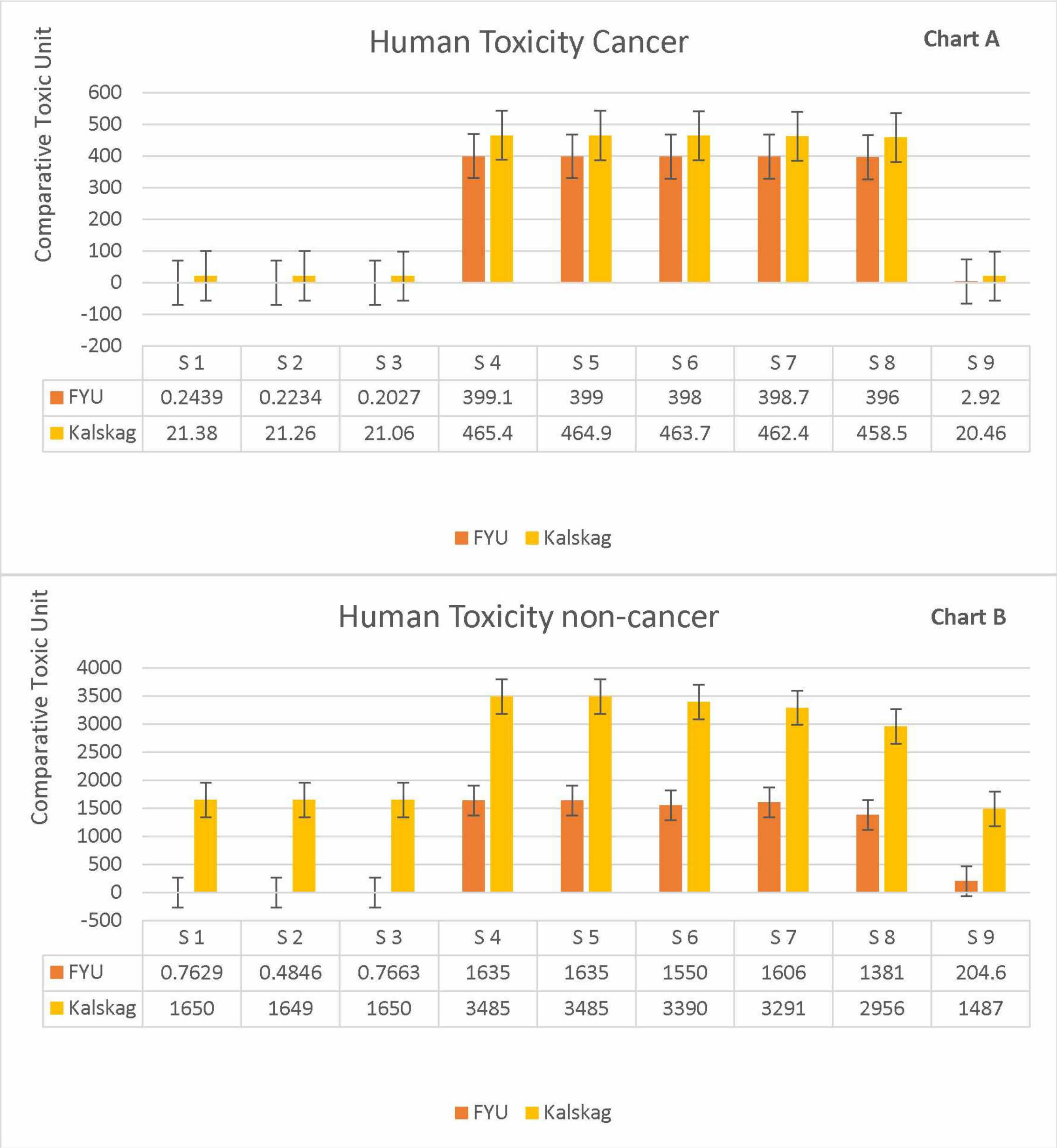


	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟩 FYU	4.472	2.799	2.802	485.1	485.1	436.1	468.4	339.2	127.2
🟦 Kalskag	955	952.5	952.5	1498	1498	1444	1386	1194	864.9



	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟩 FYU	0	1.81E-05	3.95E-05	1.61	1.61	1.61	1.609	1.638	0.2104
🟦 Kalskag	0.001767	0.001809	0.001947	1.716	1.715	1.715	1.714	1.826	1.742

Figure 3.6.Continued



	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟧 FYU	0.2439	0.2234	0.2027	399.1	399	398	398.7	396	2.92
🟨 Kalskag	21.38	21.26	21.06	465.4	464.9	463.7	462.4	458.5	20.46

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
🟧 FYU	0.7629	0.4846	0.7663	1635	1635	1550	1606	1381	204.6
🟨 Kalskag	1650	1649	1650	3485	3485	3390	3291	2956	1487

Figure 3.7. Human Toxicity Impact Categories. Scenarios 1-9. Chart A: human toxicity-cancer effects are measured by cubic meter of soil, water, or air containing carcinogenic compounds per person per year. Chart B: human toxicity-non-cancer effects are measured by cubic meter of soil, water, or air containing carcinogenic compounds per person per year. The intervals represent the confidence interval of standard errors. FYU=Fort Yukon

Chapter 4-Discussion

Both Fort Yukon and Kalskag SWM scenarios that did not include recycling (S1-S3) resulted in impacts that were similar in direction and magnitude to those produced by the preferred scenario (S9; mixed-method recycling). On the other hand, SWM scenarios that incorporated recycling (S4 –S8), showed similar responses in all modelled impact categories. Surprisingly, the SWM scenarios that included recycling had much larger negative impacts on air, water, abiotic resource depletion, and human health, compared to SWM scenarios that did not include recycling, as well as the S9. This result may be attributed to processes that occur outside of the landfill, particularly transport and recycling of waste stream components. The same SWM scenarios had strikingly larger impacts on air, water, abiotic resource depletion, and human health in Kalskag than in Fort Yukon. The most likely explanation for this finding is that the quantity of waste entering the waste stream in Kalskag was approximately four times larger than that in Fort Yukon. The results of my study imply that the benefits of recycling are outweighed by the negative impacts of the associated processes on air, water, abiotic resource depletion, and human health in both Fort Yukon and Kalskag. This result is likely to be due to the remote location of these communities, and the absence of local recycling facilities.

The depletion of abiotic resources (Figure 3.4, Charts A and B) across nine scenarios for each of the two villages followed a similar pattern, but differed slightly between elemental and fossil resources. The depletion of abiotic resources (both elemental and fossil) was noticeably higher for S4-S8, in comparison to S1, S2, S3, and S9 (Figure 3.4). Scenarios S4-S8 included aluminum recycling, whereas, S1, S2, S3, and S9 did not, suggesting that this result could be explained in large part by the negative impacts of the processes associated with recycling of aluminum waste. The smelting of bauxite and mining processes associated with the virgin production of aluminum have not been taken into account within the framework of this modelling study. In addition to processes such as transportation of recyclable materials from rural Alaska villages to recycling centers, aluminum recycling also entails processes such as re-melting that are likely to result in large emissions resulting in further environmental impacts. These emissions and impacts have not been compared to the production virgin aluminum which likely results in much larger impacts to the environment than recycling of aluminum. The consumption of fuel necessitated by these long barge trips led to higher depletion of abiotic resources (specifically fossil fuels) in scenarios S4-S8 (Figure 3.4, Chart B).

Depletion of fossil abiotic resources decreased slightly from S1 to S2 (Figure 3.4, Chart B). This difference was attributed to fuel usage necessitated by processes associated with burial, suggesting that incinerating half the waste stream resulted in less fossil fuel consumption than burial alone. The depletion of fossil abiotic resources was higher in S3, compared to S1 and S2 in both villages. This increase could be explained by the additional landfill operations required for enclosing the waste material in a burn box prior to incineration.

Depletion of elemental resources was negligible in_S1, S2, and S3. Elemental depletion in S9 was slightly higher due in part to the processes associated with recycling. Depletion of elemental resources was approximately 70-fold higher in SWM scenarios S4-S8 in comparison to S1, S2, S3, and S9 in Fort Yukon, and 7-fold higher in Kalskag. This increase in depletion in S4-S8 was due to the processes associated with aluminum recycling.

Production of CO_2, CFC's, particulate matter, and volatile gases all responded similarly to the nine SWM scenarios (Figure 3.5). CO_2 emissions increased from S1 to S3. The increase in CO_2 emissions from S1 to S2, was due to the introduction of incineration in S2. Surprisingly, enclosing waste materials in a burn box prior to incineration (S3) did not result in a decrease in emissions. In fact, the use of a burn box resulted in higher CO_2 emissions, perhaps due to the intensive processes required for separating and moving the waste materials into the burn box. A well designed burn box would emit more CO_2, but less PM 2.5 and PAHs, this result however, was inconclusive. Emissions of all substances was dramatically higher in scenarios S4-S8 in comparison to S1, S2, S3, and S9 (Figure 3.5) in both villages, due in large part to the processes associated with aluminum recycling. Recycling of glass, paper, and plastics resulted in less emissions to the atmosphere than processes associated with aluminum recycling. In particular, these emissions can be attributed to the processes associated with out-of-state transport of recyclable materials and processes such as re-melting of aluminum. A slight decrease in CO_2 emission from S7 to S8 was observed, which could be attributed to the WTE incineration (Figure 3.5, Chart A). All air emissions were higher in S9, compared to S1-S3, due to transportation of the waste to the recycling centers, increased incineration of combustibles, and emissions from recycling processes (Figure 3.5, Chart A).

Terrestrial acidification, terrestrial eutrophication, freshwater ecotoxicity, and freshwater eutrophication showed similar patterns in response to the nine SWM scenarios. Scenarios S4-S8 were more deleterious to water quality than S1, S2, S3, and S9 (Figure 3.6). The increased emissions to water resources are proposed to be attributed to aluminum recycling process and the transportation processes for recyclables. In Kalskag, S1-S3 had much larger negative impacts on freshwater ecotoxicity compared to the other three water impact categories. This may be attributed to waste stream content and the burn burial practices contributing to greater leachates to freshwater.

In Kalskag, S9 resulted in greater freshwater eutrophication than S4, S5, S6, and S7 (Figure 3.6, Chart D). This result was due to more intensive transport processes and higher percentage of organic waste composting. A possible explanation for this result is that the process of organic waste composting can result in run-off of nitrates and phosphates, which in turn can lead to freshwater eutrophication. Composting had a higher negative impact for Kalskag than Fort Yukon, which can be attributed to a higher percent of organic waste within the waste stream (Table 2.1).

The nine SWM scenarios produced similar impacts on cancer and non-cancer human toxicity (Figure 3.7). SWM scenarios S4-S8 resulted in greater production of substances that are deleterious to human health than S1, S2, S3, and S9 (Figure3.7). S1-S3 presented negative outputs for the human toxicity cancer and non-cancer causing categories for both villages (Figure 3.7, Chart A). However, S4-S8 resulted in much higher negative outputs for both human toxicity impact categories in Fort Yukon (more than a thousand times) and Kalskag. This increase can be attributed to aluminum recycling process and transportation systems emissions. S9 for Kalskag was slightly lower emissions of toxic cancer and non-cancer compounds than S1-S3. In contrast, Fort Yukon had noticeably higher release of toxic cancer and non-cancer compounds in S9, compared to S1-S3. This may be attributed to a waste composition that includes higher percentage of metals and non-combustible materials that are buried leading to emissions to soil and groundwater from leachates of these materials.

In this study I have shown that major changes to rural village SWM systems may not be practical, however, small changes that are economically feasible may mitigate human health and environmental impacts. The transport system in Kalskag was modelled with individual delivery of waste to the landfill versus Fort Yukon with a weekly curbside pickup and disposal for the whole of the community waste stream. The Kalskag waste delivery system was modelled based on an individual household delivery system and a larger waste stream, which contributed to higher emissions in all scenarios for all air impact categories. The impact categories that had major differences based on these two transport systems were the human toxicity non-cancer effects and the freshwater eco-toxicity impact category. The human toxicity categories were significantly higher for the Kalskag waste stream throughout all scenarios though, less so for the human toxicity cancer category (Figure 3.7, Chart A & B). This difference is directly attributed to the single household transport system in Kalskag. The freshwater eco-toxicity impact category had a similar response across all nine scenarios also related to the difference in waste stream and transport systems for each community (Figure 3.7, Chart B). The use of a single vehicle weekly delivery of all village waste to the landfill may diminish local negative environmental and human health impacts, as well as help reduce fuel consumption on an annual basis for the individual households within these communities.

S9 was intended to represent an optimal SWM system with mixed recycling of paper, plastic, glass, WTE, composting, and burial of only non-recyclables and non-combustibles.

Interestingly, S9 was not optimized for all twelve impact categories. Four of the twelve impact categories in S9 were either comparable or higher than S1-S3. This was due to the transport related processes for recycling and the composted portion of the waste stream.

Further, recycling options and technologies such as WTE may be impractical options for the two villages (and other remote Alaska villages) featured in this study. WTE plants present cost barriers for these remote villages, as well as limitations associated with waste stream production. For rural Alaska villages, energy produced from waste may be a desirable alternative to diesel (major source of energy generation) for energy generation based on high shipping costs and non-renewable resource depletion. Current WTE technologies require much larger waste streams than those produced in these two remote villages in order to operate. Additionally, high costs for building, maintaining, and operating these facilities limit the practicality of WTE for rural Alaska communities.

Minor changes to the SWM system, such as more efficient burning and waste transport, resulted in a decrease in overall human health and environmental degradation (or depletion). S1-S3 resulted in a slight increase in emissions of greenhouse gases in Fort Yukon. I assumed that the burn box addition to the system (for S3, S6, and S8) would decrease air emissions of gases and particulate matter. This was the case, as the volume of burned materials increased from 20% to 50%, without a significant increase in CO_2 emissions. The change in burning practices indicated lower air emissions of gas for photochemical ozone formation, but had an insignificant change in the other three air impact categories. Results indicate that using more efficient incineration devices provided no major evidence showing decreased human health and environmental degradation.

The application of an ISWM as a practical approach for rural Alaska SWM practices may not be the best strategy. Long transport distances by barge to recycling facilities make recycling for these rural villages a challenge. The use of empty barges travelling downstream for backhauling recyclables and other materials may be a future option for removing these recyclables and hazardous materials from rural Alaska villages. Backhauling was not included within the scope of this study as these programs have not been shown to be sustainable. Current backhaul programs for the removal of recyclables and hazardous waste for Kalskag and Fort Yukon (as well as with many remote villages) have stalled as a result of lack of funding and low rate of return on recyclable materials, leading to barge operators unwilling to participate without compensation (S. Price, personal communication, ADEC, February 8, 2016).

The emissions related to transport of recyclable items from Fort Yukon and Kalskag to urban city centers of Fairbanks and Anchorage, then onto Seattle for recycling have been included. Seattle remains the closest available location that offers recycling of materials such as metals, plastic, and paper. Glass as an alternative to recycling can be ground locally and used for road paving and improvements. The introduction of composting as a means of recycling the organic portion of the waste in order to mitigate environmental impacts was inconclusive. With the current transportation and access challenges for these rural Alaska villages recycling as a major component of SWM practices may not be sustainable.

I anticipated that the introduction of recycling to the village SWM systems would decrease human and environmental degradation throughout those scenarios where it was included within this study. However, I observed the opposite result. The recycling of aluminum within this study provided the greatest negative environmental impacts in those scenarios in which it was included. Recycling of scrap metals are in comparison a lot less energy demanding than the process (bauxite smelting) for producing virgin aluminum may have much higher impacts (Damgaard, Larsen, & Christensen, 2009). Recycling of metals thereby contributes to emission of GHG directly by combustion of fuel or indirectly by use of electricity, indirect contributions may also include the consumption of products and materials for cleaning and packaging, however the recycling of metals contribute to much lower emissions than the virgin production of aluminum (Damgaard, Larsen, & Christensen, 2009). The results of this study indicate that the re-melting or smelting processing used for recycling aluminum was found to be the main source of negative environmental and human health impacts, this however does not account for the emissions required for the virgin material production of aluminum. Future research efforts related to rural Alaska solid waste management practices may benefit from comparison of bauxite smelting as compared to the transport and recycling required for these remote communities.

Whereas waste characterization data were collected in late fall (October 29 through November 10, 2006) in Kalskag, waste characterization data from Fort Yukon was collected in spring and summer (May and August of 2014). An eight year gap between the two waste characterizations and a different sampling approach, may have contributed to significant differences in waste stream quantity and composition for these two villages. This was an unanticipated outcome and was the major reason that Kalskag appeared to have larger environmental and human degradation than Fort Yukon. Current annual waste streams for both communities are likely influenced by seasonal variations, i.e. decreased shipments of goods during the winter, and other unknown factors, thus were not accounted for within this study. Modelling programs such as EASETECH are tools that can support decision making for solid waste management systems, but are limited by data gaps for remote Alaska village SWM. The use of the EASETECH without accurate and applicable data may not be suitable for assessing the SWM practices of rural Alaska villages. More comprehensive data such as waste characterizations (quantity and composition) and waste management practices for more rural Alaska villages of comparable size and seasonal variations should be pursued.

The Kalskag waste stream was larger than that of Fort Yukon, waste delivery for each individual house, and a different waste composition likely contribute to larger deleterious effects on the environment (soil, air, water and abiotic resources) and human health. The larger waste stream required greater transportation processes both to the landfill and in S4-S9 for transport related to recycling processes. The transport processes of a larger waste stream contributed to greater abiotic resource depletion of fossil and elemental resources (Figure3.4) as well as higher emissions of all gases and particulate matter (Figure 3.5) in Kalskag than in Fort Yukon. The multiple vehicle delivery of waste in Kalskag compared to the Fort Yukon single vehicle weekly waste collection contributed to higher resource depletion (Figure 3.5) and environmental degradation (Figure 3.5 and 3.6) in Kalskag than Fort Yukon. Waste composition differences included a higher plastic content (four times higher in Kalskag; Table 2.1), the medical waste category at 12.0% of the waste stream in Kalskag (none in Fort Yukon), and a higher aluminum component (four times higher) in Fort Yukon. These compositional differences may have altered outcomes for several impact categories including the human toxicity cancer and non-cancer categories (Figure 3.7) along with both freshwater categories (Figure 3.6).

I concluded that: (1) Major system changes (i.e., WTE facilities and composting of organic waste) to the current system may be not be economically feasible or mitigate environmental impacts, (2) alternatives to current practices such as curbside pickup or altered burn practices appeared to mitigate environmental impacts, while only slightly increasing system costs, (3) recycling for remote Alaskan communities did not mitigate health and environmental impacts and under current constraints may not be a viable option, and, (4) waste stream variations such as size and composition drastically alter the influences on depletion of abiotic resources, air and water emissions, and human health.

The mixed method recycling S9 was proposed as the preferred SWM system in this study and included recycling, composting, and waste to energy technologies. The findings of my study suggest, albeit inconclusively, that S9 may be an impractical SWM solution for these remote Alaska villages, under current limitations (transport limited to boat or barge and access to SWM technologies). An optimal SWM system would decrease all associated impacts and energy consumption while remaining affordable and culturally acceptable.

Tradeoffs may be necessary, in order to establish a waste management system that minimizes environmental and human health degradation. These tradeoffs may include weighing emissions affecting global resources such as the ozone (atmosphere) or oceans, versus emissions to resources such as freshwater streams and local air quality. The recycling of aluminum provides one such example where large scale global air and water emissions are a result of the recycling and transportation of aluminum from these remote villages. Further, if aluminum is buried and not recycled there is a loss of elemental resources, local soil resources may be negatively affected, and leading to further mining and primary production of aluminum with major environmental consequences. Trade-offs are an important factor when considering SWM practices. SWM changes should consider the benefits of integrating practices that minimize human health and environmental degradation for local communities and impacts on global resources, allowing for tradeoffs that suit community priorities. Further analysis of recycling processes should include comparison of all recycling processes and associated emissions to the virgin production of these materials (most notably aluminum).

The use of modeling systems for LCA analysis with current, accurate, and complete data should diminish uncertainty, while providing a valuable tool for analyzing remote Alaska SWM practices. Modeling systems are tools used to predict outcomes and provide support for management decisions. Data should support an iterative process for decision making based on long term sustainability, economic elements, and environmental protection. Further LCA studies might include the further examination of waste characteristics, waste management practices, and recycling options for additional rural Alaska villages.

Current WTE options for remote Alaska villages are restricted by cost and access to these technologies. WTE facilities are expensive and are not yet suited for the small waste stream generation produced by these rural Alaska communities. Future research on WTE options within the remote Alaska communities could help establish if this is a viable alternative to recycling and import of fuels for energy consumption.

The benefits of backhaul programs may be a favorable solution for recycling non-renewable resources and removal of hazardous materials, but additional studies are needed in order to establish their viability and long term sustainability. Without data to support the claim that current system practices are negatively impacting social and ecological resources, programs such as backhauling recyclables (that have monetary value and decrease non-renewable resource loss) and hazardous waste, may not be seen as a priority. Future studies for rural Alaska SWM should include collection of characterization data for multiple villages, interviews with members within the study area, and observations for multiple rural Alaska landfills facilitate SWM decisions.

I assumed at start of this study that the annual waste stream production would have been close between the Fort Yukon and Kalskag communities. Unfortunately, this was not the case and created challenges for analysis and comparison of these two village SWM management systems and their proposed impacts. Future studies of rural village SWM practices may also benefit from comparing communities with equitable annual waste generation in both annual amounts and composition. A comparison of villages with equal waste generation but variable waste types might also help identify how this variability influences waste management practices and associated impacts.

Future research should seek an optimal SWM system that employ methods and handling which decrease all environmental and social impacts as compared to the current operating SWM systems within remote Alaska communities. Future research may include specific data for transportation methods, processes, and emissions in order to help decrease the degree of uncertainty associated with modelling rural Alaska village SWM systems. Further research comparing burning and burial of the waste stream to alternative options for reuse and recycling options and the associated emissions and energy consumption of each might help identify viable waste management options. The rural Alaska SWM system or village landfill is the source of many unknowns, however they are a necessity for these communities. Further research should seek viable options for rural Alaska SWM practices that mitigate community degradation of social and economic resources.

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Appendix A

Key Terms and Definitions

Hazardous waste – Waste, or a combination of wastes, that may cause or significantly contribute to an increase in mortality or an increase in serious or irreversible.

Incineration – Engineered process involving burning or combustion to thermally degrade waste materials into ash, flue gas, and heat.

Integrated solid waste management – Management of solid waste based on a combination of source reduction, recycling, waste combustion, and disposal.

Life-cycle Assessment (LCA) – A multi-step procedure for calculating the lifetime environmental impact of a product or service.

Life-cycle Impact Assessment (LCIA) – The inventory from the life-cycle assessment and the results of analysis for proposed environmental impact.

Normalization – Normalization or calculating the magnitude of the category indicator results relative to reference values where the different impact potentials and consumption of resources are expressed on a common scale through relating them to a common reference, in order to facilitate comparisons across impact categories.

Open burning – The combustion of any material without the characteristics below:

a. Control of combustion air to maintain adequate temperature for efficient combustion.
b. Containment of the combustion reaction in an enclosed device to provide enough residence time and mixing for complete combustion.
c. Control of emission of the gaseous combustion products.

Personal equivalent – "Impact potential per person per year" calculated as the background impact over the course of one year per person in the area for which the impact is computed, irrespective of whether they are global or regional.

Remote/Rural Alaska – The part of the state generally off the road and marine highway system and accessible by boat, barge, or plane.

Solid waste – Any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities.

Solid Waste Management – Solid waste Management is the generation, prevention, characterization, monitoring, treatment, handling, reuse and residual disposition of solid wastes, including municipal (residential, institutional, commercial), agricultural, and special (health care, household hazardous wastes, sewage sludge).

Waste generation – Act or process of generating solid wastes.

Waste hierarchy – A ranking of waste management operations according to their environmental or energy benefits. The purpose of the waste management hierarchy is to make waste management practices as environmentally sound as possible.

Waste stream – Describes the total flow of waste from a homes, businesses, institutions, and manufacturing plants that must be recycled, burned, or disposed of in landfills; or any segment thereof, such as the residual waste stream or the recyclable waste stream. The total waste produced by a community or society, as it moves from origin to disposal.

Waste to Energy – A facility that uses solid waste materials (processed or raw) to produce energy. WTE plants include incinerators that produce steam for district heating or industrial use, or that generate electricity; they also include facilities that convert landfill gas to electricity.

Weighting – Weighting where weights are assigned to the different impact categories and resources reflecting the relative importance they are assigned in the study in accordance with the goal of the study.

Appendix B

Fort Yukon Scenario Results

Name FYU	Impact Cat-1	Impact Cat-2	Impact Cat-3	Impact Cat-4	Impact Cat-5	Impact Cat-6	Impact Cat-7	Impact Cat-8	Impact Cat-9	Impact Cat-10	Impact Cat-11	Impact Cat-12
S-1	-.3349	8.13E-07	.04758	.00182	.00050	0	120E-06	.2439	.7629	4.472	.0215	.0004
S-2	.1589	8.57E-07	.1146	.0019	.00050	1.81E-05	120E-06	.2434	.4846	2.799	.0094	.0004
S-3	.4919	9.09E-07	.0032	.002	.00052	3.95E-05	120E-06	.02027	.7663	2.802	.0339	.0004
S-4	2799	102.9	478.9	2850	39.79	1.61	.293	399.1	1635	485.1	2521	1274
S-5	2799	102.9	478.8	2850	39.79	1.61	.293	399	1635	485.1	2521	1274
S-6	2799	102.9	478.8	2850	39.79	1.61	.293	398	1550	436.1	2521	1274
S-7	2799	102.9	478.9	2850	39.79	1.61	.293	398.7	1606	468.4	2521	1274
S-8	2794	102.9	478.7	2850	39.75	1.63	.293	396	1381	339.2	2520	1274
S-9	4.162	-.0027	-.0771	-.0264	-.013	.2104	.004	2.92	204.6	127.2	-1.066	-0.127

S-1=scenario one the current system within the rural villages of Fort Yukon S-2=Scenario two represents a 50/50 split of burn bury (using open burn) system. S-3=Scenario three represents a 50/50 burn bury (using a burn box). S-4=Scenario 4 includes a 50/50 burn bury (open burn) with the recycling of 60% glass, 50% paper, 80% plastic and 90% aluminum, S-5=Scenario five is an all bury of all non-recycled materials (same recycled materials as scenario four). S-6=Scenario six is a 50/50 burn bury split (using burn box) and the recycling of 60% glass, 50% paper, 80% plastic, and 90% aluminum. S-7=Scenario seven is a 50/50 burn bury (burn box) same recycling as previous scenario and the addition of composting 80% organic matter. S-8=Scenario eight represents is and 20/80 bury burn, using a waste to energy (WTE) incinerator, 90% aluminum and 60% glass recycled, and 80% organic matter composted. S-9=Ninth scenario representing an optimal system where 60% glass, 50% paper, 80% plastic are recycled, all combustible materials are incinerated using (WTE) incinerators, 80% organic matter is composted and all remaining (non-combustible) materials are buried. Recommended Fort Yukon ILCD (International Life Cycle Data system) 2013 impact categories: Cat-1=Climate Change Cat-2=Stratospheric Ozone Depletion Cat-3=Photochemical Ozone Formation scenarios Cat-4=Terrestrial Acidification Cat-5=Terrestrial Eutrophication Cat-6=Freshwater Eutrophication Cat-7=Abiotic Resource Depletion-minerals/elements Cat-8=Human Toxicity-cancer Cat-9=Human Toxicity-non-cancer Cat-10=Freshwater Ecotoxicity Cat-11=Abiotic Resource Depletion-fossil Cat-12=Particulate Matter

Appendix C

Kalskag Scenario Results

Name Kal.	Impact Cat-1	Impact Cat-2	Impact Cat-3	Impact Cat-4	Impact Cat-5	Impact Cat-6	Impact Cat-7	Impact Cat-8	Impact Cat-9	Impact Cat-10	Impact Cat-11	Impact Cat-12
S-1	45.54	.002	2.896	.0844	.0121	.00180	.095	21.38	1650	955	.1145	.1443
S-2	47.8	.002	3.224	.08456	.01212	.00181	.095	21.26	1649	952.5	.0491	.1444
S-3	49.12	.002	2.679	.0851	.01224	.00195	.095	21.06	1650	952.5	.1793	.1446
S-4	3201	114.7	536.2	3176	44.34	1.716	.407	465.4	3485	1498	3054	1419
S-5	3201	114.7	535.7	3176	44.34	1.715	.407	464.9	3485	1498	3054	1419
S-6	3201	114.7	535.7	3176	44.34	1.715	.407	463.7	3390	1444	3054	1419
S-7	3192	114.7	535.5	3176	44.34	1.714	.397	462.4	3291	1386	3055	1419
S-8	3185	114.7	534.9	3174	44.19	1.826	.408	458.5	2956	1194	3048	1418
S-9	51.4	-.0022	.5377	-1.377	-.101	1.742	.060	20.46	1487	864.9	-5.145	-.5201

S-1=scenario one the current system within the rural villages of Kalskag. S-2=Scenario two represents a 50/50 split of burn bury (using open burn) system. S-3=Scenario three represents a 50/50 burn bury (using a burn box). S-4=Scenario 4 includes a 50/50 burn bury (open burn) with the recycling of 60% glass, 50% paper, 80% plastic and 90% aluminum, S-5=Scenario five is an all bury of all non-recycled materials (same recycled materials as scenario four). S-6=Scenario six is a 50/50 burn bury split (using burn box) and the recycling of 60% glass, 50% paper, 80% plastic, and 90% aluminum. S-7=Scenario seven is a 50/50 burn bury (burn box) same recycling as previous scenario and the addition of composting 80% organic matter. S-8=Scenario eight represents is and 20/80 bury burn, using a waste to energy (WTE) incinerator, 90% aluminum and 60% glass recycled, and 80% organic matter. Recommended Kalskag ILCD (International Life Cycle Data system) 2013 impact categories, Cat-1=Climate Change Cat-2=Stratospheric Ozone Depletion Cat-3=Photochemical Ozone Formation scenarios Cat-4=Terrestrial Acidification Cat-5=Terrestrial Eutrophication Cat-6=Freshwater Eutrophication Cat-7=Abiotic Resource Depletion-minerals/elements Cat-8=Human Toxicity-cancer Cat-9=Human Toxicity-non-cancer Cat-10=Freshwater Ecotoxicity Cat-11=Abiotic Resource Depletion-fossil Cat-12=Particulate Matter