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Pre-Feasibility Study

Creating Heat from Waste: Landfill Destined Cardboard as a Raw Material for Heating Pellets

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to investigate the use of locally diverted waste cardboard to produce fuel pellets in Inuvik, NT. The remote location of Inuvik means that residents and businesses rely heavily on fossil fuels transported up the Dempster highway by truck. Fossil fuels are used for power generation, transportation, and space heating.

1.2 METHODOLOGY

In order to begin to identify the possible economic, social, and environmental effects of using locally diverted waste cardboard to produce fuel pellets for use in pellet boilers, the current state of biomass fuel usage must be understood along with the current heating and power infrastructure. (Section 2 General Information)

Technical considerations for making fuel pellets from waste cardboard and burning them in existing boilers are considered next. (Section 3, Cardboard Pellets)

Finally, the exploration of pellet manufacturing and the impacts are broken down into three subsections as follows:

- *Business case*: Is there a profitable business model for the manufacture and distribution of cardboard fuel pellets? (Section 4.1, Business Case Analysis)
- *Diesel diversion*: Does the manufacture of fuel pellets from waste cardboard reduce diesel consumption? (Section 4.2, Fossil Fuel Reduction)
- *Emissions reduction*: Are the emissions generated by the manufacture and use of cardboard pellets lower than that of other heating sources? (Section 4.3, Emission Reduction)

With a thorough understanding of the effects of the cardboard pellet production, an implementation plan can be designed to validate the research data.

2 GENERAL INFORMATION

2.1 CURRENT SYSTEMS AND PROCEDURES

2.1.1 Power Generation and Heating

Space heating was responsible for 26% of all energy usage in the Northwest Territories in 2009/10 [1]. Most of this energy came from imported fossil fuels [2]. The GNWT has created several policies promoting the move away from imported fossil fuels culminating in the 2010 *Northwest Territories Biomass Energy Strategy* [3]. This report mentions frequently the goal of moving to locally harvested wood as a source of heating in remote communities.

Next to space heating, electricity needs represented 10% of the total energy demand in 2009/10 [1]. Inuvik currently employs a mix of Synthetic Natural Gas (SNG) and Diesel fired generators to produce all of its electricity [4] [5]. Diesel provides 6.2MW of generating capacity, and three gas-fired generators provide a combined 7.7MW of generating capacity [5].

The necessity for trucking in fossil fuel resources for power generation means that the price for electricity stays high, at 60.83 cents per kWh above 600kWh in 2017 [6]. This is more than 4 times higher than the average electricity rate in Toronto ON, 14.31 cents per kWh in 2015 [7]. SNG prices are also inflated by the need to truck the fuel into Inuvik. *Inuvik Gas Ltd* supplies SNG to Inuvik at a rate of $33.45 per GJ [8] while *Enbridge Gas Distribution Ltd* in Ontario can supply Natural Gas at $3.33 per GJ [9]. All energy sources in Inuvik are impacted by diesel prices, as the trucks used to import diesel or SNG needs be transported an additional 1200 kilometers by road past Whitehorse.

2.1.2 Cardboard Waste Quantity and Disposal Practices

Currently, there is no municipal cardboard recycling program available to the residence and businesses of Inuvik. Local Grocer, *Northmart* has actioned its own recycling program in which cardboard is compacted and shipped to Edmonton [10]. *Stanton's Distributing* also employ a cardboard reuse and recycling program, using some boxes for back-haul to their suppliers and offering others to their customers as an alternative to plastic grocery bags. All other cardboard is disposed of along with regular refuse at the *Inuvik Solid Waste Facility*. Local Commercial and industrial entities pay anywhere from $35 to $325 to dump at the Inuvik Solid Waste Facility [11].

All waste cardboard generated in a residential setting is disposed of using Inuvik's network of 219 Bear safe dumpsters. These dumpsters are emptied in accordance to a contract between *Bob's Welding* and the *Town of Inuvik* [11]. There is no distinction made during the collection process between cardboard and other refuse.

2.1.2.1 Statistical Cardboard Waste Quantity in Inuvik

If Inuvik is indicative of the averages across the whole territory, then its population of 3100 people [12] should be producing 273kg of waste cardboard per day. See Appendix 9.1.

2.1.2.2 Sample Cardboard Collection Programs

Three sample collection programs were run to gather more information about the quantity and quality of waste cardboard available in Inuvik. The results of this collection are analyzed in Appendix 9.2.

The road accessible communities surrounding Inuvik provide the opportunity to capture waste cardboard via backhauling. The communities of Tuktoyaktuk, Tsiigehtchic, Fort McPherson, and Aklavik, had a combined population of 2360 in 2016 [12].

2.2 Pellet Background

The use of local wood resources and pellet fuel technologies is desired to replace the reliance of imported fossil fuel supplies as mentioned in the *NWT Biomass Energy Strategy* [3]. The 10-step action plan proposed by GNWT mentions the burning wood pellet fuel directly.

There are several pellet mills located within a 3000km driving distance from Inuvik [13]. The most notable are the *Pinnacle Renewable Energy Inc.* pellet mills spread out over southern British Columbia. They produce several pellet products varying by the wood type, and offer options with emphasis on less dust [14].

2.2.1 Pellet Regulations

ENplus is the European pellet certification provided by the European Pellet Council (EPC). This certification guarantees that manufacturers and bagging companies meet a universal industry quality standard. The certification, which began in 2010, is in its third edition as of 2017, updating itself as the industry rapidly expands [15].

2.2.2 Pellet Manufacturing

Figure 2-1 shows a typical set of pelleting procedures for different biomass sources. These procedures can be broadly grouped into two categories: a shredding or chipping phase, and a pelleting phase.

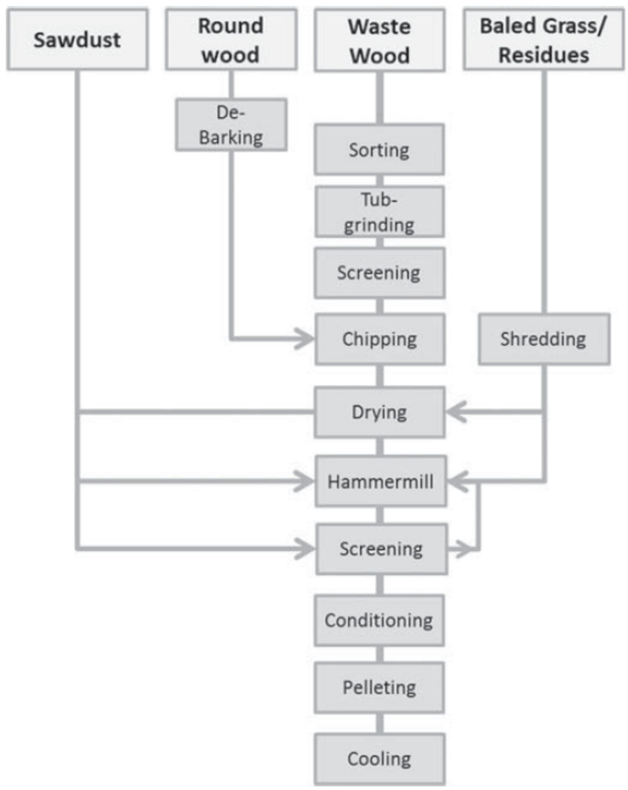


Figure 2-1 A Typical Large Scale Pelleting Procedure for a Variety of Biomass Sources [16]

2.2.2.1 Shredding and Chipping

Shredding or chipping processes are used to reduce the size of the biomass material before pelleting can take place. Depending on the type of biomass, different processes are available to achieve the required size reduction, as seen in Figure 2-1. The type of material along with the desired pellet size determines the optimum size of the post-size reduction particles, referred to as feedstock. See Table 9-11 as an example.

Hammer mills are used to reduce the particle size of a supplied material to below that determined by a screen. Large hammers spin inside the screen breaking up particles within. The size of the holes in the screen are varied to suit the material being processed [16]. Unlike hammer mills, shredders generally use a cutting operation to reduce material size.

The term densification is used to describe a shredding or chipping operation as the particles resulting from the process are usually a higher density that those entering. The bulk density of Miscanthus grass increases by an approximate factor of five times through size reduction; more details on this calculation are provided in Appendix 9.5.3. This densification is mandatory when processing low-density biomass, as a minimum feedstock density of $200\frac{kg}{m^3}$ is recommended to ensure easy pelleting [16].

2.2.2.2 Pellet Mills and the Pelleting Process

Pellet mills are comprised of a set of rollers and either a flat or a cylindrical die. The rollers rotate around a shaft perpendicular to the die face. This motion forces the material through the die holes, creating the pellets on the reverse side. Figure 2-2 shows the forcing mechanism present in a pellet mill.

The topic of biomass pelleting is extensive with considerable literature surrounding the optimization of the process for many different feedstock materials and in many different climates. The following sections try to communicate a snap shot of this industry scoped to remain relevant to the concerns of this project.

2.2.2.3 Factors Affecting Pellet Manufacturing

There are three dominant composition concerns, and two dominant process concerns to take into account for the pelleting process. They are outlined below, and summarized in Figure 2-3.

- Biomass Composition:
    1. Lignin: Lignin is an organic polymer material found in the cell walls of vascular plants. There is no fixed molecular definition for Lignin; it is a random molecular weight polymer of phenyl propane. It is important to plants, and to the creation of pellets due its high strength [17]. The Lignin content of a biomass sample has a strong positive correlation with pellet durability [16]. The lignin polymer chains aid in binding the pellets, allowing them to hold shape during transport and handling. Wood Lignin content ranges from 15-40% across species lower for Hardwoods, higher for Softwoods. [16]
    2. Extractives: Extractives include low molecular weight organic compounds such as waxes, saps, terpenes, and tannins. The presence of these extractives has been shown to have a negative effect on pellet durability [16].
    3. Moisture: The moisture content of the biomass material is heavily dependent on what the material has been exposed to during its collection and storage. The moisture content of the substrate has a non-linear relation with pellet durability with the ideal moisture content being dependent on the material itself. The average ideal moisture content for wood is 8-12% before entering the pellet mill [16]. The moisture inside the biomass will turn to steam at the elevated processing temperatures. The presence of steam in the mill helps distribute temperatures and soften lignin in the biomass. Figure 2-2 shows the steam generated under the roller spreading into the other biomass preparing it for processing.

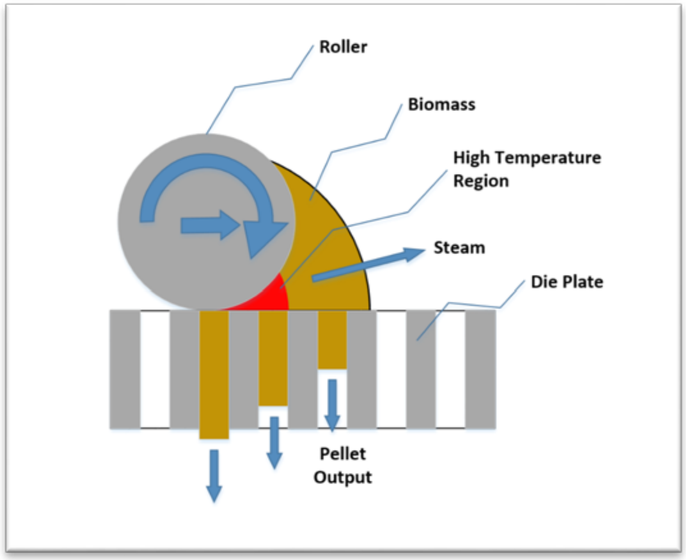


Figure 2-2 Cross section of pellet milling process.

- Process Variable:
    1. Pressure: The rollers inside most pelletizing machines exert a considerable force onto the material. Pressures are commonly in the range of 115 to 300MPa [16].
    2. Temperature: With the high pressures present inside pellet mills, comes high friction forces, and therefore elevated temperatures. The temperature of the process is crucial for softening the lignin present inside the biomass, allowing the material to flow through the dies and form the pellet. As lignin molecular weight varies considerably, so does its glass transition temperature (the temperature at which the lignin softens and starts to flow). Thus, the process temperature can be tailored to align with the specific lignin content of the material being pelleted.

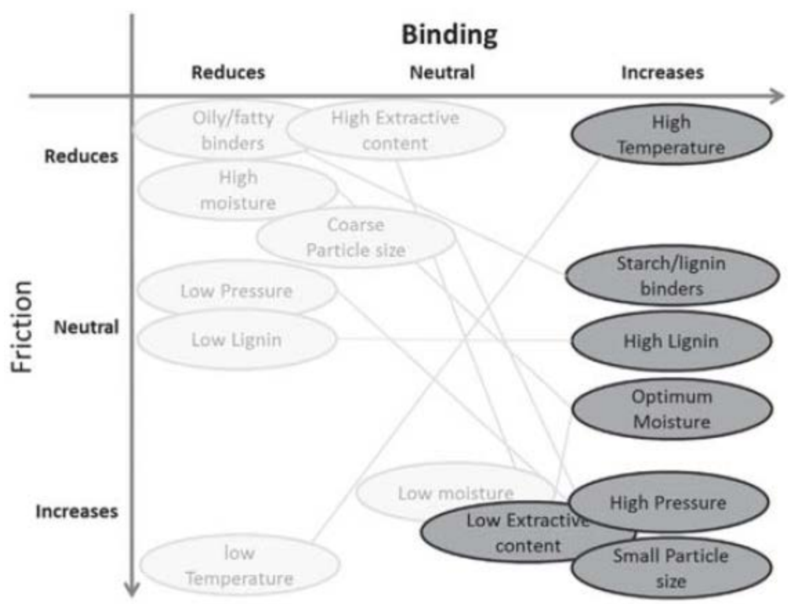


Figure 2-3 Visualization of the effect of pelleting parameters on pellet durability. [16]

Correct control of the factors described above allows the production of a dense and robust pellet. It is also important to note that the pelleting process is steady state, meaning that the process works best when running consistently for long periods. Figure 2-4 shows the temperature profile as a function of time inside a pellet mill during use. The low internal temperature at the beginning of operation will produce low quality pellets that may need to be reprocessed to ensure high pellet durability.

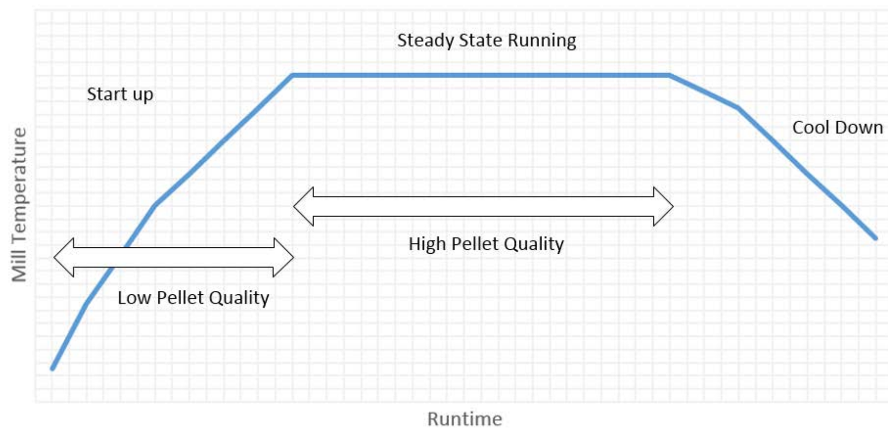


Figure 2-4 Temperature Profile during Mill Operation

Additives, such as binders, lubricants, and water may be included into the pelleting process in order to increase the durability of the pellets.

- Vegetable oil or other oil product: Lubricant, will ease the flow of material through the dies, this reduces the die temperature and pressure.
- Water: increases the moisture content of the material and quantity of steam present during milling.
- Starch: acts as a binder, in effect, increasing the effective lignin content.
- Lignin Powder: increases the quantity of lignin in the material.

For an in depth review of all the parameters that affect the performance of a pellet, the report titled *Factors affecting wood, energy grass, and straw pellet durability* written by Carly Whittaker, and Ian Shield [16] is recommended.

2.2.2.4 Post Production Fines

ENplus defines particles that exit the pellet mill below the size of 3.15mm as fines [18]. These fines pose health and safety threats to the operation of a pellet boiler, as they are hard to handle and can cause deposits to form inside boilers [16].

Pellets breaking down into fines through handling and transportation is directly related to pellet durability; Pellets with high durability tend to produce fewer fines when transported. ENplus certifications limit fines by percent weight at delivery to the end user or when delivering to a bagging operator [18]. Fines collected during manufacture or transport can be fed back into the pelleting process to reduce material wastage during processing, as they are usually the correct feedstock size.

2.2.3 Pellet Properties

The parameters shown in Table 9-8 represent the current benchmark for wood pellet fuel properties.

2.2.4 Pellet Boilers

Pellet boilers are a subclass of furnaces specifically designed to be able to operate at a steady state while using solid pellet fuel sources. The need to deliver a solid fuel at a steady rate means many pellet boilers use auger or grate systems to add fuel to the combustion chamber in conjunction with an auger that removes the ash after combustion has taken place. Most residential units are completely enclosed and computer controlled.

Most European made residential pellet boilers require the pellets to be certified with the ENplus A1 certification [19] [20] [21]. This A1 certification, discussed at greater depth in Appendix 9.3, is the highest pellet standard and guarantees certain baseline fuel properties, most importantly in the context of this report, the fuel ash content being below 0.5% by weight [18]. Local installers have confirmed that most of the boilers in use in the Inuvik region are manufactured my either Kob-Viessmann [22], or Ökofen [23].

Larger boiler systems, such as the Kob-Viessmann boiler installed in Fort McPherson, NT have slightly higher ash tolerances. Viessmann quote that the ash content limit on their Vitoflex 300-RF is 1.5% by weight [19].

2.3 Emissions Regulations

2.3.1 New Air Regulations

During the time this report was compiled the *Environment and Natural Resources* (ENR) *division* of the *Government of the Northwest Territories* was in the process of drafting new regulations for air quality in the Northwest Territories. Previously the only guiding document when it came to environmental regulation was the Environmental Protection Act (EPA), which left air quality largely unregulated [24]. As of October 2017, ENR is in the process of creating a second draft of the NWT Air Regulations based on feedback it received in the March and April feedback and consultation period. Amendments to the EPA are expected to be tabled in the summer of 2018 [25]. In regards to the introduction of new fuels, such as cardboard pellets used in residential and commercial boilers, the only restrictions come from the Small Operations Classification described in Section 2.3.1.1.

2.3.1.1 Small Operations Classification

The framework for the proposed NWT Air Regulations states that boilers and heaters under 1500kW will fall into the small operations classification. In this classification, only an equipment inventory along with fuel and chemical usage must be reported to ENR to allow operation; no registration fees, or emissions fees will have to be paid. The equipment and fuel information will have to be updated with ENR every 3 years [24].

3 Cardboard Pellets

The following sections explore the alternative of manufacturing fuel pellets out of waste cardboard diverted from the *Inuvik Solid Waste Facility*.

3.1 Size Reduction

3.1.1 Cardboard Particle Size

As discussed in Section 2.2.2.3, there is an ideal particle size range from which the highest quality pellet can be made from each biomass source. Lacking information about the optimization of the pelleting process for waste cardboard, a comparison is made to the pelleting operation of a biomass source with similar initial properties, in this case miscanthus grass. Appendix 9.5 discusses the correlation between the two in greater depth. The estimated ideal particle size for cardboard pellet manufacturing is 3-6mm based on the Miscanthus comparison.

3.1.2 Size Reduction Machinery

The *Navy Civil Engineering Laboratory* in their report titled *Comparison of Shear Shredder with Hammer mill for Size Reduction of Navy Solid Waste* found that the shredders they tested fowled less often than their hammer mills and could consume a larger bandwidth of material. The shredders also proved to consume less power per tonne of material processed [26]. Lawson Mills in New Brunswick also recommend a shredder for use with paper and cardboard processing [27].

3.2 Pellet manufacturing and Usage

3.2.1 Manufacturing Control

In correspondence with *Michael Dennis* of *The Dennis Group*, who has previous cardboard pellet production experience, the addition of vegetable oil into the pellet mill feedstock had the best impact on pellet durability at minimal additional cost [28]. Other additives are discussed in Section 2.2.2.3.

Once the cardboard pellets have been created, they need time to cool, as they will most likely exit the mill at above 70 degrees Celsius. The cooling process solidifies the lignin and starches inside the pellet, giving it strength [16].

3.2.2 Cardboard Contaminants and Combustion Emissions

The test cardboard collection program, described in Appendix 9.2, found that non-fibrous materials, such as tape, and labels, made up less than 1% by weight of the as-received cardboard. At this composition, it is expected that the presence of this non-fibrous material will have no effect on the boiler emissions, performance, or maintenance. More details about combustion emissions are discussed in Appendix Section 9.7.

3.3 Boiler Hardware

The following sections discuss several factors taken into consideration when determining if a fuel is suitable for use in a specific boiler.

3.3.1 Cardboard Pellet Ash Content

Unprocessed waste cardboard has a higher ash content, up to 10.30% by weight when completely dry [29], compared to 0.5% by weight average for wood [30]. Burning fuels with high ash contents places specific strain on the boiler. Ash build up can lead to slag creation and increased corrosion of the heat exchangers inside the boiler [31]. It is unclear whether the act of pelletizing a fuel source works to reduce the ash content. *T. A. Moe*'s report entitled *Wastepaper pellets as a source of fuel for auxiliary* *home heating* provided combustion data to ECN stating that the cardboard fuel pellets they created had an ash content of 0.98% by weight. See Appendix 9.4.1 for more details.

3.3.2 Energy Density

Reported values for the energy density of cardboard have ranged from 13.60MJ/kg [29], to 16.9MJ/kg [32]. See Appendix 9.4 for more details.

3.3.3 Sintering Temperature and Chemical Composition of Ash

Little literature currently exists on the properties of the ash produced from combusted cardboard. Compared to current wood pellets, if the sintering temperature of the ash from the cardboard pellets is lower then ash inside the boiler could slag. This can cause heat exchanger fouling and eventually shut down the boiler. Additionally, ash with large quantities of Chlorine, Potassium, or Sodium tend to be very corrosive at high temperatures and will damage the inside of the boiler and heat exchangers at a higher rate than under the conditions imposed by wood [33].

3.3.4 Boiler Suitability

As mentioned in section 2.2.4, *Viessmann* [19] restrict the allowable ash content on their commercial (45-540kW) biomass boilers to a range below 1.5%wt depending on the exact model. *Viessmann*'s industrial boilers, with outputs above 880kW (3 million BTU/hr.), are capable of handling ash contents as high as 10%. They operate using specific grate fuel delivery systems and different ash removal systems that are more suited to dealing with the extra ash in the fuel [34].

BTek Energy Roto-Net Burner, for example, is designed to handle higher ash contents characteristic of non-wood biomass fuels [35]. This unit is meant to convert an existing boiler into one capable of burning a wider range of fuels. Four models are available covering a power range of 5kW up to 350kW [35]. The *Bio-Burner* provided by *Advanced Wood Heat* is specifically designed to burn a wide variety of biomass fuels. By design, the *Bio-Burner* is more tolerant to high ash content. The manufacturer, LEI Products, recommends more frequent combustion chamber cleaning for fuels that have more volatile ash contents [36].

3.3.5 Mixed Waste Cardboard Fuel Properties

To allow the cardboard pellet product to be utilized in a wider range of existing boilers, it would be necessary to mix the pellets with existing wood pellets. Doing this would mitigate the ash content restrictions imposed by many boiler manufacturers. Not only would the ash content be able to be tailored to meet the restrictions of a specific boiler, but also the ash of the cardboard would be diluted, removing concerns of possible corrosion and sintering. Properties of the mixed fuel at different compositions are listed in Table 3-1.

Table 3-1 Expected Properties of Mixed Fuel

Mix (%wt. Cardboard)	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**
Combined Heating Value (MJ/kg)	18.13	17.96	17.78	17.60	17.43	17.25	17.07
Combined Ash	0.99%	1.48%	1.97%	2.46%	2.95%	3.44%	3.93%
Values assume cardboard is 10.3%wt ash and 16.9MJ/kg							

As seen above, a 10% mix of cardboard pellets would meet the ash composition limitations of some *Kob-Viessmann* boilers described in Section 3.3.4. A further dilution to below 5% would make the pellets suitable to use in the residential size boilers mentioned in 2.2.4.

Considering that the scale of a possible cardboard pellet program will meet less than 1% of the current wood pellet demand in Inuvik, mixing the cardboard pellets in at 10% by weight will not lead to demand restrictions. The values presented in Table 3-1 represent the worst case cardboard fuel ash content, only combustion tests performed during the pellet mill testing outlined in Section 6 can provide definite answers on boiler suitability. Appendix 9.4 comments on the variability of ash content data.

4 Benefits and Costs

The following three sections; Business Case, Diesel Reduction, and Landfill Diversion, outline the benefits and drawbacks of the manufacture and use of waste cardboard fuel pellets.

4.1 Business Case Analysis

Two business cases were analyzed - an independent venture, and a sponsored venture. The independent venture assumes that all capital and operational costs of operation are placed with the project. The sponsored venture assumes the project is running in an already existing infrastructure therefore no space rental or heating costs are associated. The latter models the opportunity for an existing private industry partner to take over the project.

4.1.1 Minimum Viable Product

Cardboard pellets will need to compete directly with the wood fuel pellets already on the market in Inuvik. The price of wood pellets in Inuvik in September 2012 was $0.55/kg [13]. If purchased by the tonne from *Wrangling River Supply*, that price drops to $0.52/kg ($522/tonne) [37].

The market in Inuvik is assumed cost driven, and so the cardboard pellets would have to be produced to be sold at the same value as the wooden pellets. The unit of value to the customer is the energy output, so dollars per BTU, or dollars per Mega-Joule are representative measurements of value. Table 4-1 shows that for the cardboard pellets to be considered at the same value to the customer they must be priced at $450 per tonne.

Table 4-1 Value Equality Using HHV

Fuel	Heating Value	Source	$/kg	$/MJ
Wood Pellet	18.3 MJ/kg	ECN - HHV	$0.52	$0.03
Cardboard Pellet	15.8 MJ/kg	Average of NTNU and ECN Values - HHV[1]	$0.45	$0.03

4.1.2 Collecting Waste Cardboard

Waste cardboard destined for the landfill can be intercepted at a variety of locations. Options explored in this report include:

[1] See Appendix 9.4.

- A single drop off location that will accept waste cardboard with no fees. The lack of drop off fees provides the incentive to the deliverer.
- A collection service that involves bins placed at the *Inuvik Solid Waste Management Facility* for voluntary sorting of cardboard away from conventional refuse by landfill users.
- A collection service that goes to large local cardboard waste producers several times per week to collect cardboard.

It is also possible to run a residential collection program alongside conventional refuse pickup; however, this would require a large initial investment (vehicles, residential collection bins) and is not considered in this report. As noted in section 2.1.2.2, an estimated 273kg of cardboard is available per day. The ability to intercept cardboard destined for the solid waste facility is discussed in section 4.1.3. The costs associated with various collection programs are analyzed in section 4.1.7.

Another possible profitability measure not discussed above is the option of a pay-for-pickup model where entities can sign up to have their waste cardboard collected by pellet mill staff. This option would add the additional complexity of maintaining a customer log and increased collection presence, but does produce a secondary revenue stream while providing a convenience for the waste cardboard supplier.

4.1.3 Cardboard Supply

As outlined in 2.1.2, the theoretical value of 273kg represents the quantity of waste cardboard produced per day in Inuvik. A diversion fraction can be defined as the ratio of mass of diverted cardboard over the statistical mass of waste cardboard available. This ratio will aid in judging the effectiveness of cardboard collection and processing procedures.

4.1.4 Fixed Setup Costs

The largest setup cost specific to this project is the purchase of the pellet milling machines.

Two quotes were received from *Lawson Mills* for two different size cardboard pellet-making operations. The first capable of generating about 250lbs of cardboard pellets per hour, and the later capable of 500lbs of cardboard pellets per hour. Both of these configurations require the use of 3 phase electrical power. Table 4-2 outlines the quotes provided by *Lawson Mills*.

Table 4-2 Pellet Manufacturing Machine Quote Summary [38]

Machine	Initial Cost	Quoted Throughput (lb./hr.)	Power (hp)
Quote 1 - Smaller System			
LMS303 Shredder	$21,800.00	250	10
BN100 Pellet Mill	$13,400.00	250	10
Storage Silo	$6,900.00		
Shipping	$3,900.00		
Total with Tax	$48,300.00		
Quote 2 - Larger System			
LMS303 Shredder	$21,000.00	500	10
LMXT Pellet Mill	$51,350.00	500	20
Shipping	$4,900.00		
Total with Tax	$81,112.50		

For the quantity of cardboard available in Inuvik, the small system using the *BN-100* pellet mill, seen in Figure 4-1, would be the best fit for the project. With a 100**%** cardboard diversion, the *BN-100* mill will only need to run for 2.5 hours a day to process all of the cardboard into fuel pellets.

Figure 4-1 BN-100 Pellet Mill [27]

As mentioned above, the BN-100 requires 3-phase power to operate. Cost estimates for an upgrade to 3-phase power into an existing building in Inuvik are $25,000 [39].

Other important items required for the successful operation of a pelleting process include equipment for the manual processing of the cardboard and organizing of ingoing and outgoing material. Approximate setup costs are outline below in Table 4-3.

Table 4-3 Fixed Setup Costs

Item	Qty.	Cost Per	Total Cost	Supplier	Manu	No
			Machines			
Shredder	1	$ 21,800.00	$ 21,800.00	Lawson Mills	Lawson Mills	LMS303
Mill	1	$ 13,400.00	$ 13,400.00	Lawson Mills	Lawson Mills	BN100
Silo	1	$ 6,900.00	$ 6,900.00	Lawson Mills	Lawson Mills	-
Shipping	1	$ 3,900.00	$ 3,900.00	Lawson Mills	-	-
Scale	1	$ 1,563.00	$ 1,563.00	Uline	OHAUS	H-2290
			Infrastructure			
3 Phase Power	1	$ 25,000.00	$ 25,000.00	NTPC	-	-
			Processing Tools			
Knifes	4	$ 11.40	$ 45.60	Uline		h-595
Staple Remover	3	$ 15.00	$ 45.00	Uline		h-289
Bins	4	$ 419.00	$ 1,676.00	Uline		H-1956 (700L)
Shipping	1	$ 1,000.00	$ 1,000.00	Est		

Misc.						
First Aid	2	$ 68.00	$ 136.00	Uline		H-5117
		Total	$ 70,465.60			

4.1.5 Fixed Running Costs

As mentioned in 2.1.1, space heating is a major cost concern in Inuvik. Although an operation as described does not require a very comfortable environment, it is important that the space be kept from freezing to ensure proper machine operation. A cold mill will take much longer to get up to working temperature, and frozen material will not behave as desired. The expected heat load required is 200GJ per year, putting the average heating cost at $463 per month.

Table 4-4 Summary of Fixed Running Costs

Item	Cost per month
Property Rent*	$ 2,500.00
Heating*	$ 1,800.00
Lighting	$ 96.40
Equipment Upkeep (10% per year)	$ 383.33
Total	$ 4,779.73
* Only for Independent Venture	

4.1.6 Variable Running Costs
The following sections describe the variable running costs associated with this project.

4.1.6.1 Mill Electricity Costs
The LMS303 cardboard shredder and the BN100 pelleting machine supplied by *Lawson Mills* are both rated at 10hp and both require 3-phase power. The machine runtime will depend on the quantity of cardboard successfully diverted. Running at 15kW and producing 250lbs per hour would mean that it would cost $110.70 per tonne in electricity to run the pellet mill. Building lighting and other systems are assumed to not exceed 1KW at max draw, making the electricity bill contribution about $96.40 per month.

4.1.6.2 Milling Labour Costs
The two main tasks that require manual labour are preprocessing the cardboard (removing staples and dangerous debris), and monitoring of the milling operation for quality control. The metric used to quantify the labour costs is the processing rate in pounds of cardboard per hour.

Monitoring the mill will be an important task to ensure the quality of the fuel pellet. The monitor may need to adjust the process additives on the fly to maintain pellet durability. Ideally, the mill will run at max capacity whenever it is switched on and so the labour costs associated with monitoring are directly related to the throughput of the mill.

There is a chance that during testing it is determined that the mill can run with very little human interaction apart from the initial setup. This would allow a reduction in labour costs as the monitor might also take part in preprocessing cardboard during the mills operation.

4.1.6.3 Milling Additives
The information presented in Section 3.2 suggests that the introduction of additives, specifically vegetable oil, to the feedstock will be mandatory to ensure the production of high quality pellets. The use of waste vegetable oil from food fryers as a pelletizing additive presents itself as an additional waste diversion strategy and removes the need of purchasing additives. Initially a variety of additives will need to be purchased to allow the best solution to be found for the exact conditions present in Inuvik. It is estimated that additive costs will not exceed $30 per tonne. Additives are regulated via the ENplus certification and cannot make up more the 2% by weight of the final pellet [18].

4.1.6.4 *Summary of Variable Running Costs*
A summary of the variable running costs is seen in Table 4-5.

Table 4-5 Variable Running Cost

Item	Cost Per Case/Unit	Cost per Tonne Produced
Mill Electricity Costs	$0.60 per kWh	$79.20
Milling Labour Costs	$18.00 per hour	$237.60
Milling Additives	n/a	$30.00
Total		$346.80

4.1.7 Cardboard Collection Program
Three possible cardboard collection programs are analyzed:

- Large producers of waste cardboard are provided a facility at which they can drop off cardboard at no cost. It is assumed that using a program such as this, there will be marginal costs inferred to the project.
- Secondly, there is the option of placing bins at the *Inuvik Solid Waste Facility* into which cardboard can be sorted when being delivered. Table 4-6 outlines the expected costs associated with landfill pickup collection program. This program is included in the business cases analyzed below.

Table 4-6 Collection Costs Associated with a Landfill Pickup

Assumes pickup from the dump		
Truck Registration	$150.00	yearly
Insurance	$600.00	yearly
Pickups	1	daily
Trip Length	10	km
Pickup Duration	1	hours
Fuel Efficiency	30	L/100km
Gas Price	$1.45	per liter
Fuel Cost	**$4.35**	per day
Driver Labour	**$24.67**	per day
Monthly Cost	**$683.46**	per month

- A collection program is offered to the large waste cardboard producers where a truck will travel to each location on a set schedule and pickup sorted waste cardboard.

Table 4-7 Collection Costs Associated with a Schedule Pickup

Assumes pickup at certain distributors.		
Truck Registration	$150.00	yearly
Insurance	$500.00	yearly
Pickups	4	daily
Trip Length	10	km
Pickup Duration	0.3	hours
Fuel Efficiency	20	L/100km
Gas Price	$1.45	per liter
Fuel Cost	**$11.60**	per day
Driver Labour	**$46.87**	per day
Monthly Cost	**$1,305.35**	per month

4.1.8 Summary of Business Case Analysis

Table 4-8 outlines the results of the business case analysis. A sponsored cardboard pellet manufacturing operation is expected to be profitable. For more details of the analysis, refer to Appendix 9.9.

Table 4-8 Business Case Analysis Outputs

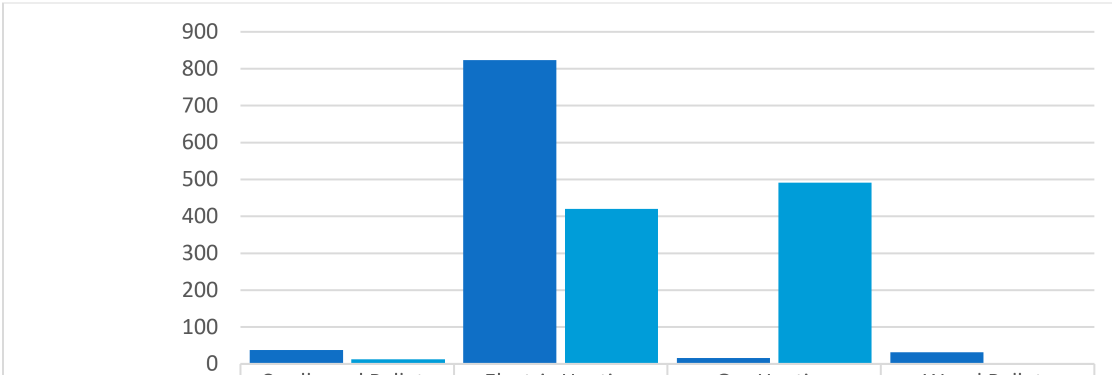
Model	Monthly Profit
Independent Business with Cardboard Drop-off	-$2,100.00
Independent Business with Landfill Collection	-$1,420.00
Sponsored Business with Cardboard Drop-off	$140.00
Sponsored Business with Landfill Collection	$820.00

4.1.9 Business Case Analysis Conclusions

From the results of the above analysis, finding a local industry partner with existing infrastructure to take over the pellet mill operation will be a crucial factor in determining the economic viability of running the pellet mill.

4.2 Fossil Fuel Reduction

Figure 4-2 shows the fossil fuel requirements of different heating sources. The values presented are the amount of fuel required to deliver to Inuvik the same heating energy as would be produced by one tonne of cardboard pellets. The cardboard pellets section is therefore self-referential and describes the fossil fuel requirements to produce one tonne of cardboard pellets. It is important to note that the analysis used to generate the above graph only analyses the late supply chain fuel requirements. For simplicity, this calculation ignores the fuel requirements of each heating source originating before Whitehorse, Yukon (British Colombia in the case of wood pellets) and their extraction and processing. This means the true fossil fuel use of other sources is understated below.



	Cardboard Pellets	Electric Heating	Gas Heating	Wood Pellets
Diesel Usage (L)	37	824	16	32
SNG Usage (m3)	13	420	492	0

Figure 4-2 Fossil fuel required to deliver the equivalent heating of one tonne of cardboard pellets to Inuvik.

As shown in Figure 4-2, cardboard fuel pellets are the second lowest fossil fuel users out of the four heating sources analyzed. See Appendix 9.7 Fossil Fuel Diversion Effects for details about the analysis.

4.3 Emission Reduction

Figure 4-3 shows the Carbon Dioxide emissions of different heating sources. The calculated values take into account the emissions from the transport of fuels into Inuvik, generation of electrical power, combustion of fuels, and landfill decomposition. Appendices 9.6 and 9.7 provide more details on the determination of these values.

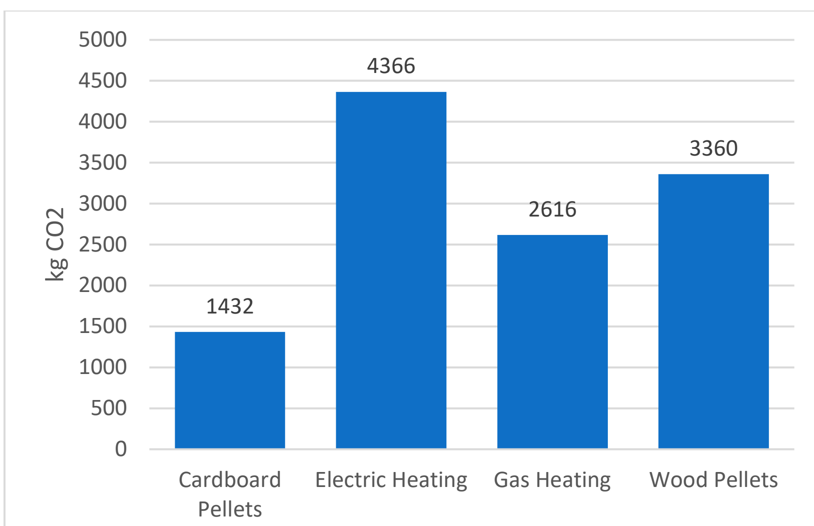


Figure 4-3 Calculated Carbon Dioxide released to deliver the same heating as one tonne of cardboard fuel pellets.

As shown in Figure 4-3 the use of cardboard pellets will have the lowest Carbon Dioxide emissions.

5 RISKS AND MITIGATIONS

The following summarizes questions and concerns that could not be answered with a high degree of certainty during the creation of this feasibility report or that pose a long-term threat to the project as a whole.

5.1.1 Technical Concerns

- What is the sintering temperature of the ash produced by the cardboard pellet fuel?
- What is the chemical composition of the ash produced by the cardboard pellet fuel?

5.1.2 Economic Concerns

- Fluctuation in Wood Pellet Prices: As momentum towards wood pellet burning grows, there is a possibility for the prices of wood pellets to drop as usage increases. With government action plans outlining the move to biomass, competition in the biomass market will increase. The *Arctic Energy Alliance* states that pellet prices could fall to below $300 per tonne if large enough quantities are demanded in the Inuvik market [13]. Without the monetization of the supply chain or availability of subsidization related to solid waste diversion, a drop in price of this magnitude would erode profitability of cardboard pellet operations.

6 Proposed Implementation Plan

Collaboration with an existing industry partner in Inuvik was critical in the design of a project to manufacture and test waste cardboard fuel pellets. The business cases outlined in Section 4.1 found that the project would have to be sponsored by an industry partner to be profitable.

6.1 Industry Partner

Delta Enterprises came forward with interest in collaborating to design and implement a project around the creation of waste cardboard fuel pellets in Inuvik.

6.2 Timeline

The proposed project will start on Dec 1 2017 and terminate March 31 2019. The project is broken into three main sections, preparation, testing, and steady state operation, with the installation of a pellet being planned for before March 31 2018.

Figure 6-1 shows an approximate timeline for the pellet project. They are briefly described in the following sections.

Figure 6-1 show a sample timeline of the project.

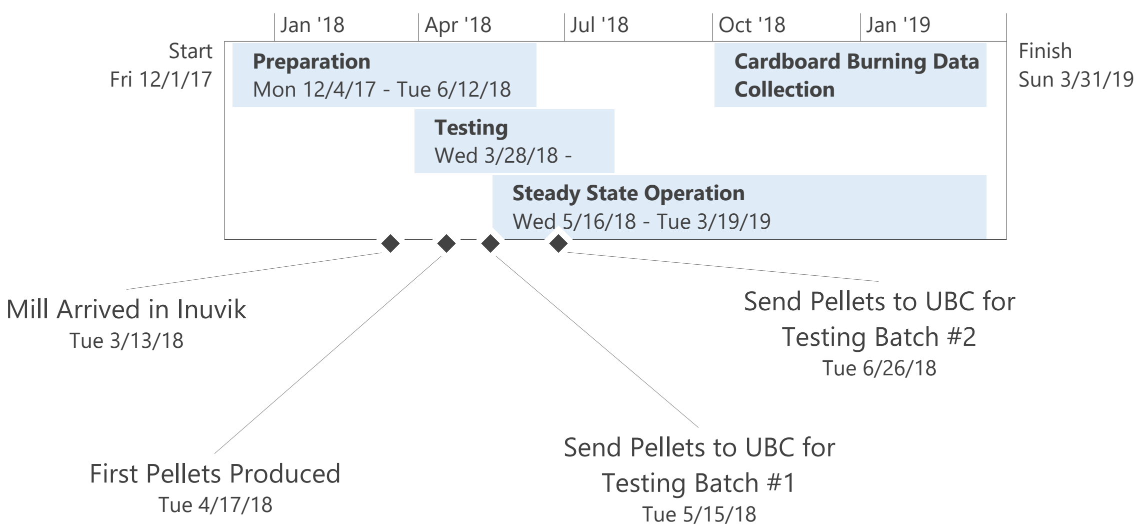


Figure 6-1 Proposed Project Timeline

6.2.1 Preparation

During the preparation phase of the project, project related materials would be purchased training facilitated. The intended pellet mill will be purchased from Lawson Mills (to date the only identified Canadian manufacturer of appropriate commercial pellet mills of this scale) who will provide delivery and a technician for three days to train staff operating the mill. The intended mill site will also be adapted, specifically installing 3-phase power if not already present.

The preparation phase is expected to take about 20 weeks to complete.

6.2.2 Testing

The goal of the testing phase is to create a pelleting procedure that consistently works in the specific environment of Inuvik. The pelleting procedure will be guided by the training provided by Lawson Mills along with the data presented in Section 2.2.2.3.

Two supporting documents titled “*Cardboard Pelleting Data Collection*” and “*Cardboard Pellet Burning Data Collection*” will be created to inform testing procedures. It is expected that pelleting testing will not take longer than 3 weeks, while burn testing will be distributed over 3 months.

After the successful creation of fuel pellets, select batches will be sent to the University of British Colombia’s Biomass and Bioenergy Research Group (BBRG) for certification testing.

The testing phase will also see the move to full-scale cardboard collection.

6.2.3 Steady State Operation

This phase will consist of the Industry partner, Delta Enterprises, continuing to operate the pellet mill at the maximum achievable cardboard diversion rate. Additional cardboard burning test will also take place during this time.

6.3 Metrics for Success

The following sections outline goals that all contribute to the project being considered successful.

6.3.1 Local Capacity Building

Creating employment and training opportunities in a remote community such as Inuvik has a great impact on the local economy.

6.3.2 Displacement of Fossil Fuel

Although it will be difficult to gather specific data on how much fossil fuel is being diverted, singular cases or instances where cardboard pellets have either displaced existing wood pellets or provided a social incentive to transition to pellet burning will be analyzed and considered towards the success of the project.

6.3.3 ENplus Certification Standards

Ideally, the waste cardboard pellets will conform as closely as possible to the ENplus certification standard, either in a pure or mixed form.

7 Recommendations and Conclusions

From the information gathered and analysis performed during the creation of this report, the following conclusions and recommendations were drafted.

7.1 Technical Conclusions

Based on experience of other producers, pellets from waste cardboard represent a viable product. The burning of cardboard pellets is also confirmed to be viable in commercial and residential boilers, but testing is required to determine the preferred mixing ratio. Ash sintering concerns is expected to be the primary driver of a low mixing ratio. Testing performed during the project will be needed to gain further insight into the performance of mixed wood-cardboard fuel.

7.2 Environmental Conclusions

The diversion of cardboard from the landfill for the manufacture of fuel pellets is expected to produce the lowest Carbon Dioxide emissions of any available fuel source and represents a net benefit to the current disposal of cardboard. The manufacturing of the fuel pellets requires electricity generated by diesel and SNG, but there is potential for renewable energy sources to be used to manufacture the cardboard pellets, decreasing both the associated diesel use, and Carbon Dioxide emissions.

7.3 Economic Conclusions

The scale of this project is simply not large enough for it to act as a stand-alone venture. The successful business case is one in which an existing entity takes on the pellet mill in addition to normal business operations, thus diluting the infrastructure costs of the project. The project has the potential of creating several part-time employment opportunities for the operation of the pellet mill itself.

7.4 Recommendations

- Pursue funding to establish a pellet mill in Inuvik.
- Investigate co-firing opportunities with other waste materials to expand the capacity of local energy production.

Future considerations also include:

- Investigate anaerobic digestion of cardboard and paper waste in a dry digester as a possible fuel production method and landfill diversion technique. During the research into landfill emissions, several documents pointed toward bio-digestion as another option to claim energy from waste cardboard and paper products.
- Investigate other uses to increase the duty cycle of the installed equipment, such as pelletizing locally harvested biomass. An increased duty cycle will reduce the per-tonne capital cost component of the project.
- Investigate the collection of back-haul waste cardboard from road accessible communities surrounding Inuvik.

8 ACKNOWLEDGEMENTS

The Aurora Research Institute would like to thank the following people and businesses for participating in the test cardboard collection program:

- Inuvik Regional Hospital
- Stanton's Distributing
- Town of Inuvik
- Arctic Energy Alliance
- Government of the Northwest Territories, Infrastructure, Energy Division

9 APPENDICES

9.1 THEORETICAL WASTE CARDBOARD PRODUCTION

The average person living in the Northwest Territories generates $0.015\frac{m^3}{person}$ per day of landfill material [40]. This landfill material contains on average 9.8% cardboard by volume [41]. This data, along with the density of uncompressed cardboard (30-90$\frac{kg}{m^3}$ [42]) and the population of Inuvik at 3100 [12] allows for an expected value of cardboard waste to be calculated as 273kg as seen in Equation 9-1.

Equation 9-1 Daily Cardboard Mass Estimation in Inuvik

$$m_{cardboard} = V_{waste}(f_{cardboard})(\rho_{cardboard})(pop)$$

$$m_{cardboard} = (0.015\frac{m^3}{person})(0.098)(60\frac{kg}{m^3})(3100 persons)$$

$$m_{cardboard} = 273kg$$

A similar process can be accomplished for the communities surrounding Inuvik (total population of 2860 persons [12]) as seen in Equation 9-2.

Equation 9-2 Daily Cardboard Mass Estimation in Surrounding Communities

$$m_{cardboard} = (0.015\frac{m^3}{person})(0.098)(60\frac{kg}{m^3})(2860 persons)$$

$$m_{cardboard} = 208kg$$

9.2 TEST CARDBOARD WASTE COLLECTION PROGRAM

9.2.1 Purpose

In order to gain an understanding on the quantity, condition, and accessibility of waste cardboard in Inuvik, a test cardboard collection program was carried out during the summer of 2017 and more intensely during October 2017. This collection program was developed to answer the following questions:

- Does the statistical value of 273kg of waste cardboard per day coincide with the values found during this study?
- Is the waste cardboard accessible/easily divert-able?
- What percent by weight of the average box is non-fibrous material?
- How long does it take to remove all the tape and labels from the average box? (pounds processed per hour)
- How often do the boxes contain materials, such as staples, that can damage a pellet mill?
- How long does it take to inspect the boxes for dangerous materials?

9.2.2 Procedures

Several major waste cardboard producers in Inuvik were contacted. They were asked if they could allow ARI staff to pick up their waste cardboard on a scheduled basis.

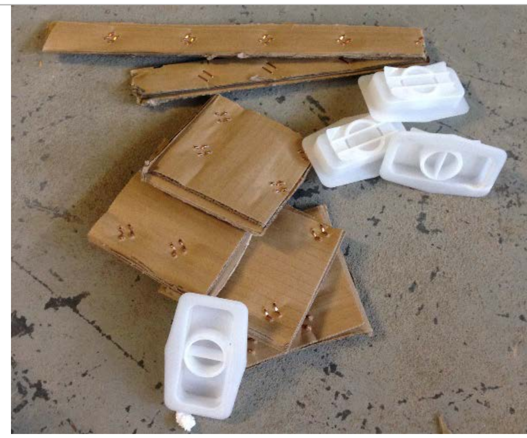
Six test batches of cardboard were randomly selected for non-fibrous material removal. The amount of non-fibrous material removed was recorded in order to calculate a percent composition by weight (%wt).

9.2.3 Qualitative Results

Table 9-1 outlines the qualitative data from the cardboard collection program.

Table 9-1 Qualitative Results of the Cardboard Collection Program

As-Received Cardboard Figure 9-1 shows the average as-received cardboard from the collection program.	 *Figure 9-1 As-Received Cardboard from the Inuvik Regional Hospital*
Tape and Labels As Figure 9-2 shows, it proved impossible to mechanically remove only the non-fibrous material while leaving the bulk of the cardboard unscathed. When removing tape and labels, sections of the boxes were often removed as well. This introduced an over estimation when trying to determine the mass of non-fibrous materials on the boxes. Some produce boxes contained no tape and so were fast to process while some heavier boxes were very tape reinforced.	 *Figure 9-2 Sample of removed labels and tape.*

Dangerous Material Some larger boxes, in the case of Figure 9-3, a washing machine box, contained staples and large plastic hardware. This material would have to be cut out of the boxes to avoid damage to the pellet mill.	 *Figure 9-3 Sample Dangerous Material*

9.2.4 Quantitative Results

Table 9-2, Table 9-3, and Table 9-4 present the results of the cardboard collection program along with the average mass of waste cardboard per day taking into account the length of the collection period.

Table 9-2 ARI Cardboard Waste Measurement Program Data

Month	Date	Mass (lbs.)
May	1st	13.5
May	3rd	16
May	11th	21
June	2nd	21.8
June	13th	42.2
July	6th	17.8
July	18th	54.8
July	27th	42
August	3rd	27.2
August	18th	53.8
August	24th	35.8
September	7th	20.74
September	15th	5.46
October	19th	12.8
Total		384.9
Average per day		2.25

Table 9-3 Beaufort Delta Regional Hospital Cardboard Waste Measurement Data

Month	Date	Mass (lbs.)
Sept	25th	71.06
Sept	26th	20.02
Sept	27th	49.15
Sept	28th	40.20
Sept	29th	70.00
Oct	2nd	70.00
Oct	3rd	61.90
Oct	4th	39.26
Oct	5th	19.20
Oct	6th	31.56
Total		472.35
Average per day		39.36

Table 9-4 Stanton Distributing Cardboard Waste Measurement Data

Month	Date	Mass (lbs.)
Oct	4th	98.7
Oct	6th	110.4
Total		209.1
Average per day		52.3

Table 9-5 summarizes the results of the non-fibrous material removal of six randomly selected batches of cardboard.

Table 9-5 Non-fibrous material composition

Mass of as received cardboard (lbs.)	Mass of non-fibrous material removed (lbs.)	%wt. Removed
71.06	1	1.4%
49.15	0.3	0.6%
18.42	0.02	0.1%
25.8	0.22	0.9%
19.2	0.42	2.2%
5.5	0.04	0.7%
	Average:	1.0%

9.2.5 Analysis

The cardboard diverted from Stanton Distributing represents about 50% of the cardboard they produce; High quality cardboard boxes are given to customers instead of plastic shopping bags. These two mechanisms result in the cardboard then being disposed of in a residential context that is more difficult to divert.

As mentioned in above in Section 9.2.3, the measured average weight of non-fibrous material shown in Table 9-5 is most likely an overestimate due to the difficulty of removing only the non-fibrous material.

Diverting waste cardboard from the participants in this test collection program would create a cardboard diversion of about 15%. See Table 9-6.

Table 9-6 Diversion factors per institution

Location	Average per day (lbs.)	Diversion Percentage
Stanton Distributing	52.3	8.7%
Inuvik Regional Hospital	39.36	6.6%
Aurora Research Institute	2.25	0.3%

The average processing rate for the removal of non-fibrous material was found to be 94.6 pounds per hour, see Table 9-7. The fluctuation in the data points reflects the difference in processing times based on the type of container being processed.

Table 9-7 Non-fibrous material processing times

Cardboard Weight	Processing Time	Processing Rate
71.06 lbs.	55min (0.93hr)	76.6 lbs./hr.
49.15 lbs.	20min (0.33hr)	146.5 lbs./hr.
5.46 lbs.	5.5min (0.09hr)	60.7 lbs./hr.
	Average:	94.6 lbs./hr.

In the entirety of the test collection program, only one box was found to contain staples. The same box also contained plastic shipping brackets. Both of these items needed to be removed with a knife to better represent the processing load they would place on the pellet mill.

9.3 Wood Pellet Fuel Properties

Regulatory bodies such as ENPlus provide certification programs for wood pellets available for residential use. This need arises from the variation in fuel properties possible between pellet manufacturers, and the biomass stream used to manufacture the pellets. ENPlus certifications guarantee that pellets have certain baseline properties to ensure safe usage [43]. Table 9-8 illustrates the variation in wood pellet fuel properties from different suppliers and sources.

Table 9-8 Wood Pellet Properties from Manufacturers / Laboratories.

Parameter	**Source**	Value	Unit
Heating Value (LHV)	ECN	19.83	MJ/kg
Heating Value (HHV)	ECN	18.31[2]	MJ/kg
Heating Value	Pinnacle Pellet SPF	>17	MJ/kg
Heating Value	Pinnacle Pellet Fir	>18	MJ/kg
Ash Content	ECN	0.50%	By weight
Density	Pinnacle Pellet	650	kg/m^3

Table 9-9 outlines the most important parameters in the ENplus pellet certification standard. A1, A2, and B represent the pellet certifications in decreasing order of performance. A1 pellets are intended to be the cleanest burning, producing the least ash and containing the least containments and are most often recommended for residential usage.

[2] It is not clear why the HHV listed by ECN is lower than the LHV.

Table 9-9 Threshold Values of the Most Important Pellet Properties [18]

Property	Unit	EN*plus* A1	EN*plus* A2	EN*plus* B	Testing standard [11]
Diameter	mm	6 ± 1 or 8 ± 1			ISO 17829
Length	mm	3,15 < L ≤ 40 [4]			ISO 17829
Moisture	w-% [2]	≤ 10			ISO 18134
Ash	w-% [3]	≤ 0,7	≤ 1,2	≤ 2,0	ISO 18122
Mechanical Durability	w-% [2]	≥ 98,0 [5]	≥ 97,5 [5]		ISO 17831-1
Fines (< 3,15 mm)	w-% [2]	≤ 1,0 [6] (≤ 0,5 [7])			ISO 18846
Temperature of pellets	°C	≤ 40 [8]			
Net Calorific Value	kWh/kg [2]	≥ 4,6 [9]			ISO 18125
Bulk Density	kg/m^3 [2]	600 ≤ BD ≤ 750			ISO 17828
Additives	w-% [2]	≤ 2 [10]			-
Nitrogen	w-% [3]	≤ 0,3	≤ 0,5	≤ 1,0	ISO 16948
Sulfur	w-% [3]	≤ 0,04	≤ 0,05		ISO 16994
Chlorine	w-% [3]	≤ 0,02		≤0,03	ISO 16994
Ash Deformation Temperature[1]	°C	≥ 1200	≥ 1100		CEN/TC 15370-1
Arsenic	mg/kg [3]	≤1			ISO 16968
Cadmium	mg/kg [3]	≤ 0,5			ISO 16968
Chromium	mg/kg [3]	≤10			ISO 16968
Copper	mg/kg [3]	≤10			ISO 16968
Lead	mg/kg [3]	≤10			ISO 16968
Mercury	mg/kg [3]	≤ 0,1			ISO 16968
Nickel	mg/kg [3]	≤10			ISO 16968
Zinc	mg/kg [3]	≤100			ISO 16968

[1] ash is produced at 815 °C
[2] as received
[3] dry basis
[4] a maximum of 1% of the pellets may be longer than 40mm, no pellets longer than 45mm are allowed.
[5] at the loading point of the transport unit (truck, vessel) at the production site
[6] at factory gate or when loading truck for deliveries to end-users (*Part Load Delivery* and *Full Load Delivery*)
[7] at factory gate, when filling pellet bags or sealed *Big Bags*.
[8] at the last loading point for truck deliveries to end-users (*Part Load Delivery* and *Full Load Delivery*)

[9] equal ≥ 16,5 MJ/kg as received
[10] the amount of additives in production shall be limited to 1,8 w-%, the amount of post-production additives (e.g. coating oils) shall be limited to 0,2 w-% of the pellets.
[11] As long as the mentioned ISO standards are not published, analyses shall be performed according to related CEN standards

9.4 Cardboard Properties

Similar to wood pellets (see Appendix 9.3) there is no single data set for the combustion properties of cardboard. A large proportion of the cardboard combustion data acquired for this report was part of various biomass energy studies [29] [32] [33] [44]. Table 9-10 summarizes the cardboard combustion properties researched during this report.

Table 9-10 Cardboard Pellet Properties

Parameter	Value	Unit	Source	Note
LHV	13.69	MJ/kg	ECN	unprocessed
LHV	15.38	MJ/kg	University of North Dakota	pelletized
HHV	14.77	MJ/kg	ECN	unprocessed
HHV	16.9	MJ/kg	NTNU	unprocessed
HHV	16.9	MJ/kg	University of North Dakota	pelletized
Ash Content	10.3%	by weight	ECN	unprocessed
Ash Content	8.4%	by weight	NTNU	unprocessed
Ash Content	0.98%	by weight	University of North Dakota	pelletized
Density	649	kg/m3	University of North Dakota	pelletized

9.4.1 The Effect of Pelletizing the Fuel on Ash Content

Only a single data point was located for the previous burning of cardboard in pellet form and that was by T. A. Moe at the University of North Dakota in 1995. T. A. Moe stated an ash content of 0.98% for the cardboard fuel pellets they created [45], considerably lower than the values listed by ECN and NTNU. *A Review of Pellets from Different* Sources by *Teresa Miranda et al.* analyzed the ash content of pellets made from a variety of other sources, including fruit and herbaceous biomass. The reported ash values ranged from 2.5% up to 10.51% by weight [46]. Figure 9-4 shows no clear relationship between bulk density and ash content. With this in mind it, the variation in cardboard ash contents listed by a variety of different sources must be a result of a factor other than bulk density and so the lower value published from the pelleted cardboard cannot support the conclusion that pelletizing reduces the ash content of the fuel.

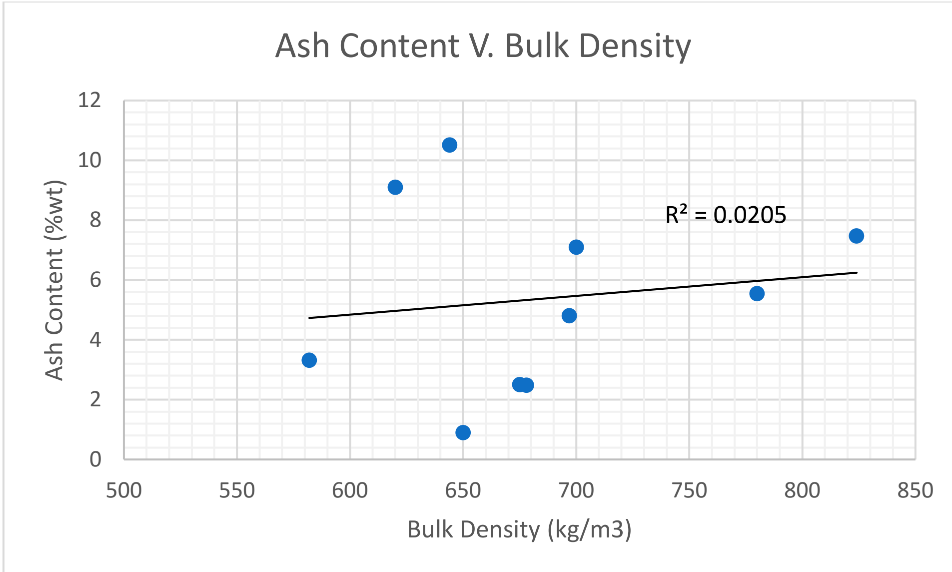


Figure 9-4 Ash Content versus Bulk Density for a variety of different biomass pellets [46]

9.5 Cardboard and Miscanthus Comparison

Miscanthus is a genus of tall-grasses native to subtropical and tropical regions that has recently gained attention as a possible biomass fuel source [47]. In terms of creating fuel pellets from Miscanthus, many of the same problems are encountered as with cardboard, low lignin content, low bulk density of feedstock, and lower initial moisture content (<20%) [16]. It is assumed that these similarities allow for the pelletizing of Miscanthus to provide insight into the pelletizing of cardboard.

The following sections describe conclusions based on Miscanthus that can possibly be applied to cardboard pelleting:

9.5.1 Moisture Content and Temperature

Miscanthus is usually harvested at low moisture contents (about 20%) and so seldom requires drying [16]. Ideal pelleting moisture content for Miscanthus is higher, at 25%, compared to the 10-12% for wood biomass. The addition of moisture for pelleting also has the effect of lowering the glass transition temperature of lignin, allowing for lower pelleting temperatures [16].

Cardboard moisture content can vary dramatically depending on exposure to different environments. The Energy Research Centre of the Netherlands gives the average as-received moisture content of cardboard involved in their combustions tests at 5.4% by weight [29]. It is assumed that cardboard will also require moisture additives (up to 25%) before pelleting.

The ideal temperature inside the pellet mill is 105 degrees Celsius for Miscanthus [48] [16]. It is assumed that with the increased moisture content of the cardboard, that a similar milling temperature will be required.

9.5.2 Binding

According to the *Department of Agro-Ecology* [16], cereal straws usually contain lignin levels below 20%, and as a result produce low durability pellets. A study of blended sawdust and Miscanthus pellets used 2% potato starch as an additive to gain a pellet durability of 97.5% [16].

As-received cardboard, on average, has a lignin content that is too low for high quality pellet manufacturing. Cardboard Lignin content ranges from 10-16.6% [44].

9.5.3 Bulk Density and Densification

As-harvested Miscanthus has a bulk density of around 40 kg/m3 [16] which rises to 220-300kg/m3 [48] when ground. This as-harvested value aligns with the as-received cardboard densities of 60-90kg/m3 [42].

9.5.4 Processing Variables

Table 9-11 compares the processing variables used for Scots Pine and Miscanthus. The values listed for Miscanthus will form the base case for pelleting testing as described in Appendix 9.5.

Table 9-11 Comparison of Miscanthus and Scots Pine Size Reduction and Pelleting Parameters [48] [16]

Material	Screen Used	Ideal Particle Size	Pellet Diameter
Scots Pine	4mm	1-2mm	8mm
Miscanthus	3mm	3-6mm	8mm

9.6 Landfill Effects

9.6.1 Purpose

To determine the change in greenhouse gas emissions resulting from burning cardboard fuel pellets instead placing the cardboard in a solid waste facility.

9.6.2 Procedures

The two sources of GHG emissions associated with the use of waste cardboard fuel pellets are the emissions from the electricity generation and the emissions from the actual combustion of the fuel. Placing waste cardboard in a landfill does not involve a combustion process but still contributes to emissions through the anaerobic decomposition process of the cardboard itself [49].

eCO_2 or equivalent Carbon Dioxde is a constructed value used to correct for the different greenhouse effectiveness of common emission gasses. For instance 1 tonne of N_2O has a value of 298 tonnes of eCO_2, as 1 tonne of N_2O released into the atmosphere would have the same greenhouse effect at 298 tonnes of CO_2 [50].

9.6.3 Results

Cardboard under the anaerobic conditions present in a landfill, will decompose to release CO_2 and CH_4 in about equal quantities [51]. Methane gas (CH_4) is roughly 25 times more effective as a greenhouse gas than Carbon Dioxide (CO_2) [50].

ICF Consulting created a report for *Environrment Canada* titled *Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions* in which various waste management programs were compared to conventional landfill programs. Table 9-12 shows a excerpt from the report results. It lists tonnes of eCO_2 released per tonne of cardboard for three landfill alternatives, that is, emissions relative to simply landfilling the cardboard.

Table 9-12 GHG Emissions for specific management options relative to landfill solid waste management program for cardboard. (Tonnes eCO_2 per tonne of cardboard) [49]

Recycling	Anaerobic Digestion	Combustion
-3.54	-0.60	-0.33

Table 9-12 shows that recycling cardboard has the greatest impact when it comes to reducing greenhouse gas emissions. This is mainly due to the forest area that remains untouched due to the recycled cardboard mitigating the need for new cardboard to be manufactured. When analyzing both the Anaerobic Digestion and Combustion options, new cardboard still needs to be manufactured, and so the GHG emission reduction will never be as high as recycling.

Table 9-12 also shows that combusting the cardboard released less eCO_2 than simply placing the cardboard in the landfill. This is primarily due to the elevated greenhouse effectiveness of the CH_4 released during decomposition.

9.6.4 Conclusions

Diverting waste cardboard for the purpose of combustion has a positive effect on greenhouse emissions.

9.7 Fossil Fuel Diversion Effects

9.7.1 Purpose

The goal of this analysis is to try to determine the quantity of fossil fuels diverted by changing from existing heating methods to the burning of waste cardboard pellet fuels to meet space-heating needs.

9.7.2 Procedure

Each heating source and required supply chain were analyzed to determine three values, the quantity of fossil fuels required to deliver a unit of heat energy ($\frac{L}{MJ}$ or $\frac{m^3}{MJ}$), the specifically defined, space heating ratio ($\frac{GJ}{GJ}$), and the carbon dioxide emissions ($kg\ CO_2$). The space-heating ratio is defined as the total heat energy delivered per unit fossil fuel consumed in the supply of that heat.

9.7.2.1 Heat Energy Comparison

In order to compare the fossil fuel usage of each heating method, an energy equivalency is used. This energy equivalence calculates what quantity of fossil fuels are required to deliver a unit of heating energy to an Inuvik based heat load. The unit of heating energy was selected to be the estimated heat energy generated by 1 tonne of cardboard pellets, about 15.8MJ.

9.7.2.2 Fuel Usage and Emissions Locations

The following sections describe the emissions sources that were taken into account for each source of heat energy. The fossil fuel requirements of each heating source was analyzed separately.

9.7.2.2.1 Wood Pellets

Importing wood pellets to Inuvik from pellet mills in British Columbia or Alberta requires the use of diesel powered transport trucks. The two emissions sources are the exhaust from the transport trucks, and the combustion of the pellets themselves.

9.7.2.2.2 Cardboard Pellets
The three emissions sources for cardboard pellets are the transport of fuels into Inuvik, electricity generation, and the combustion of the pellets themselves. The emissions related to the initial transport of cardboard to Inuvik is not taken into account as it is assumed that the operation of a waste cardboard diversion program will not have any effect on the net amount of cardboard being brought into the community. As a result, the emissions associated with the cardboard arriving in Inuvik would penalize all heating sources and would not need to be calculated for comparison. This also means that a proportional analysis, i.e. electric heating produces double the greenhouse gases of cardboard pellets, is also not possible, as the total emissions are not being calculated.

9.7.2.2.3 Electric Heating
The fossil fuel usage and emissions sources for electric heating are the transport of fuel for electricity generation into Inuvik and running the electricity generation plant on these fuels.

9.7.2.2.4 Gas Heating
The fossil fuel usage and emissions sources for gas heating are the transport of SNG into Inuvik and the combustion of SNG in boilers.

9.7.2.2.5 Greenhouse Gas Emissions
The analysis uses each combustion step in the delivery of a certain heating style to generate the total emissions of that heating source. As with the fossil fuel usage, the energy of equivalence of one tonne of cardboard pellets is used for comparison.

9.7.2.3 Landfill Penalty
As described in Appendix 9.6, cardboard placed in a landfill can produce more greenhouse gas emissions than cardboard that is burned for energy recovery. To correctly represent the effects of placing the waste cardboard in the landfill, all heating styles other than the use of cardboard pellets include the emissions generated by the cardboard being placed in the landfill.

9.7.3 Input Data
Table 9-13 outlines all the input data used in the calculations of fossil fuel usage and Carbon Dioxide emissions. The values shown as being calculated are included here as they are simple composites of other input data. These values are also restated near where they are used.

Table 9-13 Input Parameters

Parameter	**Value**	**Unit**	**Model Usage**	**Source**
SNG Density (gas)	0.736	kg/m3	All except Wood Pellet	Marks' Standard Reference
SNG Density (liq)	460	kg/m3	All except Wood Pellet	LNG Basics
SNG Energy Density	50	MJ/kg	All except Wood Pellet	Marks' Standard Reference
SNG Volumetric Energy Density (gas)	36.8	MJ/m3	All except Wood Pellet	Calculated
Diesel Density	880	kg/m3	All	Marks' Standard Reference
Diesel Energy Density	44.8	MJ/kg	All	Calculated
Diesel Volumetric Energy Density	39.4	MJ/L	All	Calculated
Truck Fuel Efficiency	57.6	L/100km	All	Natural Resources Canada
Tanker Capacity Diesel	43900	L	All except Wood Pellet	Natural Resources Canada
Tanker Capacity SNG	35.5	m3	All except Wood Pellet	Prometheus Energy
B-Train Truck Capacity	43	tonnes	Wood Pellet	Arctic Energy Alliance
Whitehorse Distance	1226	km	All except Wood Pellet	Google Maps
Pinnacle Pellet Distance	2617	km	Wood Pellet	Google Maps
Wood Pellet Heating Value	17	MJ/kg	Wood Pellet	Pinnacle Energy
Cardboard Pellet Heating Value	15.4	MJ/kg	Cardboard Pellet	University of North Dakota
Boiler Efficiency	0.85	none	Gas Heating	Cleaver Brooks
Diesel Generation %	67%	percentage	All except Wood Pellet	NTPC
SNG Generation %	33%	percentage	All except Wood Pellet	NTPC
Pellet Mill Power	15	kW	Cardboard Pellet	Lawson Mills
Pellet Mill Throughput	250	lb per hour	Cardboard Pellet	Lawson Mills
CO2 emissions from diesel	2.70	kg/L	Diesel Offset	Emissions Factors
CO2 emissions from SNG	1.18	kg/L	Diesel Offset	Emissions Factors
CO2 emissions from Wood	1.80	kg/kg	Diesel Offset	Emissions Factors
CO2 emissions from Cardboard	1.32	kg/kg	Diesel Offset	Calculated

9.7.4 Calculations and Results

9.7.4.1 Calculation of Fossil Fuel Consumption and Space Heating Ratio

Table 9-14 Fossil fuel usage for Cardboard Pellets Part 1

Parameter Name	Value	Unit	Source
Mill Usage Section			
Mill Runtime	8.8	hr per tonne	Lawson Mills
Mill Power	27.0	kW	Lawson Mills
Electricity Usage Total	237.6	KWh per tonne	Calculated
Power Generation from Diesel Section			
Generator Efficiency	0.33		NTPC
Diesel Energy Density	44.8	MJ/kg	Marks
Diesel Density	880	kg/m3	Marks
Electricity Usage From Diesel	159.2	KWh per tonne	Calculated (67%)
Generator Input Energy	1748000	MJ per tonne	Calculated
Diesel Burned per tonne for Power Generation	66.2	L per tonne	Calculated
Diesel Burned per GJ for Power Generation	4.30	L per GJ	Calculated
Diesel Transport Section			
Truck Fuel Efficiency	57.6	L/100km	Natural Resources Canada
Transportation Distance	1226	km	Google Maps
Tanker Capacity	43900	L per trip	Natural Resources Canada
Pellet Heating Value	15.4	MJ/kg	Calculated
Pellet Tonnage per tanker trip	663.0	tonnes per tanker	Calculated
Diesel Burned per trip	706	L per trip	Calculated
Diesel Burned per tonne for Diesel Transport	1.065	L per tonne	Calculated
Diesel Burned per GJ for Diesel Transport	0.0693	L per GJ of pellet	Calculated
Total Diesel Burnt per GJ	4.4	L per GJ of pellet	Calculated
Total Diesel Burnt per Tonne	67.30	L per tonne	Calculated

Table 9-15 Fossil fuel usage for cardboard pellet heating Part 2

Parameter Name	Value	Unit	Source
Power Generation from LNG Section			
Generator Efficiency	0.33	none	NTPC
LNG Energy Density	50	MJ/kg	Marks Standard
LNG Density (liq)	460	kg/m3	Marks Standard
Electricity Usage From Natural Gas	78.4	KWh per tonne	Calculated (33%)
Generator Input Energy	860000	MJ per tonne	Calculated
LNG Burned per tonne for power generation (gas)	23.36	m3 per tonne	Calculated
LNG Burned per GJ (gas)	1.52	m3 per GJ	Calculated
LNG Mass Required	1.12	kg per GJ	Calculated
LNG Volume Required (liq)	0.0024	m3 per GJ	Calculated
LNG Transport Section			
Truck Fuel Efficiency	57.6	L/100km	Lawson Mills
Transportation Distance	1226	km	Google Maps
Tanker Capacity	35.5	m3 per trip	Prometheus Energy
Pellet Heating Value	15.38	MJ/kg	University of North Dakota
Diesel Burned	706	L per trip	Calculated
Pellet Tonnage per tanker trip	14600	tonnes per tanker	Calculated
Diesel Burned per tonne for SNG Transport	0.05	L per tonne	Calculated
Diesel Burned per GJ for SNG Transport	0.003	L per GJ of pellet	Calculated
Total Diesel Burnt per GJ	4.38	L per GJ of pellet	Calculated
Total SNG (gas)	1.52	m3 per GJ	Calculated
Total Energy	0.228	GJ Fossil per GJ Heat	Calculated
Space Heating Ratio	4.4	GJ Heat per GJ Fossil	Calculated

Table 9-16 Fossil fuel usage for electric heating

Parameter	**Value**	**Unit**	**Source**
Power Generation Section			
Electricity Needs	278	KWh/GJ	1GJ is equal to 278 KWh
Diesel Required	52	L per GJ	Calculated
SNG Volume Required (gas)	27	m3 per GJ	Calculated
SNG Mass Required	20	kg	Calculated
SNG Volume Required (liq)	0.044	m3 per GJ	Calculated
Diesel Transport Section			
Truck Fuel Efficiency	57.6	L/100km	Natural Resources Canada
Transportation Distance	1226	km	Google Maps
Tanker Capacity	43900	L per trip	Natural Resources Canada
Heating Energy per tanker	847	GJ per tanker	Calculated
Diesel Burned	706	L per trip	Calculated
Diesel Burned per GJ	0.83	L per GJ	Calculated
LNG Transport Section			
Truck Fuel Efficiency	57.6	L/100km	Natural Resources Canada
Transportation Distance	1226	km	Google Maps
Tanker Capacity	35.5	m3 per trip	Prometheus Energy
Diesel Burned	706	L per trip	Calculated
Tanker Capacity	812	GJ/tanker	Calculated
Diesel Burned per GJ	0.87	L per GJ	Calculated
Total Diesel	53.5	L per GJ	Calculated
Total SNG (gas)	27	m3 per GJ	Calculated
Space Heating Ratio	0.32	GJ Heat per GJ Fossil Fuel	Calculated

Table 9-17 Fossil fuel usage for gas heating

Parameter	**Value**	**Unit**
Heat Generation Section		
Boiler Efficiency	0.85	none
SNG Energy Required	1180	MJ
SNG Mass Required	24	kg
SNG Volume Required (liq)	0.051	m3
SNG Volume Required (gas)	32.1	m3
SNG Transport Section		
Truck Fuel Efficiency	57.6	L/100km
Transportation Distance	1226	km
Tanker Capacity	35.5	m3 per trip
Diesel Burned	706	L per trip
Tanker Capacity	692	GJ per tanker
Diesel Burned per GJ	1.02	L per GJ
Total Diesel	1.02	L per GJ
Total SNG (gas)	32	m3 per GJ
Total Energy	1.22	GJ Fossil per GJ Heat
Space Heating Ratio	0.82	GJ Heat per GJ Fossil

Table 9-18 Fossil Fuel Usage for Wood Pellet Heating

Parameter Name	**Value**	**Unit**
Wood Pellet Transport Section		
Truck Fuel Efficiency	57.6	L/100km
Transportation Distance	2617	km
B Train Truck Capacity	43.0	tonnes
Pellet Heating Value	17.0	MJ/kg
Diesel Burned	1510	L of Diesel
Diesel Burned per tonne of pellets	35.1	L per tonne
Diesel Burned per GJ of pellet	2.07	L per GJ Pellet
Space Heating Ratio	12.28	GJ Heat per GJ Fossil

Table 9-19 Landfill Emissions Penalty per Tonne of Cardboard

Estimated Landfill Emissions	**1646**	kg CO2

9.7.4.2 Calculation of Carbon Dioxide Emissions

Table 9-20, Table 9-21, Table 9-22, and Table 9-23 show the results of carbon dioxide emissions calculations for each heating source.

Table 9-20 Waste Cardboard Pellets Summary

Parameter Name	**Value**	**Unit**
Pellet Mass	1000	kg
Heating Value per tonne of pellets	15.38	GJ/tonne
Diesel Used for Pellet Production	67	L
SNG (gas) Used for Pellet Production	23	m3
CO2 from Transport	3.0	kg
CO2 from Power Generation	206	kg
CO2 from Combustion	1316	kg
Total Pellet CO2 emissions	1525	kg

Table 9-21 Electric Heating Summary

Parameter Name	**Value**	**Unit**
Diesel Used for Electric Heating	824	L
SNG (gas) Used for Electric Heating	420	m3
SNG (liq) Used for Electric Heating	672	L
CO2 from Transport	71	kg
CO2 from Power Generation	2649	kg
Total Electric C02 Emissions	4366	kg
Difference to Cardboard	2841	kg

Table 9-22 Gas Heating Summary

Parameter Name	**Value**	**Unit**
Diesel Used for Gas Heating	16	L
SNG (gas) for Gas Heating	493	m3 per tonne
SNG (liq) for Gas Heating	789	L per tonne
CO2 from Transport	42	kg per tonne
CO2 from Combustion	931	kg per tonne
Total Gas Heating C02 Emissions	2619	kg per tonne
Difference to Cardboard	1094	ke per tonne

Table 9-23 Wood Pellets Summary

Parameter Name	**Value**	**Unit**
Diesel Used for Wood Pellet	32	L per tonne
SNG Used for Wood Pellets	0	m3 per tonne
CO2 from transport	86	kg per tonne
CO2 from combustion	1628	kg per tonne
Total Wood Pellet CO2 emissions	3360	kg per tonne
Difference to Cardboard	1835	kg per tonne

9.7.5 Analysis and Conclusions

According to the calculations performed above, the manufacture of cardboard fuel pellets will produce the lowest carbon dioxide emissions per unit space heating. If the landfill emission penalty is ignored, the cardboard pellets moves into second place, being bested by natural gas heating. Figure 9-5 shows the effect of the landfill penalty on the calculated emissions quantities.

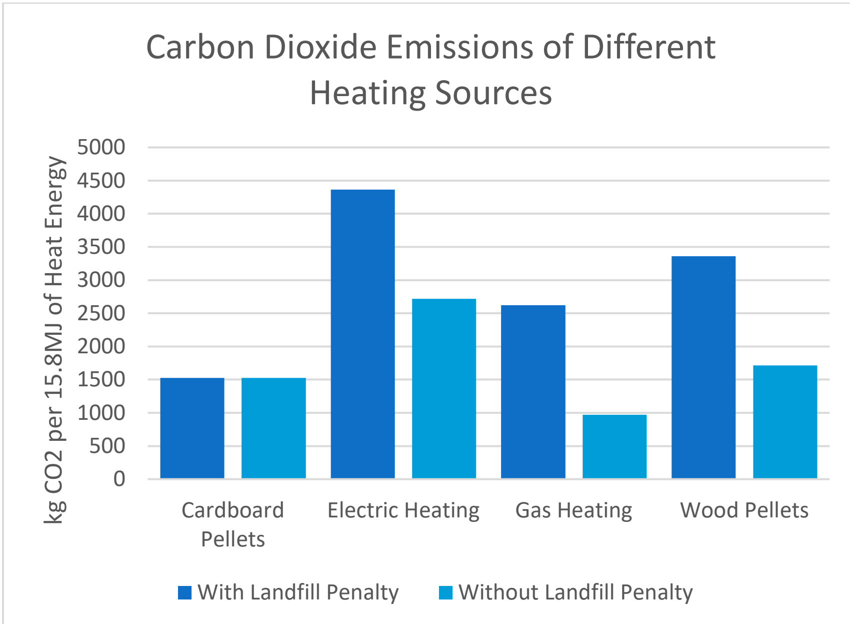


Figure 9-5 Carbon dioxide emissions for each heating source calculated based on the heat energy generation of 15.8MJ (1 tonne of cardboard pellets).

9.8 *Fuel Substitution Case* Study

9.8.1 Introduction

When considering the substitution of a cardboard pellet fuel in place of a traditional wood pellet fuel, the differences in the user apparent behavior of the fuel must be analyzed. The user is most interested in the heat generated by the fuel, and the maintenance they must perform on their boiler. Fuel ash content and calorific value represent these concerns in simplest terms.

9.8.2 Purpose

To determine the change in mass of fuel required and mass of ash created when switching from a 100% wood pellet fired boiler to a 100% cardboard pellet fired boiler.

9.8.3 Procedure

The heating requirements of the Mackenzie Hotel in Inuvik will be analyzed. The heating load of the hotel is estimated at 4874GJ per year [13]. Using the heating value of both wood and cardboard pellets, an average daily consumption of pellets can be determined. This average is not indicative of peak loading during the winter months, but assumes uniform heat load.

9.8.4 Results and Conclusions

Table 9-24 Fuel Usage Comparison

Parameter	Value	Unit
Wood Pellet		
Fuel Mass (HHV)	0.9	tonne/day
Ash Produced	0.004	tonne/day
Cardboard Pellet		
Fuel Mass (HHV)	1.0	tonne/day
Ash Mass (Lower)	0.05	tonne/day
Differences		
Increase in Fuel Usage Range	16%	by weight
Increase in Ash Output Limits	1000%	by weight

As shown in Table 9-24, it is expected that approximately 16% more mass of fuel will need to be burnt to achieve the same heating load. The quantity of ash left in the boiler would increase about 10 times. The ash produced by the cardboard combustion is also chemically different. Cardboard ash contains about 0.32% by weight [29] sulfur compared to the average wood pellet, which is at 0.05% [32]. The presence of Sulphur and other alkali metals is linked with higher corrosion and deposit formations inside the boiler [31]. This results in the need for more frequent boiler cleaning to ensure long heat exchanger life.

9.9 Business Case Analysis Results

9.9.1 Independent Venture

Table 9-25 summarizes the expected profitability of an independent venture in which cardboard is dropped off at the mill location, i.e. there are no collection costs.

Table 9-25 Summary of Independent Venture Business Model Not Including Collection Costs

Parameter	**Value**	**Unit**
Assumes that all costs are placed with the project		
Environmental Parameters		
Daily Cardboard	273	kg per day
Diversion Fraction	0.6	frac
Mill rate	250	lb per hour
Manual Process rate	500	lb per hour
Pellet Price	$0.45	per kg
Labour Rate	$12.50	per hour
Building Rent	$2,000.00	per month
Electricity Cost	$0.60	per KWh
Estimate Heating Load	200	GJ
Additive Costs	$30.00	per tonne
Model Outputs		
Diverted Cardboard	164	kg per day
Diverted Cardboard	360	lbs per day
Diverted Cardboard	2523	lbs per week
Diverted Cardboard	505	lbs per work day
Mill run time	2.02	hours per work day
Manual Process time	1.01	hours per work day
Labour Cost	$540.00	monthly
Building Costs	$2,000.00	monthly
Lighting Costs	$190.00	monthly
Mill Costs	$700.00	monthly
Heating Costs	$460.00	monthly
Total Cost	$3,890.00	monthly
Pellet Value	$2,160.00	monthly
Profit	-$1,730.00	monthly

Table 9-26 Summary of Independent Venture Business Model Including Collection Costs

Parameter	**Value**	**Unit**
Assumes that all costs are placed with the project		
Environmental Parameters		
Daily Cardboard	273	kg per day
Diversion Fraction	0.6	frac
Mill rate	250	lb per hour
Manual Process rate	500	lb per hour
Pellet Price	$0.45	per kg
Labour Rate	$12.50	per hour
Building Rent	$2,000.00	per month
Electricity Cost	$0.60	per KWh
Estimate Heating Load	200	GJ
Additive Costs	$30.00	per tonne
Model Outputs		
Diverted Cardboard	505	lbs per work day
Mill run time	2.02	hours per work day
Manual Process time	1.01	hours per work day
Labour Cost	$540.00	monthly
Building Costs	$2,000.00	monthly
Lighting Costs	$190.00	monthly
Mill Costs	$700.00	monthly
Heating Costs	$460.00	monthly
Collection Cost	$680.00	monthly
Total Cost	$4,570.00	monthly
Pellet Value	$2,160.00	monthly
Profit	-$2,410.00	monthly

From the data presented above, it can be seen that the independent venture renting a facility to produce cardboard pellets is not expected to be profitable. The building and heating costs are too high to have the project as a standalone operation.

9.9.2 Sponsored Venture

Table 9-27 summarizes the expected profitability of a sponsored venture manufacturing waste cardboard pellet fuel in Inuvik. This model includes the costs of collecting the waste cardboard at the landfill.

Table 9-27 Summary of Sponsored Venture Business Model Including Cardboard Collection Costs

Parameter	**Value**	**Unit**
Assumes a heated space is available for zero cost.		
Environment Parameters		
Daily Cardboard	273	kg per day
Diversion Fraction	0.8	frac
Mill rate	250	lb per hour
Manual Process rate	500	lb per hour
Pellet Price	$0.45	per kg
Labour Rate	$18.50	per hour
Building Payments	$0.00	per month
Electricity Cost	$0.60	per KWh
Estimate Heating Load	0	GJ
Additive Costs	$30.00	per tonne
Model Outputs		
Diverted Cardboard	218	kg per day
Diverted Cardboard	480	lbs per day
Diverted Cardboard	3363	lbs per week
Diverted Cardboard	673	lbs per work day
Mill run time	2.69	hours per work day
Manual Process time	1.35	hours per work day
Labour Cost	$1,070	monthly
Collection Costs	$680	monthly
Mill Cost	$1,130	monthly
Total Cost	$2,880	monthly
Pellet Stock Value	$2,880	monthly
Profit	$0	monthly

As seen in the table above, a sponsored cardboard pellet manufacturing operation is expected to be break-even.

Table 9-28 summarizes the profitability of sponsored business venture in Inuvik assuming that cardboard is dropped off at the mill location.

Table 9-28 Summary of Sponsored Venture Business Model not Including Cardboard Collection Costs

Parameter	**Value**	**Unit**
Assumes a heated space is available for zero cost.		
Environment Parameters		
Daily Cardboard	273	kg per day
Diversion Fraction	0.6	frac
Mill rate	250	lb per hour
Manual Process rate	500	lb per hour
Pellet Price	$0.45	per kg
Labour Rate	$18.50	per hour
Building Payments	$0.00	per month
Electricity Cost	$0.60	per KWh
Estimate Heating Load	0	GJ
Additive Costs	$30.00	per tonne
Model Outputs		
Diverted Cardboard	164	kg per day
Diverted Cardboard	360	lbs per day
Diverted Cardboard	2523	lbs per week
Diverted Cardboard	505	lbs per work day
Mill run time	2.02	hours per work day
Manual Process time	1.01	hours per work day
Labour Cost	$800	monthly
Mill Cost	$850	monthly
Total Cost	$1,650	monthly
Pellet Stock Value	$2,160	monthly
Profit	$510	monthly

9.10 Applicable Funding

The following sections outline possible funding streams for furthering this project.

9.10.1 Natural Resources Canada Project Concept Questionnaire

This questionnaire was setup to provide preliminary information to ENR in preparation for a call for proposals that will happen later.

9.10.2 Northern REACHE Program

This program was setup by Indigenous and Northern Affairs Canada (INAC) to provide funding for projects aimed at reducing Northern communities' dependence on imported fossil fuels for heating and electricity [52].

9.10.3 WRRI (Waste Reduction and Recycling Initiative)

This program runs as part of the Waste Reduction and Recycling Program established by the GNWT. It offers up to $50,000 a year to NWT operations that accomplish the any of the four goals set out by the WRRI.

9.10.4 Green Municipal Fund (GMF)

This fund provides support for feasibility studies, and pilot projects involving reuse, recycling, and composting programs.

10 INDEX

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