Used Horse Bedding & Broiler Litter Gasification Feasibility Study

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Abbreviations and Acronyms

B.C.	British Columbia
BDS	Basic Distribution System
BTU	British Thermal Units
Ca	Calcium
CCS	Census Consolidated Subdivision
CH_4	Methane
CHP	Combined Heat and Power (co-generation)
Cl	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
^oC	Degrees Celsius
DAF	Dissolved Air Floatation
EAA	Environmental Assessment Act
EAO	Environmental Assessment Office
EIA	Environmental Impact Assessment
EMA	Environmental Management Act
FV	Fraser Valley
GJ	Gigajoule
GV	Greater Vancouver
H	Hydrogen
HCBC	Horse Council B.C.
IRR	Internal Rate of Return
K	Potassium
LHV	Lower Heating Value
M^3	Cubic Metre
Mg	Magnesium
MoE	Ministry of Environment
MW	Megawatt (1,000kW)
MWh	Megawatt Hour
MWhe	Megawatt Hour Electric
N	Nitrogen
P	Phosphorus
POI	Point of Interconnection
PPM	Parts per Million
S	Sulphur
SCR	Short Circuit Ratio
Si	Silicon
SOP	Standing Offer Program
WDAP	Waste Discharge Authorization Permit
WDR	Waste Discharge Regulation
WMP	Waste Management Plan
Wt	Weight

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1. Executive Summary

B.C.’s Lower Mainland is home to an estimated 15,000 horses and 80,000,000 broilers, the majority of which are located in Langley and Abbotsford. It is estimated that these animals produce in excess of 110,000 tonnes/year of used broiler litter and 150,000 tonnes/year of used horse bedding. Due to limited space for composting at many equine facilities, coupled with the current nutrient surplus in the Lower Mainland, some broiler farms and many equine facilities are looking for more sustainable, local, long-term, year-round alternatives to the local land application of their used bedding and litter.

One alternative to the local land application of used broiler litter and horse bedding is gasification. Gasification involves the partial, oxygen starved combustion of feedstocks at relatively high temperatures to produce a combustible gas called syngas, and an ash by-product. Syngas can be utilised in a range of applications to produce renewable heat, or heat and electricity, while ash, if it has sufficiently high nutrient content, can be incorporated into existing fertilizer products.

While widely adopted for use with coal and wood, the application of gasification for used horse bedding and broiler litter is very limited. Due to this limited application, gasification tests with used horse bedding and broiler litter from the Lower Mainland were carried at the SP Technical Research Institute of Sweden. These tests helped to determine potential syngas production and quality, optimal feedstock mixtures, and potential feedstock-based obstacles for gasifying used broiler litter and horse bedding. These tests also enabled assessment of both the volume and quality of the ash by-product.

Results from the gasification tests show that both used broiler litter and horse bedding produce high quality syngas when gasified, and that different feedstock mixtures of used broiler litter and horse bedding have little impact on overall syngas energy content, quality, and tar levels. The only feedstock-based obstacle encountered during the gasification tests was that of ash sintering with 100% used horse bedding. While somewhat surprising based on the higher ash deformation temperature shown in previous laboratory analysis of used bedding, it is assumed that this lower sintering temperature was due to the presence of uneaten hay.

The gasification tests also showed that while ash yields were lower than expected, all ash produced from the gasification tests held good potential for being incorporated into existing fertilizer products. The tests also showed clear patterns between the concentrations of Phosphorus, Calcium and Magnesium in the ash, which increased with the amount of used broiler litter gasified, and Potassium, Chlorine and Silicon, which increased with the amount of used horse bedding gasified. Based on the syngas and ash quality and quantity results from the gasification tests, it is clear that the driver for choosing which feedstock mixture of used horse bedding and broiler litter to gasify should be based on the cost and difficulty of feedstock acquisition.

A fluidised bed technology supplied by EQTEC was deemed to be the most suitable for gasifying used horse bedding and broiler litter in the Lower Mainland. This choice was based on the technology’s ability to handle the feedstock’s heterogeneity, high moisture content, volumes, desired operating temperatures to avoid potential ash sintering of used horse bedding, and syngas quality. Production of renewable electricity was deemed to be the most suitable energy generation pathway based on the need for large volumes of heat to dry both the used horse bedding and broiler litter prior to gasification, and difficulty in finding a heat sink of sufficient size in or around Langley or Abbotsford to make use of all the produced heat.

The proposed EQTEC gasification plant size of 50,000 tonnes/year would gasify 37,500 tonnes/year of used horse bedding and 12,500 tonnes/year used broiler litter. Size and feedstock mix were based on current estimated volumes and availability of used horse bedding and broiler litter in the Lower Mainland. The syngas would be combusted in combined heat and power engines to produce 3.95MW of renewable electricity and heat. The electricity would be sold to B.C. Hydro under the Standing Offer Program, while most of the heat would be used to dry the used horse bedding and broiler litter to 12% moisture content before gasification. The remaining 1.85MW of heat (as 90^{o}C hot water) would be sold locally.

When searching for a site in the Lower Mainland to locate the gasification plant, it is important that this site be within close proximity to both the feedstocks and sufficient on-site heat demand, have appropriate site characteristics, and be able to connect to the B.C. Hydro grid with minimal difficulties. With these characteristics in mind, two potential areas were identified; one on the boarder of Langley and Surrey near the Golden Ears Bridge, the other on the boarder of Langley and Abbotsford near Highway 1. Further research into both of these areas is required to determine where exactly the gasification plant could be located.

Estimated net annual revenue for the gasification plant from the sale of electricity ($111.56/MWh), heat ($4.2/GJ), ash ($20/tonne), and used horse bedding tipping fees ($10/tonne) are $4,462,080. Estimated capital cost of the gasification plant is $29,315,000, while annual operating costs are $1,733,000. Gross rate of return on total capital investment before any interest charges, depreciation or taxes indicates a payback period of 10.7 years. By normal industry expectations, this payback period indicates that the gasification plant is not attractive from a financial prospective.

While unattractive from a financial prospective, this changes significantly if 40% funding ($11.7 million) were available for the gasification plant. 40% funding for a renewable energy project with such wide-reaching agricultural and environmental benefits is a reasonable amount based on past funding announcement by the Innovative Clean Energy (ICE) Fund, where project funding is often >30%. Under this scenario, the pre-tax internal rate of return for the gasification plant, based on 10-year cash flow projections, 40% funding, 45% debt financing and 15% equity, and assuming 8% interest and 2% inflation, is 16.1%. By normal industry expectations, this internal rate of return is attractive from a financial prospective.

Of the assumed values for grant funding, tipping fees, ash sales, financing and capital costs used for the economic feasibility, those that are most critical are capital costs and used horse bedding tipping fees. For example, a 5% increase in capital costs reduces the internal rate of return to 10.5%, while a 5% decrease increase the internal rate of return to 25%. Furthermore, an increase in the tipping fee charged for used horse bedding from $10/tonne to $20/tonne or $30/tonne decreases required grant funding by $2 million (17%) and $4.1 million (35%), respectively.

As previously noted, different feedstock mixtures of used broiler litter and horse bedding gasified had little impact on syngas energy content, quality and tar levels, ash yield or potential value. As such, the proposed gasification plant design, site selection and feasibility assessment for this study will be similar regardless of the feedstock mixture gasified. The one key difference, due to significant differences in the moisture content of used horse bedding (60%) and broiler litter (25%), is that if a greater proportion of used broiler litter were gasified, more heat would be available after feedstock drying. However, being able to sell this extra heat will depend very much upon where the gasification plant is located.

2. Introduction

Horses are a large part of B.C.'s agricultural sector, providing substantial economic benefit and employment to B.C.'s economy. Used for a variety of sports, in farming, as work animals, for therapy, recreation and tourism, all horses require bedding. Disposal of used horse bedding (herein referred to as 'used bedding'), consisting of wood shavings, manure, urine, and uneaten feed (grain and hay)[1], is a constant challenge and on-going cost for equine facilities in the Lower Mainland with limited pasture availability.

While used bedding can be a source of Phosphorous (P) and Potassium (K), it is not an effective fertilizer. Wood contains carbon that soil microbes use for energy, but not enough Nitrogen (N) to build proteins. When used bedding is land-applied, microbes draw N from the soil to make up for this deficit to such a degree that they can actually limit plant growth[2]. N fertilizer can be applied to overcome this induced N deficiency, but this is rarely cost-effective.

One possible management option for used bedding is to compost it before land application. Composting reduces mass and increases nutrient concentration, thereby reducing haulage requirements and improving desirability. However, the use of wood shavings increases the period of time necessary for used bedding to decompose, making it challenging for equine facilities with limited space, infrastructure, and resources to compost. Moreover, some farmers hesitate to accept composted used bedding as it can contain oat weeds, while others prefer alternative locally available agricultural wastes that have more appealing characteristics.

For the many equine facilities in the Lower Mainland unable to land-apply or compost, used bedding is stored on-site for several months (especially from October to April) until commercial haulers remove it for a cost. Appropriate long-term storage can be expensive, while inappropriate storage can result in contamination of surface and groundwater.

Poultry production is an economic cornerstone of B.C.'s agriculture sector. According to the 2013 B.C. Agri-Food Industry Year in Review, at any one time during the year the Lower Mainland is home to almost 90% of B.C.'s 100 million chickens[3]. Although many different bedding materials are available for these birds, most broiler farmers in the Lower Mainland use wood shavings.

Once removed from the barn, used broiler litter (herein referred to as 'used litter') is stored in piles for use primarily as a fertilizer through land application. Currently there are more nutrients available in the Lower Mainland than are needed for the crops that are grown, or that the land can sustain.[4] This nutrient surplus can make it challenging to find land on which to apply broiler litter in the Lower Mainland, while over application can cause nutrient build-up in soils over time and increase potential for nutrients leaching into the environment.

Due to limited space for used bedding composting and the nutrient surplus in the Lower Mainland, some broiler farms and many equine facilities are looking for more sustainable, local, long-term, year-round alternatives to local land application of used bedding and litter. These alternatives would help to reduce storage costs and the over-application of nutrients in the Lower Mainland, while providing equine facilities and broiler farms with stable, long-term options for used bedding and litter removal.

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[1] Manure collected from rings and other outside locations will likely also contain sand/dirt.

[2] Virginia Cooperative Extension: Horse Manure Management https://pubs.ext.vt.edu/406/406-208/406-208.html

[3] Due to rotation cycles, at any one point in time during the year there are approximately 18 million chickens in the Lower Mainland.

[4] Fraser Valley Soil Nutrient Study 2005.

Simply stated, gasification involves the partial, oxygen starved combustion of feedstocks, such as used litter and bedding, at relatively high temperatures of 800 – 1,400°C to convert the feedstock's chemical energy into a combustible gas called syngas. Syngas, the quality and energy content of which is greatly affected by type of gasification technology and feedstock used, can be utilised in a range of applications to produce renewable heat, or heat and electricity. The by-product of gasification is ash, the quality and volume of which also depends upon type of gasification technology and feedstock used.

A gasification plant in the Lower Mainland would provide a long-term, year-round alternative to the land application of used bedding and litter. This gasification plant would also reduce used bedding storage needs and provide equine facilities and broiler farms in the Lower Mainland with a stable, long-term removal option. However, while a gasification plant is theoretically possible, the technical and economic feasibility of building such a plant in the Lower Mainland to convert used bedding and litter into renewable energy and ash is currently unknown. Determining the technical and economic feasibility is the reason for this study.

3. Feedstock

The cornerstone of a successful gasification plant is feedstock. Understanding the location, volume, characteristics, and availability of used bedding and litter in the Lower Mainland is essential to determining possible locations, size and type of gasification technology required, and potential costs/revenues associated with acquiring the feedstock.

3.1 Location

Used Bedding

Statistic Canada's Census of Agriculture[5] shows that despite a slight decrease since 2001, horse numbers in Greater Vancouver (GV) and the Fraser Valley (FV) have been fairly stable over the past ten years[6]. Statistic Canada's Census of Agriculture also shows that since 2001, GV and the FV have been home to 17 - 19% of B.C.'s total horse population (Table 1).

Unfortunately, Statistic Canada's Census of Agriculture only captures horses located on farm businesses; those classified as farmland or that file farm income tax. As such, horse number estimates provided by Statistic Canada underestimate actual horse populations. According to the B.C. Horse Industry Report (2009)[7], Statistic Canada's Census of Agriculture "captures a little over half the total horse population" (page 17). This claim is substantiated by Horse Council B.C.'s (HCBC) estimation that only 59% of horse properties in B.C. are farm businesses, and explains the consistent difference between Stats Canada and HCBC's estimated horse numbers over the past ten years (Table 1).

To develop a more accurate estimate of horse numbers in the Lower Mainland, it is therefore necessary to multiply Statistic Canada's Census of Agriculture numbers by 1.75; thereby accounting for the horses not captured by Statistic Canada's Census of Agriculture. In doing this, the estimated number of horses located in the Lower Mainland in 2011 increases from almost 8,500 to almost 15,000 (Table 1). Of these horses, almost half (44%) are located within Statistic Canada's Census Consolidated Subdivision (CCS) of Langley, while most of the remaining horses are located in Abbotsford (12%), Fraser Valley E (11%), Delta (7%), and Surrey (7%) (Figure 1).

[5] http://www5.statcan.gc.ca/cansim/a03?lang=eng&pattern=004-0200..004-0242&p2=31
[6] Expectations are that this number will remain fairly consistent as the industry stabilises and possibly experiences modest growth.
[7] http://www.hcbc.ca/_customelements/uploadedResources/2009HorseIndustryReportFinal.pdf

Table 1: Horse Numbers in Lower Mainland and B.C. (2001 – 2011)

	Year			
	2001	**2006**	**2009**	**2011**
Stats Canada: Horses in B.C.	53,366	53,246	----	45,791
Stats Canada: Horses in GV†	7,399	6,237	----	5,951
Stats Canada: Horses in FV††	2,785	2,634	----	2,493
Total horses in Lower Mainland	*10,184*	*8,871*	----	*8,444*
Percentage of B.C. horses in Lower Mainland	*19%*	*17%*	----	*18%*
HCBC: Horses in B.C.	91,500	94,000	94,925	----
Percentage not captured by Stats Canada	*42%*	*43%*	----	----
Estimated horses in GV†	12,981	10,942	----	10,440
Estimated horses in FV††	4,886	4,621	----	4,374
Total Horses in Lower Mainland	***17,867***	***15,563***	----	***14,814***

† *CCS of Greater Vancouver A, Vancouver, Burnaby, Richmond, Delta, Surrey, Pitt Meadows, Maple Ridge and Langley.*
†† *CCS of Abbotsford and Fraser Valley B, D, E, F and G.*

Used Litter

Statistic Canada's Census of Agriculture[8] shows that on census day in 2011 there were just over 12 million broilers[9] in GV and the FV (Table 2). Unlike with horses, Statistic Canada's Census of Agriculture is thought to capture the vast majority of broilers raised in B.C. Unfortunately, Statistic Canada's Census of Agriculture only captures broilers number on census day; broilers on farm businesses on a particular day. Because broiler farms in B.C. average 6.5 production cycles a year, it is therefore necessary to multiply Statistic Canada's Census of Agriculture numbers by 6.5 to find the total number of broilers raised in the Lower Mainland in a year (Table 2). Of these broilers, almost half are located within Statistic Canada's CCS of Abbotsford (49%), while the rest are located in Fraser Valley E (22%), Langley (15%), Surrey (10%) and Vancouver (4%) (Figure 1).

According to the B.C. Chicken Marketing Board Annual Report (2013)[10], broiler production in B.C. increased by 56% between 1995 and 2013 (as shown by sales growth in tonnes of eviscerated weight). Despite this growth, broiler production in B.C. increased by less than 2% between 2005 and 2013 (Table 2). As such, it is assumed that current broiler numbers in the Lower Mainland are similar to those from Statistic Canada's 2011 Census of Agriculture, once these numbers are multiplied by 6.5.

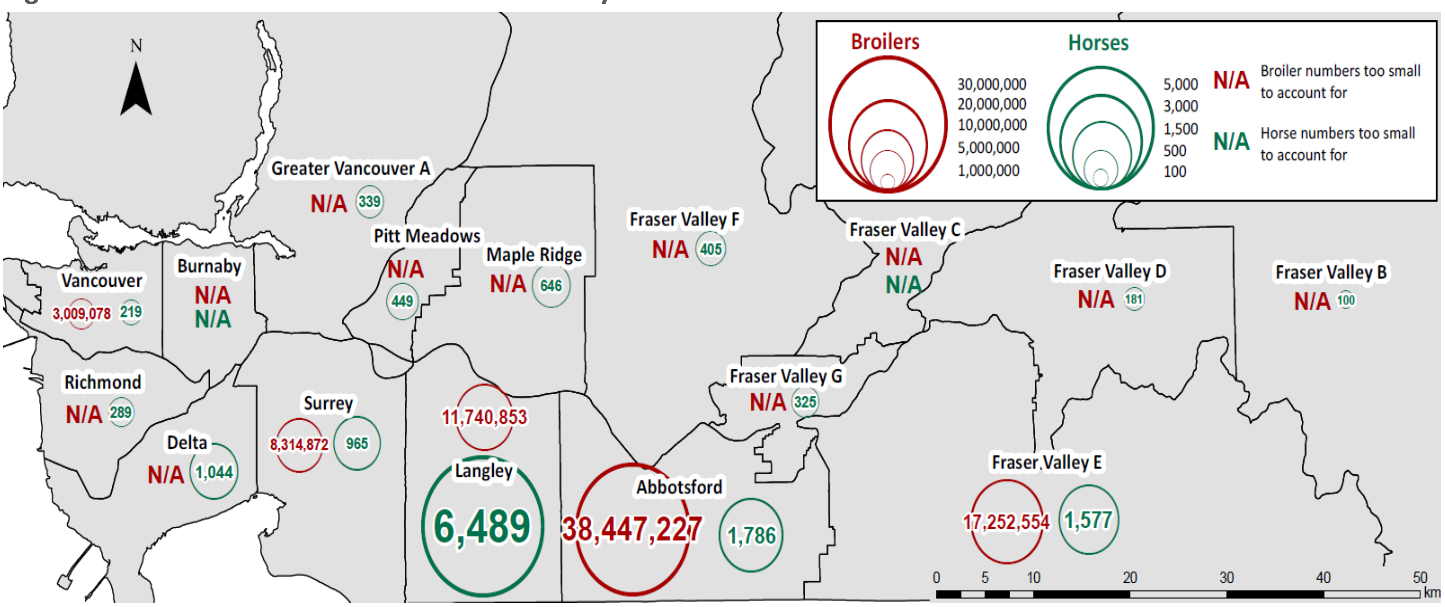
[8] http://www5.statcan.gc.ca/cansim/a03?lang=eng&pattern=004-0200..004-0242&p2=31
[9] For the purpose of this study, 'broilers' refers to broilers, roasters and Cornish birds.
[10] http://bcchicken.ca/BCChickenAnnualReport2013.pdf

Table 2: Broiler Numbers in Lower Mainland (2011) and Sales Growth in Tonnes Evisc Wt. (1995 – 2013)

	Year					
	1995	2001	2005	2008	2011	2013
Stats Canada: Broilers in GV†	----	----	----	----	3,548,431	----
Stats Canada: Broilers in FV††	----	----	----	----	8,569,197	----
Total broilers in Lower Mainland	----	----	----	----	*12,117,628*	----
Estimated broilers raised in GV†	----	----	----	----	23,064,802	----
Estimated broiler raised in FV††	----	----	----	----	55,699,781	----
Total Broilers in Lower Mainland	----	----	----	----	***78,764,583***	----
Tonnes B.C chicken sold	100,233	141,060	154,374	157,384	----	156,543
Percentage change from previous yr	--	*41%*	*9%*	*2%*	----	*-1%*

† CCS of Greater Vancouver A, Vancouver, Burnaby, Richmond, Delta, Surrey, Pitt Meadows, Maple Ridge and Langley.
††CCS of Abbotsford and Fraser Valley B, D, E, F and G.

Figure 1: Estimated Horse and Broiler Numbers by Census Consolidated Subdivision



3.2 Bulk Density

Limited information exists regarding the amount of used litter and bedding produced in the Lower Mainland. Most estimations are created by multiplying an assumed average amount of material produced per animal by animal numbers. While open to criticism, this approach is seen as sufficient to develop a rough idea of the amount of used bedding and litter produced in the Lower Mainland.

Used Bedding

The amount of used bedding produced is mostly affected by the type of material used, exercise levels, and the equine facility owner's bedding management philosophy and that of their clients. Interviews with industry experts and bedding removal companies confirmed that most equine facilities in the Lower Mainland use wood shavings for bedding and exercise their horses on average 4 – 8 hours a day. Stalls are cleaned daily (sometimes twice daily) by removing manure and wet bedding. As manure and wet bedding are removed, fresh bedding is added to the stall. Stalls are usually only 'stripped' (i.e., all bedding removed) when new horses are moved into the stall.

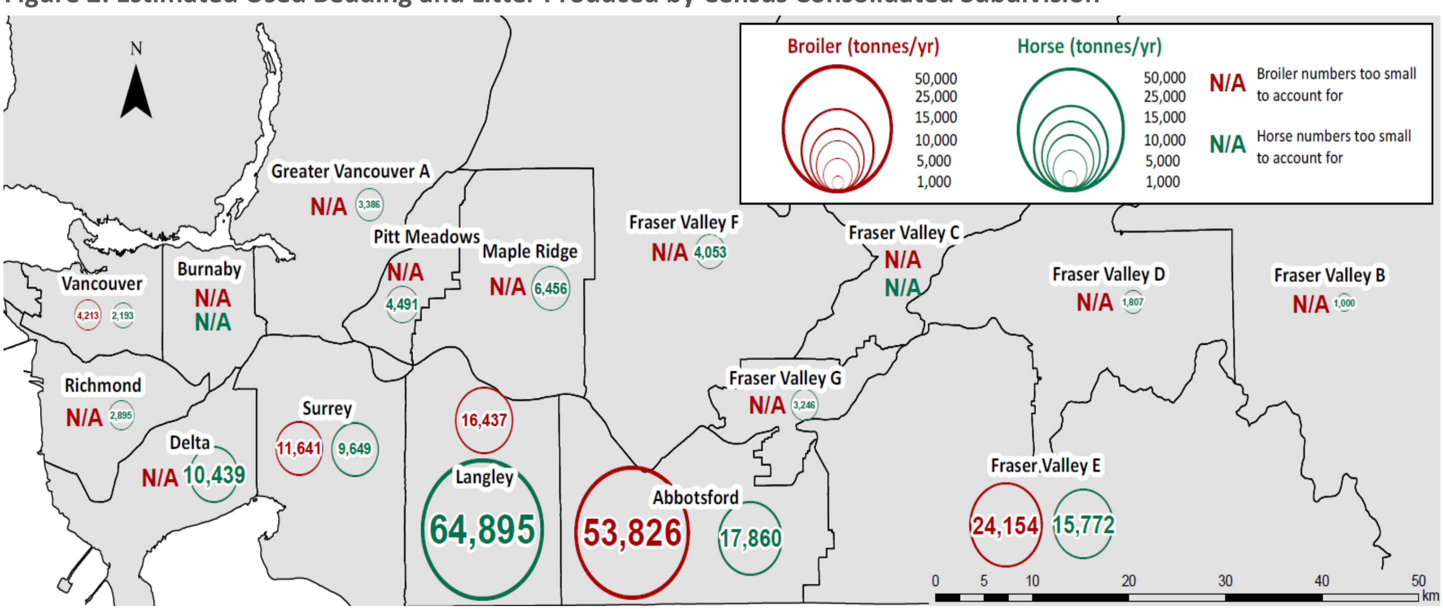
On average, and based on the use of wood shavings, exercise levels, and management philosophy described above, a fully grown stalled horse in B.C. generates an estimated 10 tonnes used bedding/year, and this bedding has a bulk density of 500 – 600kg/m^3 (380 – 460kg/cubic yard). Based on this, it is estimated that >148,000 tonnes/year of used bedding is produced in the Lower Mainland, with the vast majority of this bedding produced in Statistic Canada's CCS of Langley (~65,000 tonnes/year), Abbotsford (~18,000 tonnes/year), and Fraser Valley E (~16,000 tonnes/year) (Figure 2).

Used Litter

The amount of used litter produced is mostly affected by the type of bedding material used, stocking density, and number of flocks reared on the litter. In the Lower Mainland, almost all commercial broiler farmers use wood shavings for bedding, while most farms raise broilers at or near the maximum allowable density mandated by the Chicken Farmers of Canada's Animal Care Program. After each production cycle, all barns are thoroughly cleaned and all litter is removed from the barn floor following an "all in, all out" philosophy.

On average, and based on the use of wood shavings, stocking density, and litter management philosophy described above, it is estimated that a 20,000 broiler farm in the Lower Mainland produces 28 tonnes of used litter per production cycle (1.4kg litter/broiler/production cycle), and that this litter has a bulk density of 350 – 450kg/m^3 (270 – 345kg/cubic yard). Based on this, it is estimated that >110,000 tonnes/year of used litter is produced in the Lower Mainland[11], with the vast majority of this litter produced in Statistic Canada's CCS of Abbotsford (~54,000 tonnes/year), Fraser Valley E (~24,000 tonnes/year), Langley (~16,000 tonnes/year), and Surrey (~12,000 tonnes/year) (Figure 2).

Figure 2: Estimated Used Bedding and Litter Produced by Census Consolidated Subdivision



[11] These numbers are similar to those in the Evaluation of Options for Fraser Valley Poultry Manure Utilization (Timmenga & Associates Inc. 2003), which estimated 124,418 tonnes of chicken litter in the Lower Mainland with a bulk density of 295kg/yard.

3.3 Characteristics

Used Bedding

Used bedding is a mixture of excrement, bedding material, and uneaten feed (grain and hay). As with weight, the characteristics of used bedding are mostly affected by the type of bedding material used and bedding management philosophy. As mentioned previously, most equine facilities in the Lower Mainland use wood shavings and have similar bedding management philosophies; manure and wet bedding is removed daily and stored on concrete pads or in bunkers/bins until taken away.

To understand the suitability of used bedding as a feedstock for gasification, it is important to know its physical, chemical and energetic characteristics, as only feedstocks with certain characteristics are suitable for gasification (Table 3). When compared to wood, often considered a good feedstock for gasification, used bedding has a relatively high moisture content. Because most gasification technologies require feedstocks to have a moisture content of <30%, pre-drying of used bedding will be required before it can be gasified. The volatile matter content of used bedding is also high, although no higher than wood. High volatile matter content indicates that some type of tar removal system post-gasification will be required before the syngas can be combusted to produce renewable electricity.[12]

Used bedding has slightly higher ash and chlorine contents, and similarly low sulphur content than wood. This indicates that while the risk of slagging and fouling during gasification is higher with used bedding than with wood, this risk is minor and there is likely little need for additional ash handling and emission control technology. The higher calorific value and ash deformation temperature of used bedding are also similar to wood. Overall, therefore, used bedding is seen as a suitable feedstock for gasification.

Used Litter

Used litter is a mixture of excrement, bedding material, feathers, and waste feed. As with weight, characteristics of used litter are mostly affected by housing climate, bedding material, and management philosophy. Characteristics can also be impacted by bird type. As mentioned previously, most commercial broiler farms in the Lower Mainland use wood shavings and have similar litter management philosophies; after each production cycle all litter is removed from the barn. Most commercial broiler farms in the Lower Mainland also have computer systems to control the temperature and air flow in the barns, and raise the same type of bird.

To understand the suitability of used litter as a feedstock for gasification, it is important to know its physical, chemical and energetic characteristics, as only feedstocks with certain characteristics are suitable for gasification (Table 4). When compared to wood, used litter has similar moisture and volatile matter content. This means it is unlikely that used litter will require much pre-drying before gasification, while some tar removal system post-gasification will be required before the syngas can be combusted to produce renewable electricity.[13]

Used litter has higher ash, chlorine and sulphur content than wood. This indicates that the risk of slagging and fouling during gasification is higher than with wood, and there is a higher risk of corrosion and emissions. The higher calorific value and ash deformation temperature of used litter are similar to wood. Overall, therefore, despite the potential need for additional ash handling, anti-corrosion and emission control technologies, used litter is seen as a suitable feedstock for gasification.

[12] In practice the only feedstock that doesn't need a tar removal system post-gasification is high-quality charcoal.
[13] *Ibid.*

Table 3: Proximate and Ultimate Analysis of Used Bedding in the Lower Mainland[14]

	Horse Bedding		Clean Wood	
Proximate Analysis	**As Received Basis**	**Dry Basis**	**Dry Basis**	**Unit**
Moisture content	60	----	----*	% Wt.
Ash content	3	8	1 – 3	% Wt.
Volatile matter	29	73	73 – 78	% Wt.
Fixed carbon	8	19	19 – 22	% Wt.
Sum, proximate	*100*	*100*	*100*	*%*
Chlorine	----	0.256	0.004	% Wt.
Fluorine	----	<1	<1	ppm
Higher calorific value	3,293	8,260	8,000 – 9,500	BTU/lb
Ultimate Analysis				
Moisture content	60.1	----	----	%
Carbon	19.1	47.8	45 – 52	%
Hydrogen	2.3	5.8	5.5 – 6.5	%
Nitrogen	0.3	0.8	0.1 – 0.5	%
Sulphur	0.06	0.15	0.01 – 0.1	%
Ash	3.0	7.6	1 – 3	%
Oxygen (diff)	15.1	37.9	38 – 44	%
Sum, ultimate	*100*	*100*	*100*	*%*
Ash deformation temperature	----	1,150	1,100 – 1,400	°C
Ash fluid temperature	----	1,175	1,300 – 1,700	°C

** Wood tends to have an as received moisture content of 30 – 40%.*

[14] Horse bedding samples were taken from four equine facilities in the Lower Mainland.

Table 4: Proximate and Ultimate Analysis of Used Litter in the Lower Mainland[15]

	Broiler Litter		Clean Wood	
Proximate Analysis	**As Received Basis**	**Dry Basis**	**Dry Basis**	**Unit**
Moisture content	26	----	----*	% Wt.
Ash content	8	11	1 – 3	% Wt.
Volatile matter	56	76	73 – 78	% Wt.
Fixed carbon	10	14	19 – 22	% Wt.
Sum, proximate	*100*	*100*	*100*	*%*
Chlorine	----	0.614	0.004	% Wt.
Fluorine	----	0.003	<0.0001	% Wt.
Higher calorific value	4,803	7,072	8,000 – 9,500	BTU/lb
Ultimate Analysis				
Moisture content	26.0	----	----	%
Carbon	36.3	49.1	45 – 52	%
Hydrogen	3.9	5.3	5.5 – 6.5	%
Nitrogen	3.1	4.2	0.1 – 0.5	%
Sulphur	0.5	0.6	0.01 – 0.1	%
Ash	7.8	10.5	1 – 3	%
Oxygen (diff)	22.4	30.3	38 – 44	%
Sum, ultimate	*100*	*100*	*100*	*%*
Ash deformation temperature	----	+1,482	1,100 – 1,400	°C
Ash fluid temperature	----	+1,482	1,300 – 1,700	°C

** Wood tends to have an as received moisture content of 30 – 40%.*

3.4 Availability

Knowing the location and amount of used bedding and litter in the Lower Mainland isn't sufficient to determine availability; used bedding and litter may already be used for other purposes and therefore supply may be restricted due to existing contracts. To better understand availability, interviews were conducted with several used bedding and litter transportation companies that operate in the Lower Mainland. As first-level aggregators, these companies know where used bedding and litter is currently going, why it is going there, and at what cost.

Used Bedding

Used bedding transportation companies in the Lower Mainland provide most of their clients with 40 cubic yard bins. These bins are filled until they reach their maximum payload. Once bins are full, they are taken to the closest disposal location and equine facilities are charged for transportation and a small fee for finding the disposal location. While used bedding is most often transported less than 20km from the equine facility where

[15] Broiler litter samples were taken from three broiler farms in the Lower Mainland.

it was collected, there are times when it must be transported further (at a higher cost to the equine facility). Over the past few years, finding locations in the Lower Mainland that accept used bedding has become more and more difficult.

Currently, around one-fifth of equine facilities in the Lower Mainland are charged a small tipping fee for their used bedding (in addition to transportation costs and a finding fee). While difficult to predict the future, it is likely that changes to regulations and nutrient management planning will result in more equine facilities being charged a tipping fee, or used bedding being transported over longer distances.

One challenge for used bedding transportation companies is finding locations that will take guaranteed volumes of used bedding for extended periods of time. If companies were able to find such locations, they wouldn't need to charge a finding fee and would also be able to deliver significant volumes of used bedding on a regular basis.

Used Litter

Used litter transportation companies in the Lower Mainland collect litter during barn clean-outs or shortly afterwards. When collected, used litter is loaded into trucks. Once collected, most used litter is trucked to ranches in the interior, to fruit orchards in the Okanagan, to mushroom composting facilities, or used locally by dairy farms. Ranches, orchards and mushroom composting facilities accept broiler littler year-round, while dairy farmers generally only want litter in the spring for their corn.

Used litter transportation companies charge ~$125/hour trucking rate and a ~$150 loading rate. As such, it costs roughly $650 to deliver a load of used litter to the Okanagan if there is no backhaul. Currently, whomever takes the used litter pays the trucking and loading charge, while broiler farms pay nothing. There have been instances (such as in the spring and summer months of 2014) when some broiler farms were paid a small amount for their used litter. This is in sharp contrast to a decade ago when broiler farmers in the Lower Mainland were paying to have their used litter taken away. The greatest drivers for this change have been the growth of organic farming and the increasing cost of nitrogen.

Due to the distances over which it is transported, the cost of fuel does impact used litter trucking charges. The adjustment for any increases or decreases in fuel price and how they are factored into trucking costs are specified in contract agreements. While difficult to predict the future, it seems unlikely that current demand for used litter is going to fall anytime soon. This is because the price of nitrogen fertilizers is likely to stay high, and growth in organic farming is likely to continue. Furthermore, while demand for used litter stays the same, transportation companies will find no shortage of locations to take it.

3.5 Summary

Based on Statistic Canada's Census of Agriculture data and industry estimates, it is estimated that B.C.'s Lower Mainland is home to almost 15,000 horses and 80,000,000 broilers. These numbers are likely to remain fairly stable over the coming years. Both horse and broiler populations in the Lower Mainland are concentrated in the CCS of Langley, Abbotsford and Fraser Valley E. Despite limited information regarding used bedding and litter volumes in the Lower Mainland, estimations indicate that each year >148,000 tonnes of used bedding and >110,000 tonnes of used litter are produced.

The characteristics of used bedding and litter indicate that both are suitability feedstocks for gasification as both have sufficiently high calorific value and high ash deformation temperatures. While used bedding will require significant drying prior to gasification, its low ash, chlorine, and sulphur contents indicate there is little risk of slagging or fouling during gasification, and little need for additional emission controls. Used litter is much drier than used bedding, and as such will require much less drying prior to gasification. Relatively high ash, chlorine, and sulphur contents suggest however that additional measures may be required to prevent slagging or fouling during gasification, as well as to reduce emissions. Gasification of used litter and bedding will also require some type of tar removal system post gasification, although in practice almost all biomass feedstocks require this.

Due to limited demand, possible changes to regulations and nutrient management planning, and lack of other viable alternatives, it is probable that a large portion (>50%) of used bedding in the Lower Mainland would be available for gasification. This used bedding would almost certainly be available free of charge, and may even command a small tipping fee of $10/tonne[16]. Furthermore, used bedding transportation companies would likely be in favour of a gasification plant as it would provide them with local, long-term, year-round secure off-take contracts for bedding, and would encourage equine facilities to have their used bedding removed more frequently (causing less damage to storage bins).

Unlike used bedding, there currently seems to be sufficient demand for used litter produced in the Lower Mainland. Furthermore, only significant increases in fuel prices would result in the transportation of used litter to the interior and Okanagan becoming cost prohibitive when compared to alternative fertilizers. As such, it is probable that only a small portion (<20%) of used litter produced in the Lower Mainland could be available for gasification. This used litter would almost certainly not come with a tipping fee and the cost of transportation may have to be paid by the gasification plant.

4. Test Gasification

While widely adopted for the conversion of coal and wood to produce energy, the application of gasification for used litter and bedding is limited. This limited application means that relatively little is known about the potential viability of gasifying different types and especially different mixtures of used bedding and litter. Due to this limit knowledge, gasification tests were carried out by the SP Technical Research Institute of Sweden with several different feedstock mixtures of used litter and bedding from the Lower Mainland to:

- Determine potential syngas production and quality;
- Determine optimal feedstock mixtures;
- Identify possible feedstock-based obstacles; and
- Determine by-product ash volume and quality.

4.1 Feedstock Collection & Preparation

Samples of used bedding and litter were collected from four equine facilities (both boarding/training facilities and show/tournament facilities) and three broiler farms in the Lower Mainland between February and April. Collected on several different occasions, the samples were packed in Ziploc-bags and stored in a fridge (to keep the samples between 1 – 4°C). Once all samples were collected, they were transported in cool boxes to the SP Technical Research Institute of Sweden, where they were kept in a refrigerator until prepared for the gasification tests.

The subsamples of used bedding and litter were first combined to create representative samples of used litter and bedding that averaged out differences between storage structures and equine/farm operations, and then dried in the sunshine using black plastic foil (Figure 3). After drying, when moisture content was reduced to

[16] A tipping fee of $10/tonne would cost a 20 horse equine facility an additional $2,000/year.

25% for the used bedding and 17% for the used litter, the samples were crushed by a hammer mill to reduce any oversized particles that would hinder the pelletizing press. Once crushed, different recipes of used bedding and litter were made into pellets using a 'Morumspressen' (Table 5). Pelletizing, necessary for test gasification to enable controlled feedstock feeding into the gasification reactor, produce pellets that were 8mm in diameter and 12 – 17mm long.

Figure 3: Drying feedstock (colour variations are a result of samples being taken from different locations).

Table 5: Different Fractions of Used Bedding and Litter Pellets

Pellets	Percentage by Mass as Mixed	
	Used Bedding	Used Litter
#1	100	0
#2	87.5	12.5
#3	75	25
#4	62.5	37.5
#5	50	50
#6	0	100

4.2 Experimental Set-up & Methodology

The test gasifier consists of a vertical reactor 8 cm in diameter and 15 cm long. In the middle of the reactor is a perforated steel plate upon which the pellets rest. The reactor is enclosed in a temperature controlled electrically heated oven (Figure 4). The flow of air into the bottom of the reactor is controlled by mass flow regulators and heated to temperature before reaching the feedstock, which is continuously fed into the top of the reactor.[17] The pellet feed rate is controlled by a vibratory bowl feeder to provide a nearly continuous feedstock flow.

Once removed from the reactor, the syngas passes through a vertical steel tube to cool it and collect condensed water and tars, before being filtered and bubbled through isopropanol. The syngas is then sampled once every three minutes using a micro-gas chromatograph Agilent 490 Micro Gas Biogas Analyzer and Open Labs software.

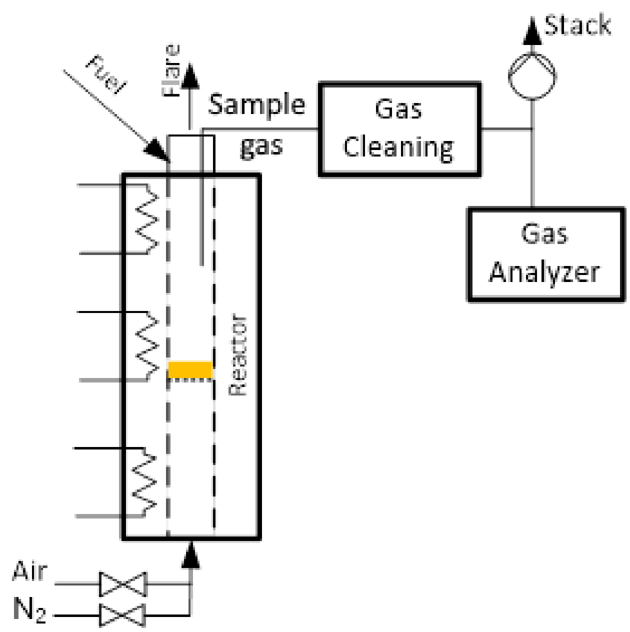


Figure 4: Simplified sketch of the test gasifier.

[17] The set-up corresponds to an "up draft" gasifier where incoming feedstock from the top meets hot gas from the bottom.

At the start of each experiment the reactor is heated by the oven while air enters through the bottom at a flow rate of 6 liters per minute (chosen flow rate is based on earlier experiences with the reactor). The pellet feed rate is then set based on the fixed air flow to provide a suitable feedstock to air ratio in the reactor. The pellet feed starts when stable temperatures inside the reactor have been reached.

The first phase of each experiment provided transient gas conditions, during which time the pellet bed was building up. Stationary operation was reached after about 30 minutes when a sufficiently high pellet bed had formed on the perforated plate inside the reactor. Average gas concentrations, presented later, were calculated from stationary operation only. Each test ended when all pellets had been fed into the reactor. When the pellet feeding ended, the air flow was reduced and N was added to help cool the reactor. After the reactor had cooled, ash in the reactor was collected, weighed and analysed.

4.3 Syngas Results

Average gas concentrations and specific lower heating values (LHV) of the syngas produced during the six gasification tests are given in Table 6 and Figure 5. The important gases for renewable energy production are Hydrogen (H), Carbon Monoxide (CO) and Methane (CH_4). The LHV is important because it represents the amount of heat produced when syngas is combusted.[18] The higher the LHV, the more heat and therefore more value the syngas has. As a point of reference, coal generally has a LHV of ~15,000 - 25,000 kJ/kg and wood generally has a LHV of ~10,000 – 15,000 kJ/kg.

All feedstock mixtures of used litter and bedding produced high quality syngas. These results suggest that used bedding and litter are not that dissimilar to wood pellets (although not quite as good) for handling, feeding into the gasifier, tar levels, and energy content. This is perhaps not that surprising as both the used litter and bedding tested contained large amounts of wood shavings.

Any variations in syngas compositions in Table 6 and Figure 5 between the six feedstock mixtures was caused by factors other than the feedstock mixture ratio, such as slight variations in bed temperatures and feedstock feeding rates. Therefore, the design and operational parameters of a full-scale gasification plant will have much greater impact on the quality of syngas produced than the mixing ratios of used bedding and litter.

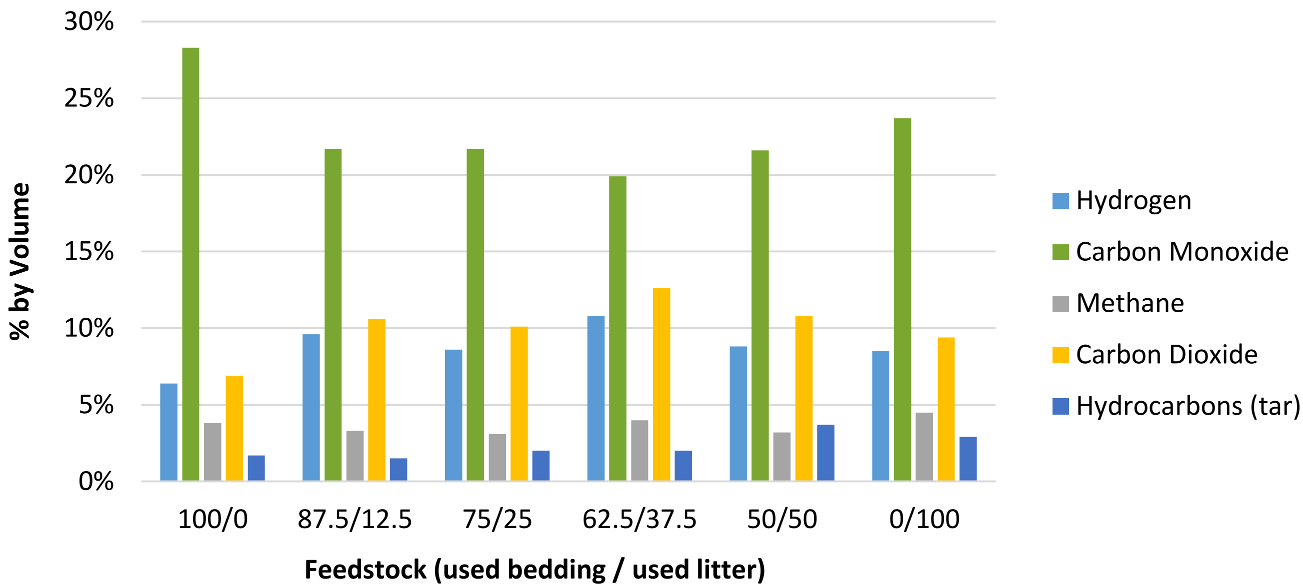
Table 6: Average Syngas Concentrations (% by volume) and Lower Heating Value

Gas	Feedstock (Used Bedding/Used Litter %)					
	100/0	87.5/12.5	75/25	62.5/37.5	50/50	0/100
Hydrogen	6.4	9.6	8.6	10.8	8.8	8.5
Carbon monoxide	28.3	21.7	21.7	19.9	21.6	23.7
Methane	3.8	3.3	3.1	4.0	3.2	4.5
Carbon dioxide	6.9	10.6	10.1	12.6	10.8	9.4
Hydrocarbons (tar)	1.7	1.5	2.0	2.0	3.7*	2.9
LHV (kJ/kg)	5,636	4,954	5,043	5,375	6,091	6,413

** Test had lower feedstock bed temperature, likely explaining the increased concentrations of hydrocarbons.*

[18] The LHV of a fuel is defined as the amount of heat released by combusting.

Figure 5: Average Syngas Concentrations (% by volume)



4.4 Ash Results

The first gasification test, performed with pellets of 100% used bedding and at a temperature of 860°C, resulted in significant ash sintering (Figure 6). While somewhat surprising, as results from the proximate and ultimate analysis of used bedding show a sintering temperature of >1,100°C, it is assumed that this lower sintering temperature was due to uneaten hay in the used bedding. Because of the sintering, all gasification test, including the 100% used bedding test which was repeated, were performed at a temperature of 760°C.

The amount of ash remaining after the gasification tests ranged from 5.2 – 7.9% by mass (Figure 7). These yields were lower than expected from the proximate and ultimate analysis of used bedding and litter (7.6% and 10.5%, respectively). While some ash losses did occur from the reactor, as fly ash for example, it is puzzling that there was no clear pattern between ash yield and feedstock mixture, even though the proximate and ultimate analysis suggests that ash yield should be higher for feedstock mixtures with higher ratios of used litter.

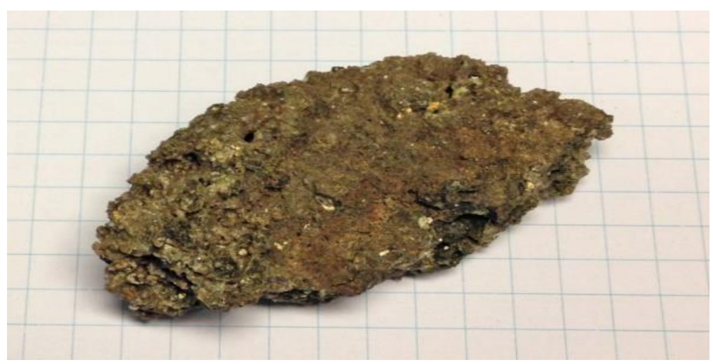


Figure 6: Sintered ashes from the first 100% used bedding gasification test (squares on the paper are 5 mm).

Sieving of the ash samples provided size distributions (Figure 8). Most notable is that the ash from 100% used bedding pellets showed a higher fraction of large particles (> 3 mm), most likely caused by partial ash sintering.

Figure 7: Ash Collected from Gasification Reactor (% of feedstock)

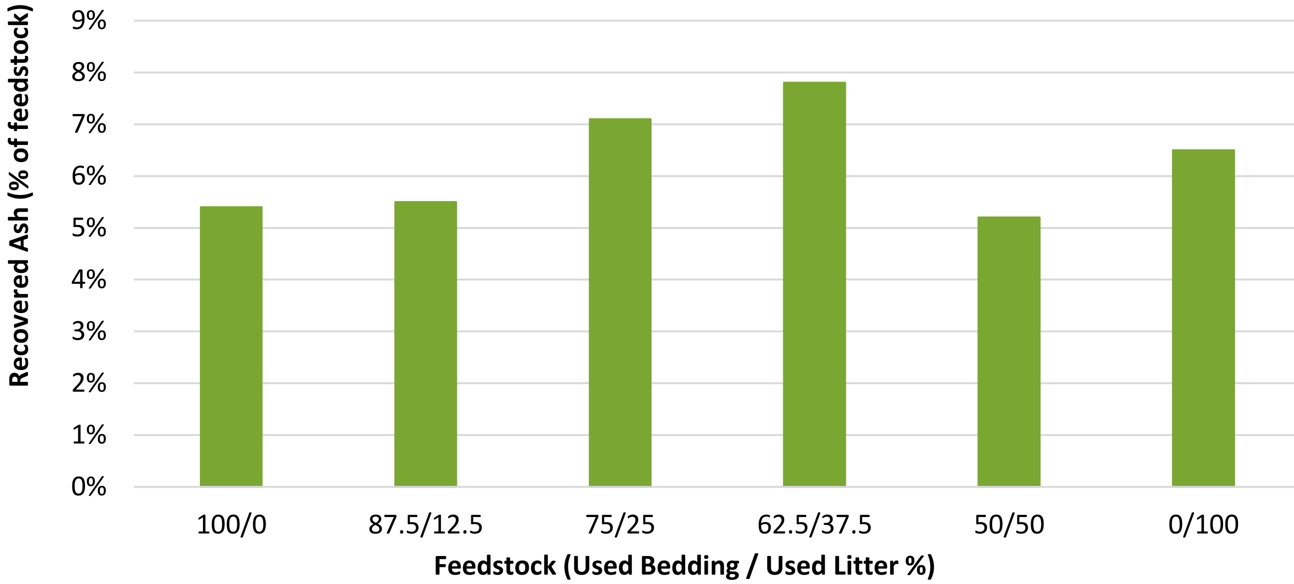
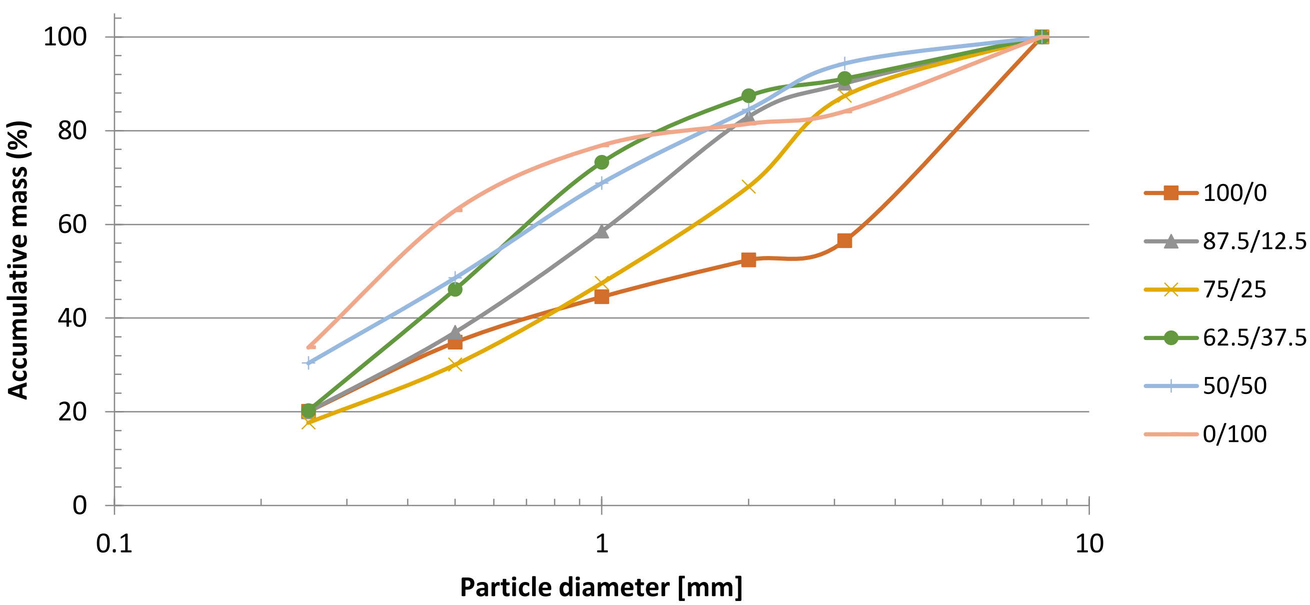


Figure 8: Accumulative Mass Distribution of Ash (used bedding to litter ratios)



Obtaining value from the ash by-product is important. Landfilling is expense and may be interpreted as a waste of valuable nutrients. The primary nutrients of economic value in ash from gasification are P and K; there is little N because any N in the feedstock is converted to gaseous forms during gasification. Other nutrients contained in the ash, such as Sulphur (S), Magnesium (Mg) and Calcium (Ca), may also provide marketing benefits.

Elemental compositions of the ash samples were investigated using an x-ray fluorescence analyzer. Conventional fuel analysis methods were also used to measure for Carbon, H, N, Boron, Sodium and 'inert fraction'[19] (Table 7). The trends of P, K, Ca, Chlorine (Cl), Silicon (Si), and Mg as functions of feedstock mixture are shown in Figures 9 and 10. This clearly illustrates that the content of P, Mg and Ca in ash increase with the amount of used litter in the feedstock mixture, while the content of Cl, K[20] and Si increase with the amount of used bedding.

Table 7: Elemental Compositions of Ash Samples (mass % in ash)

	Use Bedding / Used Litter %					
	100/0	**87.5/12.5**	**75/25**	**62.5/37.5**	**50/50**	**0/100**
Inert fraction* (ds)	74.4	57.3	83.4	40.7	75.5	64.5
Carbon* (C)	23.7	40.7	16.0	56.0	23.0	32.4
Hydrogen* (H)	0.3	0.3	0.2	0.4	0.3	0.3
Nitrogen* (N)	1.30	0.59	0.35	1.30	0.69	0.75
Boron* (B) µg/g	110	50	70	60	70	60
Sodium (Na)	2.27	2.39	2.36	2.24	2.30	2.28
Chlorine (Cl)	4.20	4.66	3.65	3.74	3.32	2.16
Sulphur (S)	2.62	2.72	3.06	2.85	2.77	2.40
Phosphorous (P)	3.10	4.20	6.52	6.84	7.74	10.70
Potassium (K)	20.3	20.0	12.2	15.5	13.5	11.0
Palladium (Pb)	0.00	0.00	0.00	0.00	0.00	0.00
Zinc (Zn)	0.13	0.09	0.16	0.15	0.14	0.20
Silicon (Si)	5.20	4.84	3.74	3.88	2.93	1.41
Aluminum (Al)	0.48	0.29	0.31	0.38	0.21	0.32
Magnesium (Mg)	0.00	0.00	1.29	1.36	1.46	1.60
Calcium (Ca)	9.19	10.2	13.7	13.5	13.8	16.5
Iron (Fe)	3.60	2.35	3.31	2.65	2.33	1.66
Titanium (Ti)	0.08	0.06	0.06	0.06	0.05	0.05
Manganese (Mn)	0.25	0.24	0.34	0.31	0.35	0.41
Chromium (Cr)	0.32	0.18	0.29	0.40	0.25	0.16
Copper (Cu)	0.18	0.22	0.36	0.31	0.27	0.20
Nickel (Ni)	0.14	0.11	0.20	0.11	0.13	0.05

** = dry sample. Note: Bicarbonate (HCO_3) is dissolved at 200°C and was therefore not found in the ash.*

[19] Inert fraction denotes the inorganic fraction of the ash samples obtained from the experiments.
[20] Hay has a high K content and the relationship between the content of K in the ash and the amount of used bedding in the feedstock mixture indicates that the low sintering temperature of 100% used bedding may have been due to hay.

Figure 9: Concentrations of P, Mg and Ca in Ash (used bedding to litter ratio)

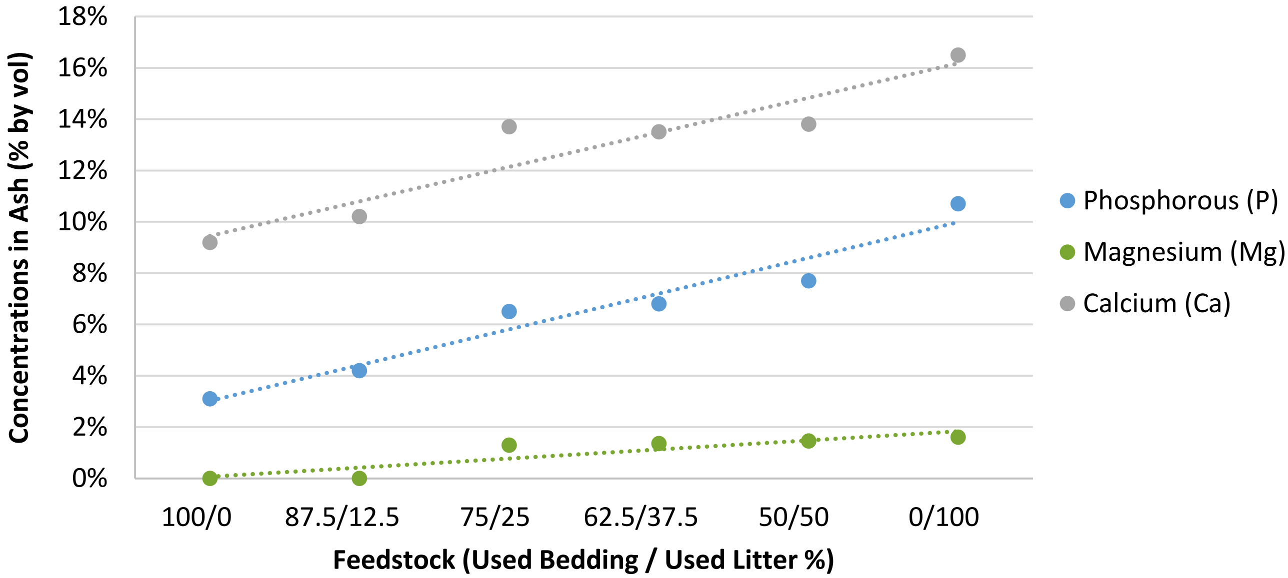
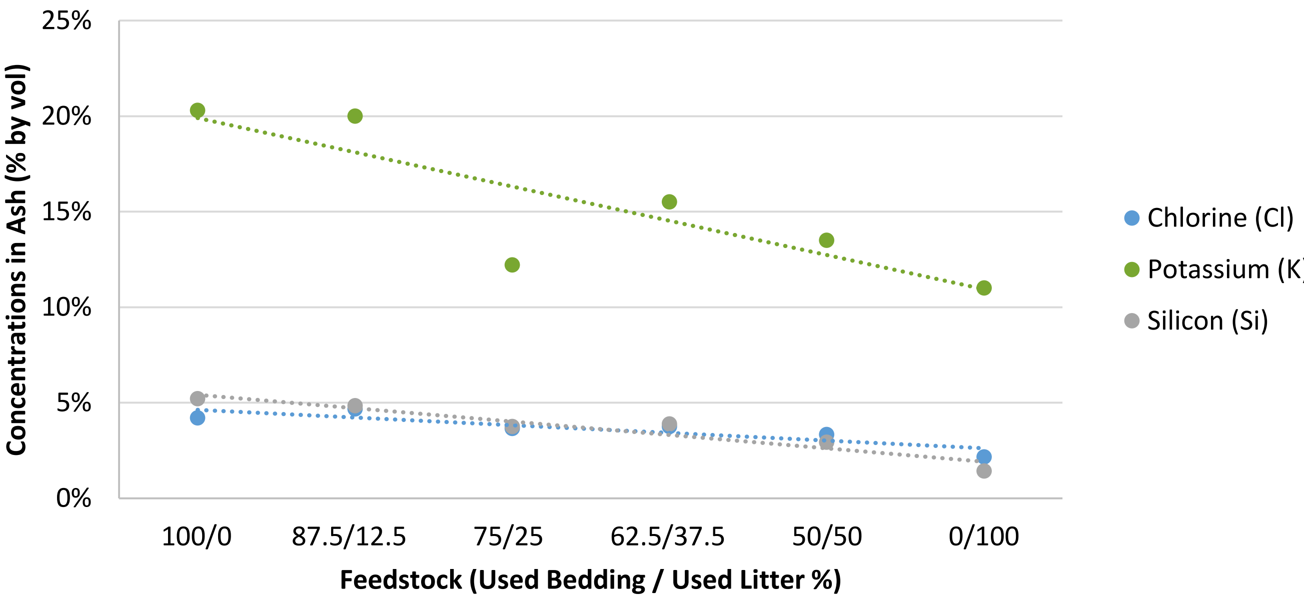


Figure 10: Concentrations of Cl, K and Si in Ash (used bedding to litter ratio)



4.5 Summary

Results from the gasification tests show that used bedding and litter produce high quality syngas, and that different feedstock mixtures of used litter and bedding have little impact on energy production, quality, and tar levels. The only problem encountered during the gasification tests was with gasifying 100% used bedding, which resulted in significant ash sintering at a temperature of 860°C. This suggests that if high gasification temperatures are used (>800°C), used bedding should be mixed with >12.5% used litter to avoid sintering.

Ash yields from the gasification tests were lower than expected and there was no pattern between ash yield and feedstock mix. However, there were clear patterns between P, Mg and Ca in the ash, which increased with the amount of used litter gasified, and Cl, K and Si, which increased with the amount of used bedding gasified.

Based on the syngas and ash quality and quantity results from the gasification tests, it is clear that the driver for choosing which feedstock mixture of used litter and bedding to gasify should be based on the cost and difficulty of feedstock acquisition.

5. Technology Selection

5.1 Gasification Technology & Energy Generation Choice

Gasification Technology Options

There are three types of gasification technology suitable for used bedding and litter; updraft, downdraft and fluidised bed. When deciding which technology is most suitable for used bedding and litter in the Lower Mainland, it is important to consider:

- Tolerance for feedstock heterogeneity: differences between housing climate, bedding material, and management practices can impact size, moisture content and composition of used bedding and litter, while pre-processing, such as pelletizing, is costly;
- Scalability: only a plant that gasifies large volumes of feedstock will provide equine facilities and broiler farms in the Lower Mainland with a year-round, long-term alternative to local land application;
- Temperature control: ash sintering temperature of used bedding is low; and
- Syngas quality: significant tar and particulate removal can be costly.

Feedstock enters an updraft gasifier from the top of the reactor while the oxidation agent (air, O_2, etc.) is added from the bottom. Near the bottom of the reactor is a grate on which the feedstock rests, while produced syngas flows upwards. Updraft gasifiers are simple and robust, have high thermal efficiency and carbon conversation, good scale-up potential, and are able to gasify a range of feedstocks. The disadvantages of updraft gasifiers are that they produce syngas with high tar and particulate levels. These tars and particulates must be removed if the syngas is to be burnt to produce renewable electricity.[21]

Feedstock also enters a downdraft gasifier reactor from the top, while the oxidation agent (air, O_2, etc.) is added from the side. Produced syngas flows downwards. Downdraft gasifiers are simple and reliable, and because syngas passes through a hot bed of char as it flows downwards, tar levels are low. The disadvantages of downdraft gasifiers are that they have low tolerance for differences in feedstock size and quality, meaning feedstock often requires pelletizing. Downdraft gasifiers are also hard to scale-up.

Fluidised bed gasifiers use a fluidising agent, such as silica sand. Feedstock enters a fluidised gasifier reactor from the side or bottom, while the oxidation agent enters from the bottom with enough velocity to fully suspend or 'fluidize' the reactor bed. Operating at lower temperatures of 800 – 850^{o}C, fluidising bed gasifiers have a high mixing and reaction rate (due to contact between the syngas, feedstock, and reactor bed), a high tolerance for variation in feedstock size and quality, good temperature control, and good scale-up potential. The disadvantages of fluidised bed gasifiers are that despite moderate tar levels, which means the syngas can be burnt to produce renewable electricity, the technology is more complex than updraft and downdraft gasifiers, and carbon conversion is lower.

[21] Lower quality syngas is best used in heating systems.

Energy Generation Pathways

There are two possible energy generation pathways for syngas that are relevant for syngas from the gasification of used litter and bedding in the Lower Mainland; heat or heat and electricity. When deciding which energy generation pathway is most suitable for syngas produced by gasifying used litter and bedding in the Lower Mainland, it is important to consider:

- Energy demand: the gasification plant will produce heat or electricity twenty-four hours a day, year-round (if heat or electricity cannot be sold when produced it will go to waste);
- Price: B.C. Hydro pays ~$111/MWh for renewable electricity, heat will have to be cost-competitive with natural gas at ~$7/GJ (1MWh = 3.6GJ); and
- Infrastructure: to sell heat, on-site piping will be necessary, to sell electricity interconnection to B.C. Hydro's distribution system is required.

Technology and Energy Choice

Fluidised bed gasification technology is deemed to be the most suitable for gasifying used litter and bedding in the Lower Mainland (Table 8). This is because this technology will be able to tolerance the differences in size, moisture content and composition of used bedding and litter from different equine facilities and broiler farms, it can be scaled-up to gasify large volumes of feedstock, and the lower operating temperatures will help to avoid ash sintering of used bedding. While the syngas quality from fluidised bed gasification isn't as good as from downdraft gasification, any tars and particulates in the syngas can be removed.

Table 8: Comparison of Gasification Technologies

Technology Considerations	**Technology Type**		
	Updraft	**Downdraft**	**Fluidised Bed**
Tolerance for feedstock heterogeneity	Fair	Poor	Good
Scalability	Good	Poor	Good
Temperature control	Poor	Poor	Good
Syngas quality	Poor	Good	Fair

Production of heat and electricity is deemed to be the most suitable energy generation pathway for the syngas produced by gasifying used litter and bedding in the Lower Mainland (Table 9). This is because injecting electricity onto B.C. Hydro's distribution system year-round is much easier than finding a large heat sink that requires heat year-round. Furthermore, while infrastructure cost to produce heat and electricity are greater than those to produce just heat, the price for selling renewable electricity will more than compensate for these costs.

Table 9: Comparison of Energy Generation Pathways

Energy Considerations	**Energy Pathway**	
	Heat	**Electricity (and heat)**
Energy demand	Challenging	Easier
Price	~$7/GJ (equivalent to $25/MWh)	$111/MWh
Infrastructure	Cheaper	More expensive

Technology Supplier

A search was conducted to find a suitable fluidised bed gasification technology supplier in North America or Europe with experience gasifying feedstocks similar to used bedding and litter. From this search, EQTEC, a well-established Spanish gasifier supplier specializing in gasification of wet feedstocks, was selected. The proposed 50,000 tonne/year EQTEC gasification plant will gasify 37,500 tonnes/year of used bedding (75%) and 12,500 tonnes/year of used litter (25%) to produce syngas. The syngas will be cleaned and combusted in Combined Heat and Power (CHP) engines to produce renewable electricity and heat. The electricity will be sold to B.C. Hydro under the Standing Offer Program (SOP), while heat will be used to dry the used bedding and litter to 12% moisture content before gasification. Any remaining heat will be sold locally.

The proposed gasification plant size and feedstock mix were based on estimated amounts of available used bedding and litter in the Lower Mainland. Because feedstock mixes of used litter and bedding have been shown to have little impact on syngas quality and ash yield, the following gasification plant design, site selection and feasibility assessment will be similar regardless of the ratio of used bedding and litter gasified. The one exception is 100% used bedding, as ash sintering may occur.

5.3 EQTEC Gasification Plant & CHPs

EQTEC's fluidised bed gasifier transforms feedstock in a thermo-chemical process to produce syngas, containing H, CO and CH_4 (Figure 11). Once subjected to conditioning for solid particles removal, thermal cracking of tars, filtration, and subsequent cooling and adsorption of soluble contaminants, the clean syngas is combusted in CHPs coupled with alternators to produce renewable electricity. All undesirable products are removed from the syngas during the cleaning process, ensuring that the only by-product is ash.

Figure 11: Photo of an EQTEC gasification plant.

The proposed EQTEC plant for gasifying 50,000 tonnes/year of used bedding and litter in the Lower Mainland consists of the following key pieces of equipment:

- Feedstock storage, drying, and ash storage;
- Feeding system;
- Gasifier reactor;
- Syngas cleaning and cooling system;
- Water treatment plant;
- Thermal oxidizer;
- CHP plant; and
- Control panels and monitoring equipment.

Feedstock Storage, Drying and Ash Storage

Used litter and bedding requires storage, mixing and drying before being fed into the fluidized-bed gasifier reactor. The total amount of used bedding and litter is 50,000 tonnes/year, consisting of 37,500 tonnes of bedding (75%) and 12,500 tonnes of litter (25%). Operating for 360 days/year, the gasification plant will process 104 tonnes/day of used bedding and 35 tonnes/day of used litter; roughly four daily truckloads of used bedding and two of used litter. The used bedding has an estimated moisture content of 60%, while the used litter has an estimated moisture content of 25%. The moisture content of the feedstock mix is thus 51%.

The used litter and bedding will be delivered by self-unloading trucks. The trucks will drive into the storage building and discharge their loads into storage bays consisting of concrete slabs with lock-block walls (two and a half meters high) on three sides. The lowest row of lock blocks will be sealed to prevent any seepage. The storage bays will have a 1 – 2% decline towards the open side of the bays, ensuring that any run-off flows towards concrete trenches covered with a grate and is collected. The used bedding storage bay will be 20m by 40m (total storage of 800m^3) while the used litter storage bay will be 10m by 40m (total storage of 400m^3) to ensure sufficient storage for four days.[22]

A front-end loader will move used litter and bedding from the storage bays to a feedstock pocket (15m by 15m), where it will automatically be mixed in the correct proportions (3:1) to create a uniform feedstock, before being automatically fed onto a conveyor belt dryer. Inside the dryer, the feedstock will be dried to 12% moisture content using heat recovered from the gasification plant, before being delivered to the gasifier reactor feeding system. When dried to 12% moisture content, tonnage of used bedding and litter will be reduced to 17,050 and 10,650 tonnes, respectively (for a total of 27,700 tonnes).

When the feedstock is gasified, ash by-product is created. With an estimated ash content of 8% of dry mass and gasifying 50,000 tonnes/year of horse bedding and poultry litter at 51% moisture content, it is estimated that 2,000 tonnes/year of ash (5.6 tonnes/day) will be produced. The ash will be stored in a 100m^3 elevated silo to ensure sufficient storage for at least two weeks.[23]

Feeding System
The feeding system consists of three hoppers in series. The first, atmospheric hopper, receives the feedstock from storage. Equipped with a level sensor to regulate filling, a screw conveyor at the bottom of the hopper discharges feedstock into the second hopper. The second hopper has a level detector to activate this screw conveyor when feedstock is required. During feedstock transfer between the hoppers, the second hopper is at atmospheric pressure.

A third hopper is located beneath the second hopper. When the third hopper requires feedstock, the second hopper is sealed and pressurised with air to match the pressure in the third hopper. Once achieved, the third hopper opens to receive the feedstock. The feedstock is then fed into the gasifier reactor with a water cooled screw feed. Once closed, the second hopper is blanketed with N for gas and air evacuation, ensuring that it is clean and safe to receive the next load of feedstock at atmospheric pressure.

Gasifier Reactor
The fluidized-bed gasifier reactor consists of a steel cylinder internally insulated with a refractory lining, where gasification takes place at 750 – 850^{o}C and slightly above atmospheric pressure. The fluidized-bed reactor (Figure 12) functions with a fluidized mix of bed material and feedstock. The gasification agent (air) flows in from the reactor bottom, fluidizing the bed material of inert quartz sand. 3.1 tonnes/hr of 12% moisture content used bedding/litter feedstock mixture is fed into the reactor, where constant turbulence of feedstock and bed material ensures good contact between both, while preventing a partitioning of reaction areas (the process of drying, pyrolysis, oxidation and reduction takes place in the entire reaction chamber).

[22] Assumed bulk density of 550kg/m^3 for used bedding and 400kg/m^3 for used litter.
[23] Assumed ash bulk density of 800kg/m^3.

Natural gas is required during start-up to achieve appropriate temperature inside the gasifier reactor. Once optimum operating conditions are reached, the process becomes auto-thermal. Syngas leaves the gasifier with ash particles from the top of the reactor, while ash particles also leave from the bottom of the reactor.

Bed material is continuously extracted from the gasifier reactor to be cleaned. A water cooled screw sends all extracted material to a hopper. The hopper is water cooled to reduce the temperature of the extracted material. The material is then sent to a vibrating sieve with two particle size screens to obtain three different flows. Particles of small and large size are collected in a hopper, while particles of intermediate size are recirculated back to the reactor. New bedding material is added to the reactor to make-up for any losses.

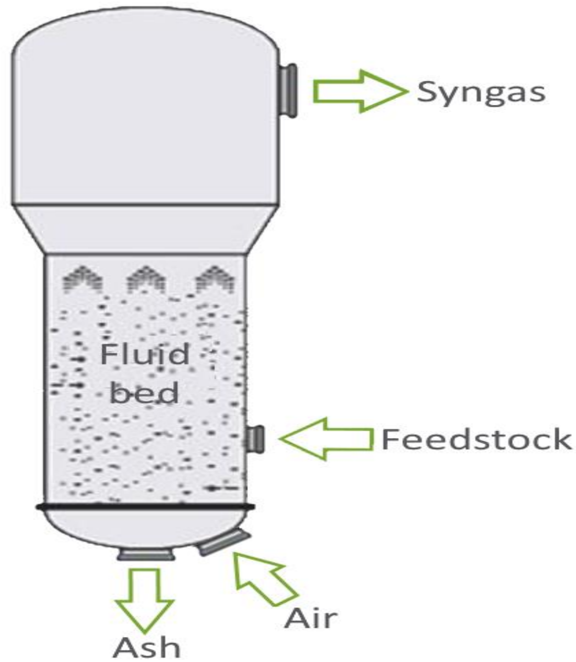


Figure 12: Bubbling fluidized-bed gasifier.

Syngas Cleaning and Cooling System

When syngas leaves the reactor, it enters a cyclone precipitator to remove ash and char (Figure 13). A high speed rotating flow is established within the precipitator in a helical pattern, beginning at the top (wide end) of the cyclone and ending at the bottom (narrow end), before exiting the cyclone in a straight stream through the centre of the cyclone and out the top. Larger (denser) particles in the rotating stream have too much inertia to follow the tight curve of the stream, and strike the outside wall of the precipitator and fall to the bottom, where they are removed. These particles can be re-circulated back to the reactor to maximise syngas production, or collect in a hopper.

Once the syngas has passed through the cyclone precipitator, it undergoes thermochemical treatment to reduce tar levels to mg/m^3 syngas. This is achieved by adding pre-heated oxygen to increase the temperature and cause hydrocarbons (tars) to become gas. Syngas then leaves the thermal cracker and is cooled to 340^{o}C. Recovered heat from syngas cooling is used to reheat the syngas before it is driven to the CHPs, and is sent to the conveyor belt dryer to dry the feedstock before it enters the gasifier reactor.

Cooled syngas is then filtered to remove particulate matter. As particle cake develops on the surface of the media filter, pressure inside the filter drops. Once a terminal pressure is reached, the filter element is cleaned with a pulse of N_2 to dislodge the particle cake. A screw conveyor is used to remove the filter ash into a hopper. Possible remaining tar condensation is prevented by maintaining a minimum temperature of 340^{o}C.

Figure 13: Cyclone precipitator.

After filtration, and because the presence of pollutants (ammonia, Cl, S and hydrogen chloride) in the syngas still exceed CHP engine limits, a water scrubber is used. The water scrubber removes contaminants by first cooling the syngas to 80°C, and then using venture-type scrubbers where syngas temperature is reduced further to 40°C[24]. Once the saturated syngas leaves the cleaning system, dynamic precipitators are used to remove water from the syngas. All water used in the cleaning process is sent to the water treatment plant.

Water Treatment Plant & Thermal Oxidizer

Process water from scrubbers and condensers with tars and particles removed from the syngas is sent to the water treatment plant where it is clarified for recirculation. The process water enters the treatment plant's agitator tank for homogenization and, if necessary, to adjust pH before flocculants are added. The process water/flocculants mix then enters the Dissolved Air Floatation (DAF) unit where pressurized air is injected to create bubbles (Figure 14). Suspended particles in the water adhere to the micro bubbles, floating them to the surface. Once at the surface, the particles are collected and stored in a tank. Cleaned water effluent from the DAF unit is filtered before being pumped back to the water scrubber.

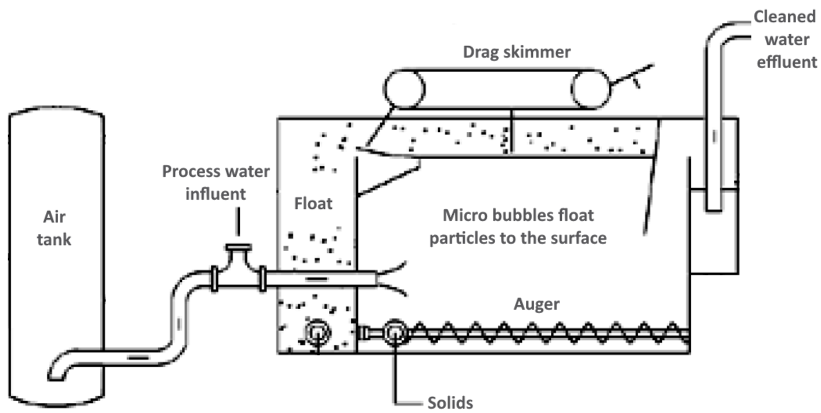


Figure 14: Dissolved Air Flotation Process.

Tars and particles recovered from the DAF unit, as well as water flow purge, are sent to the thermal oxidizer. The thermal oxidizer oxidizes tar, particles, and water flow purge from the DAF unit, as well as syngas during start-up and transient periods when the CHP engines are not running. Combustion inside the thermal oxidizer is at 850°C for two seconds. Due to the thermal oxidizer, the only by-product from the gasification plant is ash.

CHP Plant

The CHP plant consists of two Jenbacher 620 engines and alternators. These four stroke, turbo compressed and after cooled engines each have a high and low temperature water cooling circuit, water jacket, and exhaust gas stack with three-way vale. Heat from the CHP water jackets can be used on-site, while heat from the exhaust gas stack is sent to the conveyor belt dryer to dry the feedstock before it enters the reactor.

Control and Monitoring Equipment

The gasification plant will be equipped with a PC based control, monitoring and supervision station, including appropriate monitor, software and hardware. The main functions of the control and monitoring system are for gasification plant operation and monitoring, parameter setting and adjustments, data acquisition, and alarm, status and message processing.

5.4 Energy Balance & Plant Layout

The EQTEC fluidised bed gasification plant will produce 10MW of cleaned syngas (thermal power). This syngas will be combusted in CHP engines to produce 3.95MW of electricity for sale to B.C. Hydro. Heat from the CHP exhaust gas stack will be used to dry the feedstock before it enters the reactor, while 1.85MW of heat (as 90°C hot water) will be available for sale locally (Figure 15). The physical footprint of the gasification plant is

[24] Prior to combustion, syngas is re-heated to 60°C to prevent condensation during transfer and when mixed with combustion air.

estimated to be around 8,000m^2 (Figure 16). This space is required for optimum layout of feedstock storage and drying, ash storage, the gasification and CHP plants, control and administration rooms, and feedstock delivery.

Figure 15: EQTEC Gasification Plant Energy Balance

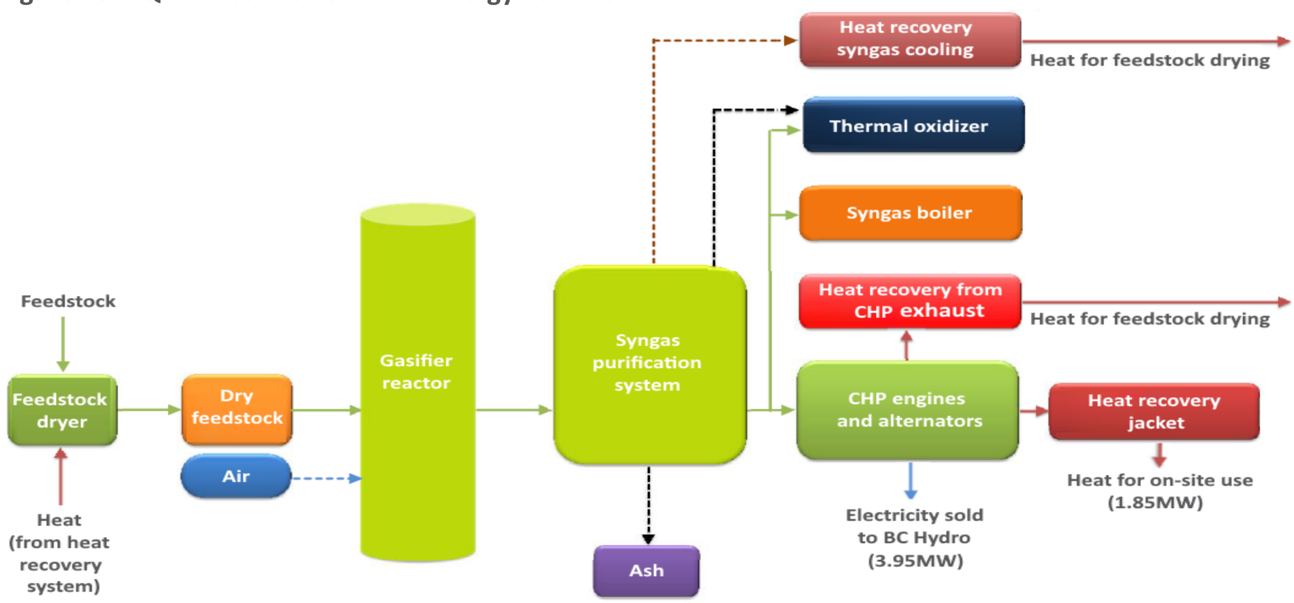
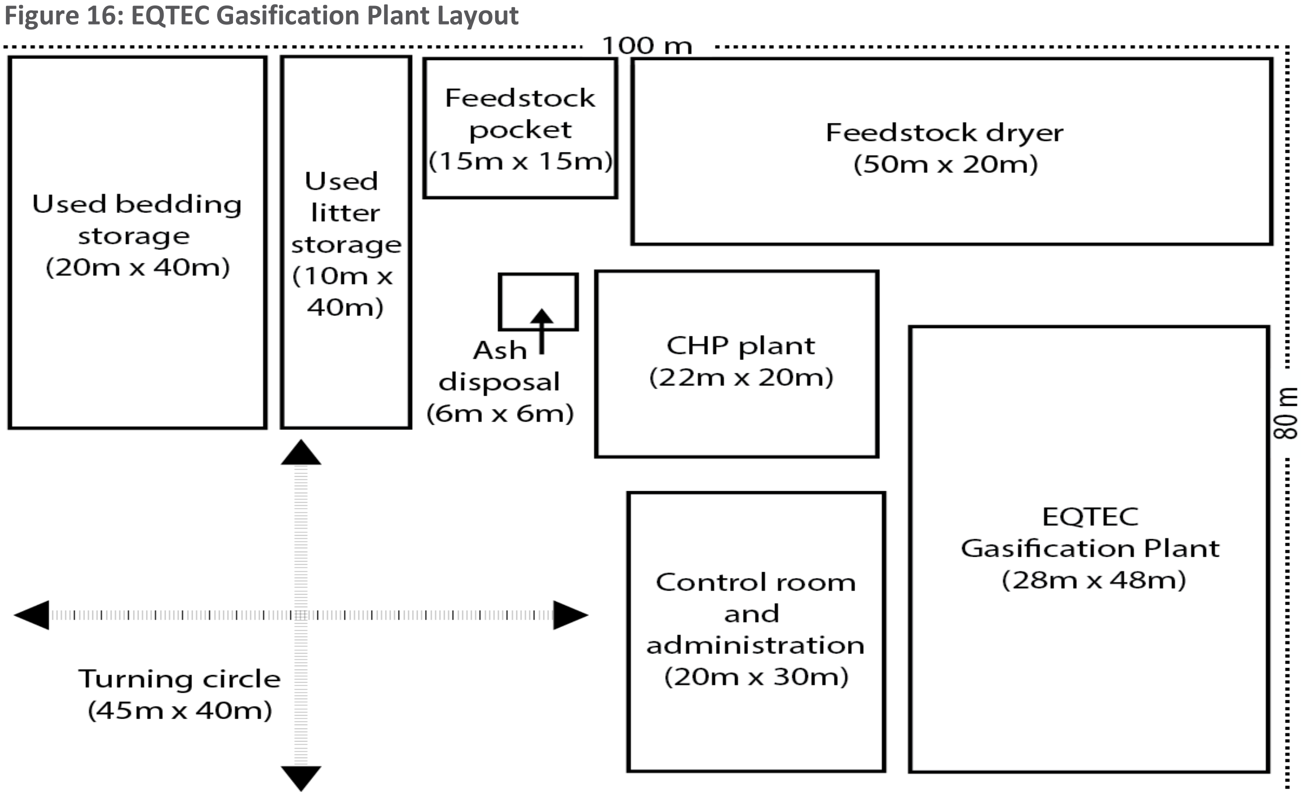


Figure 16: EQTEC Gasification Plant Layout



6. Site Selection

When searching for potential sites in the Lower Mainland to locate the gasification plant, the key variables to consider are that the sites must:

- Be within close proximity to feedstock and have sufficient local heat demand;
- Have appropriate site characteristics for a gasification plant; and
- Be able to connect to the B.C. Hydro grid with minimal difficulties.

6.1 Feedstock & Heat Demand

Based on the Statistic Canada's Census of Agriculture data and industry estimates, horse and broiler populations in the Lower Mainland are concentrated in the CCS of Langley and Abbotsford. Therefore, the gasification plant should be located within or close to these municipalities to minimize feedstock transportation costs.

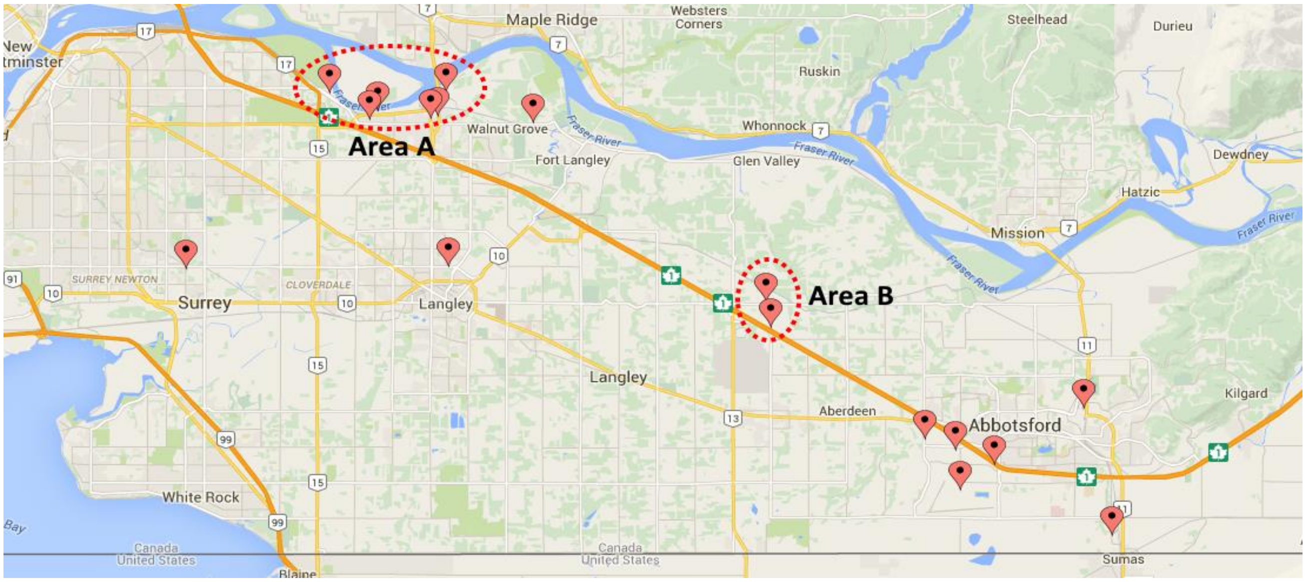
There is little publically available information on large heat users in or around Langley or Abbotsford. To create a list of potential sites that may have sufficient heat demand to utilize the 1.85MW (60,000GJ/year) of heat (as 90^{o}C hot water) from the CHP heat recovery jackets, information from Business in Vancouver and municipal economic development offices was used to determine the largest manufacturers, based on number of employees, in Surrey, Langley and Abbotsford (Table 10 and Figure 17).

Table 10: Largest Manufacturers by Manufacturing Staff/Employees

Company	Product/Service	Municipality	Staff/Employees
Starline Windows Group	Windows	Langley	1,000*
Canada Bread Co	Food Products	Langley	750*
EV Logistics	Food Warehousing	Langley	750**
Sunrise Farms	Food Products	Surrey	675*
Teal-Jones Group	Lumber	Surrey	570*
Cascade Aerospace	Aircraft Maintenance	Abbotsford	>500**
Vedder Transport	Warehousing	Abbotsford	>450**
S&R Sawmills	Lumber	Surrey	390*
FG Deli Group	Food Products	Langley	350**
LMS Reinforcing Steel Group	Steel Fabricator	Surrey	350**
Dynamic Windows & Doors	Windows & Doors	Abbotsford	>300*
JD Sweid Foods	Food Products	Langley	300*
Vitrum Industries	Glass	Langley	200*
Highland Foundry	Casting	Surrey	110*
Clearbrook Grain and Milling	Animal Feed	Abbotsford	Unknown†
Lhoist North America Of Canada	Lime Manufacturing	Langley	Unknown†
Lilydale	Food Products	Abbotsford	Unknown†

** Manufacturing staff. ** Employees. † Identified by economic development office as 'large employer'.*

Figure 17: Largest Manufacturers by Manufacturing Staff/Employees



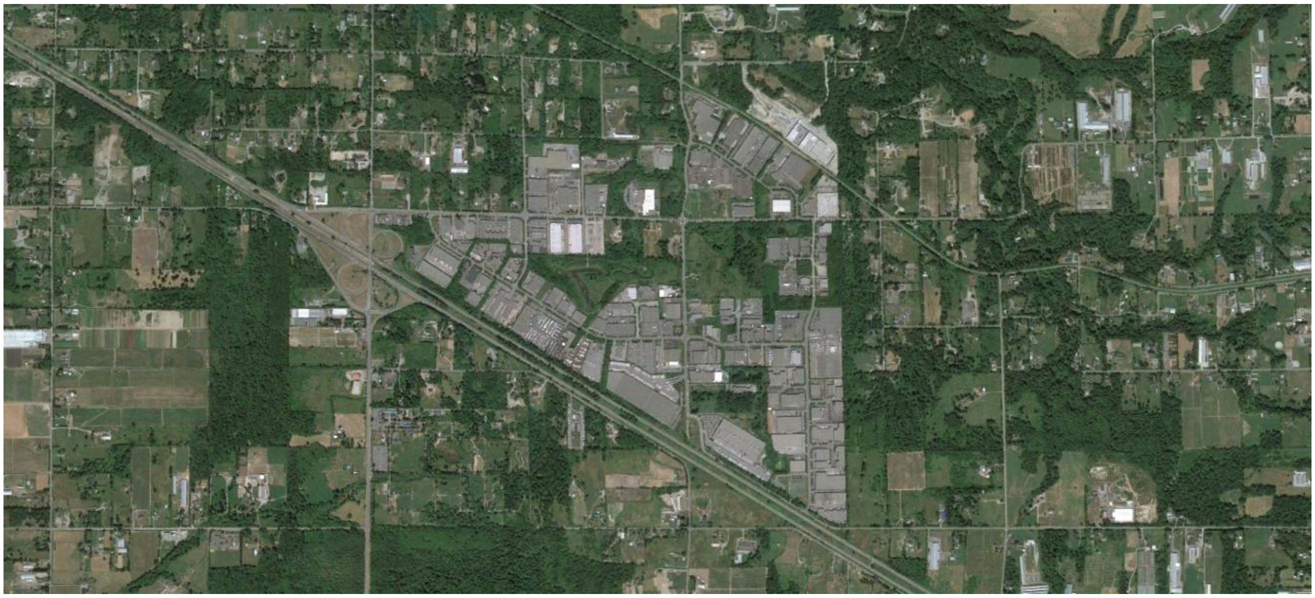
6.2 Characteristics

For a site to be suitable for a gasification plant it should not be close to residential areas, or at least be located near other heavy industry. The site must also have sufficient land (>8,000m^2) for optimum layout of buildings and feedstock delivery, and be accessible through existing roads. Of the sites identified in Table 10, two areas of interest stand out. These are Area A on the boarder of Langley and Surrey near the Golden Ears Bridge (Figure 18), and Area B on the boarder of Langley and Abbotsford near Highway 1 (Figure 19).

- Area A: heavily industrialised with some available space and several large manufacturers, including Lhoist, Teal-Jones Group, Highland Foundry, S&R Sawmills, JD Sweid Foods, and Vitrum Industries; and
- Area B is less industrialised but has plenty of available space, is far from residential areas and contains a few manufacturers, including EV Logistics and FG Deli Group.

Figure 18: Google Earth Image of Area A

Figure 19: Google Earth Image of Area B



6.3 Interconnection

To sell renewable electricity under B.C. Hydro's SOP a gasification plant must be able to connect to B.C. Hydro's distribution system. While connection is often technically possible, cost can vary greatly depending upon a variety of distribution system factors, including:

- Distance to the closest B.C. Hydro distribution feeder;
- Required distribution conductor upgrades on the B.C. Hydro system; and
- Ability to inject renewable electricity into the distribution system at the identified point-of-interconnection (feeder capacity).

To determine potential for connection to B.C. Hydro's distribution system, a Basic Distribution System (BDS) Information request was submitted to B.C. Hydro for two sites within Areas A and B.

Distance to Closest Distribution Feeder

The Point of Interconnection (POI) is estimated based on the shortest perpendicular line from a proposed location to the closest B.C. Hydro distribution feeder. Generally speaking the shorter the distance the lower the interconnection cost.[25] For the sites in Area A and B, connection to B.C. Hydro at the POI only requires a few hundred meters of private 25 kV line. This indicates that there are distribution feeders in both areas.

Required Distribution Conductor Upgrades

For the POIs identified for Area A and B there are zero km of single phase line that require upgrading. This indicates that both areas have 3-phase line.

Feeder Capacity

The capacity to inject electricity into the distribution system can be limited by conductor size, existing generation, and the Short Circuit Ratio (SCR). Conductor sizes for Areas A and B are large enough for the proposed gasification plant, while there is currently zero MW of committed or installed generation on the

[25] In some cases land ownership or other issues may make shortest route infeasible and distances may be greater.

feeders in Area A or B. The SCR for Areas A and B, calculated to determine the characteristics of generator stability and the impacts to the feeder voltage profile and power quality, are 12 and 13, respectively. Any SCR >7 indicates that reconductoring or upgrading is likely insignificant.

6.4 Summary

A list of potential sites in Surrey, Langley and Abbotsford were identified that could potentially have sufficient local heat demand to utilize all or most of the 1.85MW (60,000 GJ/year) of available hot water from the CHP heat jackets. From these sites, two areas of interest were identified that are far enough away from residential areas or located near heavy industry, with sufficient land for buildings and feedstock delivery, and accessible through existing roads. Both sites were assessed for their potential to connect to B.C. Hydro's distribution system, and these assessments indicate that interconnection shouldn't be expensive. Further research into both of these areas is required to determine exactly where the gasification plant could be located.

7. Economic Feasibility

7.1 Revenues

Syngas

All produced syngas will be combusted in CHP engines coupled with alternators to produce 34,128MWhe of renewable electricity. This renewable electricity will be injected onto the grid and sold to B.C. Hydro under the SOP. The current price paid under the SOP for projects in the Lower Mainland is $111.56/MWh.

Heat

Heat from the CHP engines will be captured using water jackets. This 1.85 MW of 90^{o}C hot water will be sold for $15/MWh (equivalent to $4.2/GJ).

Tipping Fees

A growing number of equine facilities in the Lower Mainland are being charged a small tipping fee for their used bedding (in addition to transportation costs). While difficult to predict the future, it is estimated that a tipping fee of $10/tonne for the 37,500 tonnes of used bedding can be charged. Due to current demand for used litter, it is estimated that no tipping fee can be charged for this feedstock.

Ash

Ash production is 2,000 tonnes/year. This ash will contain an estimated 6.5% of P, 12.2% of K, 3.1% S, 1.3% Mg, and 13.7% Ca by mass. While revenues are speculative at this point, initial reaction to the ash's potential from a local fertilizer company for incorporation into existing fertilizer products was positive. As such, ash is estimated to have a value of $20/tonne.[26]

Carbon Dioxide

While there will be CO_2 in the flue gas from the CHP engines, this CO_2 will be highly dilute (~10%). Low dilution coupled with the need to liquefy the CO_2 for storage and transportation make it highly uneconomical to produce and sell CO_2.

7.2 Capital Cost Estimates

The following are capital cost estimates for building an EQTEC gasification plant in the Lower Mainland to gasify 50,000 tonnes/year of used bedding and litter to produce 3.95MW of renewable electricity and 1.85MW of heat (Table 11). All costs are in Canadian dollars.

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[26] Ash value will ultimately demand upon how easy it is to make use of the nutrients while being able to remove Cl.

Direct Costs

EQTEC Gasification Plant

An EQTEC gasification plant consisting of feedstock handling/drying and ash storage, feeding system, gasifier reactor, syngas cleaning and cooling system, water treatment plant, thermal oxidizer, CHP plant, control panels and monitoring equipment, and all necessary structures is estimated to cost $23.85 million.

Civil and Structural Works

An estimated $1 million of civil and structural works will likely be required for the gasification plant, including:

- Earthworks associated with site preparation and yard surfacing/paving;
- Water supply and distribution, and storm drainage; and
- Administrative offices and fencing/security of the gasification plant.

Interconnection

Based on the results of the BDS information request, interconnection is estimated to cost $600,000.[27]

Indirect Costs

Indirect costs for plant construction, civil and structural works are estimated to be $1.2 million and include:

- Preliminary and detailed engineering;
- Permit application; and
- Construction management and insurance.

Contingency

A contingency allowance of $2,665,000, equivalent to 10% of capital costs, is included to cover costs that are currently unforeseen and may become apparent as detailed engineering and construction proceed.

Exclusions

Land procurement is excluded from capital cost estimate, as it is assumed that the 1.85MW of heat (as 90^{o}C hot water) from the CHPs will be sold to the host site at a low cost in exchange for land on which to build.

Table 11: Summary of Capital Cost Estimates

Capital Cost Summary ($CD)	
Direct costs	
EQTEC gasification plant	$23,850,000
Civil and structural works	$1,000,000
Interconnection	$600,000
Total direct costs	$25,450,000
Indirect costs	$1,200,000
Total direct and indirect costs	$26,650,000
Contingency (10%)	$2,665,000
Total Project Capital Costs	**$29,315,000**

[27] For greater accuracy, a screening study is required to provide conceptual level estimates of interconnection costs for a specific site.

7.3 Operating Cost Estimates

The following are operating cost estimates for an EQTEC gasification plant in the Lower Mainland to gasify 50,000 tonnes/year of used bedding and litter to produce 3.95MW of renewable electricity and 1.85MW of heat (Table 12). All costs are in Canadian dollars.

Plant Personnel

The gasification plant will require 10 staff, including a plant manager, operations manager, shift engineers, feedstock handling operators, maintenance technicians and secretary/administrative assistant. Assuming an average salary, including benefits and payroll taxes of $60,000/year, gives average payroll of $600,000/year.

Operations and Maintenance

The gasification and CHP plants will require on-going maintenance estimated at $19/MWhe, where approximately $14/MWhe is for the CHP plant and $5/MWhe for the gasification plant. For a 3.95MWe plant this is approximately $650,000/year. Annual operating supplies for the gasification plant, including electricity and sand, are estimated at $150,000/year. Total operations and maintenance costs are therefore estimated at $800,000/year.

Administration and Overheads

Annual administration and overhead costs for the proposed gasification plant, including general office expenses, insurance, property and other relevant taxes, permits and licences, travel and compliance testing are estimated at $250,000/year.

Contingency

A contingency allowance of $83,000/year, equivalent to 5% of operating costs, is included to cover unexpected costs that may occur.

Table 12: Summary of Operating Cost Estimates

Operating Cost Summary ($CD/year)	
Plant personnel	$600,000
Operations and maintenance	$800,000
Administration and overheads	$250,000
Contingency (5%)	$83,000
Total Project Operating Costs	**$1,733,000**

7.4 Gross Return on Investment

A simple method for evaluating the financial worth of a project is gross rate of return on total capital investment before any interest charges, depreciation or taxes (Table 13). Calculated by dividing gross annual operating profit for one year by total capital investment, the projected gross return for the gasification plant is 9.3%, indicating a payback period of 10.7 years. By normal industry expectations, this payback period indicates that this project is not very attractive from a financial prospective.

Table 13: Gross Rate of Return

Item	Amount
Total net annual revenues	$4,462,080
Total annual operating cost	$1,733,000
Gross annual operating profit	$2,729,080
Total capital investment	$29,315,000
Gross rate of return	9.3%

7.5 Financial Projections

Feasibility assessment for the proposed gasification plant is based on cash flow projections for the period from first draw down of capital funds to end of initial 10-year operating period (Table 14 and Appendix A). The feasibility model is based on an Internal Rate of Return (IRR) and cash-on-cash return (ratio of total cash received over the life of the project to total cash invested) to determine profitability of investment. The model assumes 40% funding, 45% debt financing and 15% equity.[28] Interest payable on debt is assumed to be 8% and repayment is assumed over a 9-year period commencing at the end of the first year of plant operation.[29] Average annual inflation is assumed to be 2% and is applied to revenues and expenses where appropriate.

Revenues from the gasification plant reflect the sale of electricity under the SOP ($111.56/MWh), heat to local end-users ($4.2/GJ), tipping fee for used bedding ($10/tonne), and sale of ash ($20/tonne). Electricity sales include a 50% annually escalated base price at B.C. Consumer Price Index. Heat sales are assumed constant. Cash outflows reflect the estimated gasification plant's operating costs excluding depreciation. Capital expenditures include all capital costs to be incurred by the plant project from inception until the end of the 10-year analysis period.

It has been assumed that the proposed gasification plant will run 24 hours/day, 360 days/year, from the first until the tenth year of operation. Starting in the first year of plant operation, a 5% contingency allowance had been included in the model to cover unexpected costs that might occur. The contingency allowance is not intended to cover normal maintenance and repairs. No provisions have been included for termination of the gasification plant as it is assumed the plant we remain operational for 20 years.

Only pre-tax calculations are shown, as after tax calculations are greatly impacted by multiple variables that are unknown at this point. These variables include application of Capital Cost Allowance, Canadian Renewable and Conservation Expense, investment tax credits, corporate structure, and tax circumstances of investors and financiers. Furthermore, as a result of the gasification plant's capital expenses and interest being tax deductible, it is highly unlikely that the economic feasibility of the gasification plant will be much different on a post-tax basis.

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[28] Gearing ratio was estimated using projected earnings before interest, taxes, depreciation and amortization (EBITDA) and a minimum coverage ratio of 1.5.

[29] A nine year operating period was used as it is unlikely that the gasification plant will be able to secure feedstock supply contracts greater than ten years.

Table 14: Projected Cash Flow Statement

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Electricity sales	4,081	4,122	4,163	4,205	4,247	4,289	4,332	4,375	4,419	4,463
Thermal energy sales	242	242	242	242	242	242	242	242	242	242
Used bedding tipping fee	375	375	375	375	375	375	375	375	375	375
Used litter tipping fee	-	-	-	-	-	-	-	-	-	-
Ash sales	40	40	40	40	40	40	40	40	40	40
Total Revenue (000s)	**4,738**	**4,778**	**4,820**	**4,861**	**4,903**	**4,946**	**4,989**	**5,032**	**5,076**	**5,120**
Plant personnel	600	612	624	637	649	662	676	689	703	717
Operations + maintenance	648	661	675	688	702	716	730	745	760	775
Utilities + consumables	152	155	158	161	164	167	171	174	178	181
General + administration	250	255	260	265	271	276	282	287	293	299
Contingency	83	84	86	88	89	91	93	95	97	99
Total Expenses	**1,733**	**1,767**	**1,802**	**1,839**	**1,875**	**1,913**	**1,951**	**1,990**	**2,030**	**2,070**
EBITDA (000s)	**3,005**	**3,011**	**3,017**	**3,023**	**3,028**	**3,033**	**3,038**	**3,042**	**3,046**	**3,049**

Capital Stack Summary	
Total project costs	29,315,000
Debt proceeds	13,302,302
Grant proceeds	11,700,000
Equity	4,312,698

Levered Investor Returns	
Levered IRR	16.1%
Levered CoC	2.6x

7.6 Sensitivity Analysis

A sensitivity analysis was carried out to determine how different values for grant funding, used litter and bedding tipping fees, ash sales, financing, and capital costs impact the economic feasibility of the gasification plant. This analysis provides valuable insight into which of these values are most critical (i.e., affect feasibility).

Grant Funding

A change in grant funding significantly impacts the gasification plant's economic feasibility. For example, a small reduction in grant funding of only 2.5% ($0.7 million) reduces IRR by 3.1%. Alternatively, a small increase in grant funding of 0.9% ($0.3 million) increases IRR by 1.6% (Table 15). Therefore, the economic feasibility of the gasification plant is highly sensitive to amount of grant funding available.

Tipping Fees

While a change in the tipping fee for used litter has minimal impact on the gasification plant's economic feasibility, a change in the tipping fee for used bedding has a more significant impact. For example, if a tipping fee of $10/tonne, $20/tonne or $30 tonnes were charged for used litter, IRR would only increase by 3.4%, 7.3% and 12.4%, respectively. However, if the tipping fee for used bedding were reduced to $0/tonne, or increased to $20/tonne or $30/tonne, IRR would decrease by 8.3%, or increase by 12.4% and 49.8%, respectively (Table 15). Therefore, the economic feasibility of the gasification plant is sensitive to the tipping fee charged for used bedding but not used litter. This is not surprising as used bedding accounts for a much larger proportion of the feedstock (75%) than used litter (25%).

Table 15: Funding, Tipping Fee, Ash, Financing and CapEx Sensitivity Analysis

Grant Funding		
% of Costs	$ Grant	IRR
0%	-	-4.7%
17.1%	5,000,000	0.1%
23.9%	7,000,000	3.0%
27.3%	8,000,000	4.8%
30.7%	9,000,000	6.9%
34.1%	10,000,000	9.6%
37.5%	11,000,000	13.0%
40.9%	12,000,000	17.7%
44.3%	13,000,000	24.9%

Tipping Fee			
Used Litter		Used Bedding	
$/tonne	IRR	$/tonne	IRR
0	16.1%	0	7.8%
10	19.5%	10	16.1%
15	21.4%	15	21.4%
20	23.4%	20	28.5%
25	25.6%	25	40.7%
30	28.5%	30	65.9%
35	31.8%		
40	35.8%		
50	46.8%		

Ash Value	
$/tonne	IRR
0	15.1%
10	15.6%
15	15.8%
20	16.1%
25	16.3%
30	16.6%
40	17.1%
50	17.7%
60	18.1%
70	18.7%
80	19.3%
90	19.9%
100	20.5%

Financing	
Rate (%)	IRR
2	67.8%
3	44.0%
4	32.8%
5	26.0%
6	21.7%
7	18.6%
8	16.1%
9	13.9%
10	12.1%
11	10.6%
12	9.3%

CapEx	
Total ($mill)	IRR
26	56.8%
28	23.8%
30	13.2%
32	7.2%
34	3.2%
36	0.2%
38	-2.2%
40	-4.1%
42	-5.7%

Ash Sales

The value of ash has minimal impact on the gasification plant's economic feasibility. For example, even if the ash were sold for twice, three, or four-times as much ($40, $60, or $80/tonne), IRR would only increase by 1.0%, 2.0% and 3.2%, respectively (Table 15). Therefore, the economic feasibility of the gasification plant is not sensitive to the value of ash. This is not surprising as estimated ash production is only 2,000 tonnes/year.

Financing

A change in financing has a small impact the gasification plant's economic feasibility. For example, a reduction in financing to 7% or 6% increases IRR by 2.5% and 5.6%, respectively. Alternatively, an increase in financing to 9% or 10% decreases IRR by 2.2% and 4.0%, respectively (Table 15). Therefore, the economic feasibility of the gasification plant is somewhat sensitive to the amount of interest payable on debt.

Capital Costs

As with grant funding, a change in capital costs significantly impacts the gasification plant's economic feasibility. For example, a small increase in capital costs of only 2.5% ($0.73 million) reduces IRR by 3.1%. Alternatively, a small decrease in capital costs of only 1% ($0.3 million) increases IRR by 1.4% (Table 15). Therefore, the economic feasibility of the gasification plant is sensitive to capital costs.

Two Variable Analysis

From the above sensitivity analysis it can been seen that the values most critical to economic feasibility of the gasification plant are grant funding, used bedding tipping fees and capital costs. To understand the relationship between these variables and how they impact feasibility simultaneously, a two variable analysis was carried out using grant funding and used bedding tipping fees (Table 16).[30]

From this analysis it is clear that as used bedding tipping fees increase, grant funding decreases significantly. For example, as tipping fees increase from $10/tonne to $20, $30, $40 and $50/tonne, required grant funding decreases from almost $12million to < $10million, < $8million, < $5.5million, and < 4 million, respectively.

Table 16: Two Variable Sensitivity Analysis for Funding and Used Bedding Tipping Fees

Target IRR 16.1%		**Used Bedding Tipping Fee ($/tonne)**								
		0	10	15	20	25	30	35	40	50
Grant Funding ($)	0	-7.5%	-4.7%	-3.3%	-1.8%	-0.4%	1.2%	2.8%	4.6%	8.5%
	4,000,000	-4.5%	-1.0%	0.7%	2.6%	4.6%	6.8%	9.2%	11.9%	18.7%
	5,000,000	-3.5%	0.1%	2.1%	4.1%	6.3%	8.8%	11.5%	14.7%	23.2%
	6,000,000	-2.4%	1.5%	3.6%	5.8%	8.3%	11.1%	14.4%	18.3%	29.5%
	7,000,000	-1.2%	3.0%	5.3%	7.8%	10.7%	14.1%	18.1%	23.1%	39.4%
	8,000,000	0.1%	4.8%	7.4%	10.3%	13.7%	17.8%	23.0%	30.0%	59.2%
	9,000,000	1.7%	6.9%	9.9%	13.3%	17.6%	23.0%	30.4%	41.7%	135.5%
	10,000,000	3.6%	9.6%	13.1%	17.3%	22.9%	30.7%	43.1%	68.2%	----
	11,000,000	5.9%	13.0%	17.3%	22.8%	31.2%	44.7%	74.8%	386.8%	----
	12,000,000	8.8%	17.7%	23.5%	31.6%	46.7%	84.1%	----	----	----

[30] Because the sensitivity analysis results for grant funding and capital costs are very similar, it can be assumed that the two variable analysis results would be similar for used bedding tipping fees and capital costs.

7.7 Summary

The capital and operating cost estimates for building an EQTEC gasification plant in the Lower Mainland to gasify 50,000 tonnes/year of used bedding and litter to produce 3.95MW of renewable electricity and 1.85MW of heat are $29,315,000 and $1,735,000/year, respectively. Estimated annual revenues from the sale of renewable electricity and heat, tipping fees, and ash sales are $4,462,080. Pre-tax IRR and cash-on-cash returns for the gasification plant, assuming a 10-year operating period, 40% funding, 45% debt financing and 15% equity, 8% interest, and 2% inflation are 16.1% and 2.6x, respectively.

Of the values for grant funding, used litter and bedding tipping fees, ash sales, financing and capital costs used for estimating the economic feasibility of the gasification plant, the values most critical to economic feasibility are grant funding, used bedding tipping fees, and capital costs. Any changes to these variables significantly impact the economic feasibility of the gasification plant's IRR.

8. Regulatory Review

Provincial government, regional districts and municipalities have jurisdiction over various permits and processes that are necessary for the proposed gasification plant. Once an engineering study has been performed to produce sufficient technical information (sizing, plant layout, drawings, emission calculations, etc.) the necessary regulatory, permitting and approvals process should begin.

8.1 Ministry of Environment

The Ministry of Environment's (MoE) Environmental Management Act (EMA) prescribes, through the Waste Discharge Regulation (WDR), that Schedule 1 activities, such as the gasification of waste, must obtain Ministry authorization to discharge waste. This authorization, known as a Waste Discharge Authorization Permit (WDAP), is a site-specific authorization setting out the terms under which waste may be discharged to the environment.

To obtain a WDAP an application is submitted directly to the MoE regional office and, subsequent to favourable application review, public consultation and notice, MoE will issue the permit. Technical information about the gasification plant, including engineering plans, feedstock sourcing, discharge quality and quantity, and details about potential environmental impacts, must be provided. No amendments are required to regional solid and liquid Waste Management Plans (WMP) because the gasification plant will not gasify municipal solid waste.

8.2 Environmental Assessment Office

The Environmental Assessment Office (EAO), whose involvement in the environmental approval process is defined under the Environmental Assessment Act (EAA), conducts assessments of proposed major projects in B.C. Within the Environmental Assessment Process, the Executive Director of the EAO determines the need for an Environmental Impact Assessment (EIA) based on information about how the project would positively or negatively affect the natural environment.

If it is decided that the project will not have a significant adverse environmental, economic, social, heritage or health effect, an environmental assessment certificate is not required for the project. However, if it is considered that the project may have a significant adverse effect, an environmental assessment certificate is required for the project, and as such the project must undergo an EIA. It is unlikely that the gasification plant will require an EIA because it does not exceed any of the thresholds for energy project under the EAA.

8.3 Metro Vancouver

Under the EMA, Metro Vancouver has been delegated authority to manage all air discharges within its regional boundaries. Because gasification doesn't fall under a Metro Vancouver Bylaw, a site-specific permit is required. To obtain this permit, an application is submitted to Metro Vancouver with a biomass fuel management plan and air quality dispersion model. Based on this application, Metro Vancouver assesses the potential impacts of the gasification plant (such as odour, dust, particulates, emissions, etc.) in relation to the local environment and potential site sensitivities.

Conditional on a favourable review, the district director issues a permit to allow discharge of air contaminants subject to requirements for the protection of the environment that the district director considers advisable. Example emission discharge limits for a gasification plant could be similar to those under Metro Vancouver's Boilers and Process Heaters Emission Regulation Bylaw No. 1190. However, if the gasification plant is located in an area deemed to be more sensitive to emissions, it is possible that these limits could be lower.

Metro Vancouver's Boilers and Process Heaters Emission Regulation Bylaw No. 1190 allows operators of boilers or process heaters fuelled by biomass to discharge emissions up to the following limits[31]:

- Nitrogen oxides: 200 mg/m^3;
- Carbon monoxide: 250ppmv;
- Opacity: 5%;
- Condensable particulate matter: 15mg/m^3;
- Filterable particulate matter: 10mg/m^3;
- Total volatile organic compounds:
    - of which 9mg/m^3 are photoreactive, and
    - 11mg/m^3 are non-photoreactive.

8.4 Local Government

Municipalities issue building and plumbing permits to ensure that building codes are respected. The building permit may also dictate any siting requirements with respect to height, parcel size, set-back, etc. Other standard permits include certification by the B.C. Safety Authority for any work related to electrical, gas and/or boilers, and a business licence. These permits may be conditional to obtaining certificate of authorization from the Ministry of Environment.

9. Conclusion

This study set out to determine the technical and economic feasibility for gasifying used litter and bedding in the Lower Mainland to produce renewable electricity, heat, and ash. This study also aimed to establish the necessary levels of funding required for a gasification plant in the Lower Mainland to generate an attractive IRR for investment.

Gasification test results showed that used litter and bedding can be gasified to produce high quality syngas, and that different feedstock mixes had little impact on overall syngas energy content, quality, and tar levels. Gasification tests also showed that while ash yields from the gasification of used litter and bedding were lower

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[31] All concentrations are referenced at 8% oxygen content in stack. Gas volumes are corrected to dry conditions at 20°C and a pressure of 101.325 kPa.

than expected, the elemental composition of the ash varies depending upon feedstock mix, and the ash contains significant enough levels of P, K, S, Mg, and Ca to be of potential value as a fertilizer input.

Fluidised bed gasification technology was deemed to be the most suitable for used bedding and litter in the Lower Mainland, while production of renewable electricity and heat was deemed to be the most suitable energy generation pathway. Two areas in the Lower Mainland, one on the boarder of Langley and Surrey near the Golden Ears Bridge, the other on the boarder of Langley and Abbotsford, were identified as having the necessary criteria to build the gasification plant.

Based on estimated capital and operating cost estimates and annual revenues from the sale of renewable electricity and heat, tipping fees and ash sales, 40% funding ($11.7 million) is required for the gasification plant to generate an IRR of 16.1%. Of the estimated values for grant funding, used litter and bedding tipping fees, ash sales, financing and capital costs used, grant funding, used bedding tipping fees and capital costs are the most critical to economic feasibility.

Appendix A: Financial Analysis

					Project Year									
			-2	-1	1	2	3	4	5	6	7	8	9	10
Gasification Plant Outputs														
Electricity output	MWh	34,128	-	-	34,128	34,128	34,128	34,128	34,128	34,128	34,128	34,128	34,128	34,128
Heat output	GJ	57,542	-	-	57,542	57,542	57,542	57,542	57,542	57,542	57,542	57,542	57,542	57,542
Horse bedding	t/a	37,500	-	-	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500	37,500
Broiler litter	t/a	12,500	-	-	12,500	12,500	12,500	12,500	12,500	12,500	12,500	12,500	12,500	12,500
Ash	t/a	2,000	-	-	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Gasification Plant Revenues ('000 $)														
Electricity output	$/MW	111.56	-	-	4,081	4,122	4,163	4,205	4,247	4,289	4,332	4,375	4,419	4,463
Heat output	$/GJ	4.2	-	-	242	242	242	242	242	242	242	242	242	242
Horse bedding	$/t	10	-	-	375	375	375	375	375	375	375	375	375	375
Broiler litter	$/t	0	-	-	0	0	0	0	0	0	0	0	0	0
Ash	$/t	20	-	-	40	40	40	40	40	40	40	40	40	40
Total Gasification Plant Revenues ('000 $)					**4,738**	**4,778**	**4,820**	**4,861**	**4,903**	**4,946**	**4,989**	**5,032**	**5,076**	**5,120**
Gasification Plant Operating Costs ('000 $)														
Plant personnel			-	-	600	612	624	637	649	662	676	689	703	717
Operations & maintenance				-	-	661	675	688	702	716	730	745	760	775
Utilities & consumables			-	-	152	155	158	161	164	167	171	174	178	181
General & administration			-	-	250	255	260	265	271	276	282	287	293	299
Contingency (5%)			-	-	83	84	86	88	89	91	93	95	97	99
Total Plant Operating Costs ('000 $)					**1,733**	**1,767**	**1,802**	**1,839**	**1,875**	**1,913**	**1,951**	**1,990**	**2,030**	**2,070**
EBITDA ('000 $)					**3,005**	**3,011**	**3,017**	**3,023**	**3,028**	**3,033**	**3,038**	**3,042**	**3,046**	**3,049**
Construction Costs ('000 $)			(14,658)	(14,658)	-	-	-	-	-	-	-	-	-	-
Unlevered Cash Flows			**(14,658)**	**(14,658)**	**3,005**	**3,011**	**3,017**	**3,023**	**3,028**	**3,033**	**3,038**	**3,042**	**3,046**	**3,049**
Unlevered IRR		0.55%												
Unlevered CoC		1.0x												
Grant Proceeds			11,700	-										
Debt Proceeds			-	13,302										
Principle & Interest					(2,129)	(2,129)	(2,129)	(2,129)	(2,129)	(2,129)	(2,129)	(2,129)	(2,129)	-
Levered Investor Returns			**(2,958)**	**(1,355)**	**876**	**882**	**888**	**893**	**899**	**904**	**908**	**913**	**916**	**3,049**
Levered IRR		16.1%												
Levered CoC		2.6x												