An Investigation into the Production of Fuelstock at UBC Farm for Energy Creation and Greenhouse Gas (GHG) Reduction

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ABSTRACT

UBC Farm stakeholders are investigating the potential of biofuel production for the purpose of energy generation and greenhouse gas reduction. This paper examines a triple bottom line assessment for the addition of Giant Miscanthus (*Miscanthus x giganteus*) biofuel to UBC farm margins and hedgerows. The methodology behind choosing Miscanthus rather than Alder or Willow is discussed as well as background information for this perennial plant. An annual yield of 15t/ha was estimated for an overall available area of 1ha. A cost analysis determined an establishment cost of $650USD for a 1ha plot of Giant Miscanthus and a literature study allowed for estimating operating costs to be roughly $30/t DM. A sensitivity analysis determined annual net project economics of $274-823.

To add value for the farm and campus community, insight is given into the social implications of planting and harvesting biofuels. It was determined that many relationships can be gained and nurtured through collaborations with fellow researchers and communities including native groups and prospective biofuel growers. It is expected that educational opportunities will arise from the plantations in both agroforestry and biofuel research as well as both student body and community volunteer opportunities. Biofuel crops on the farm are also expected to give UBC a stronger overall image as an environmental leader in GHG reduction.

In investigating the environmental implications of growing a biofuel crop at the farm, understanding the carbon footprint and green energy offset as well as agricultural and wildlife impacts is necessary. The carbon savings compared to the current acquisition process is approximately 140 kg and is further reduced through human labor harvest by ~40 kg. The estimated green energy output annually is 62.5MWh which equates to 225GJ. By planting Miscanthus hedgerows animal corridors are created as well as habitat for pollinators. Furthermore, soil erosion is prevented and wind shelter for neighboring crops is provided. Although the environmental and economic considerations are important, the social implications were paramount in coming to the conclusion that this project should proceed. The project is revenue generating but relatively insignificant.

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GLOSSARY

Average peak annual biomass - *mean harvestable dry matter at the time of peak biomass production*

Primary Research - *original data collected by the researcher*

Secondary Research - *collation, synthesis or summary of existing research*

Coppicing – *a method of woodland management which takes advantage of some plants ability to grow from cut down stumps or roots*

LIST OF ABBREVIATIONS

Avg – Average

BRDF - Bioenergy Research and Demonstration Facility

DM - Dry Mass

GJ – Gigajoules

kg - Kilogram

kWh – Kilowatt hour

t - Metric Tonne

UBC - University of British Columbia

1.0 INTRODUCTION

In an effort to help reduce University of British Columbia's greenhouse gas emissions, the UBC Farm proposed an investigation of wood fuel growth on the farm for use at the Bioenergy Research and Demonstration Facility. Stakeholders involved at the farm noted available hedgerow growth space and were interested in a triple bottom line analysis of its potential biomass yields. While the BRDF does provide UBC with an alternative energy source, the GHG emissions from its wood chip transportation are highly inefficient. This investigation reports on the prospective gains and losses surrounding fuel stock harvest from the UBC Farm.

The University of British Columbia Farm is located at the south end of the Vancouver campus. The farm encompasses 24 hectares of integrated agricultural and forestland and facilitates many community and research programs. In addition, agricultural crops yield fruit and vegetables that are sold through weekly markets in season. The farm exemplifies the university's vision of being a 'living lab' and adopts programs accordingly. Although a small biofuel demonstration crop was piloted at the farm, this report will investigate a larger scale project and its implications.

As climate is a major contributor to crop success, it is important to incorporate typical conditions in Vancouver, British Columbia. According to Environment Canada, the average annual temperature is 11 degrees Celsius with an average rainfall of 1211.3mm. Although dense forest is typical, the farmland has been cultivated and as such, has significant direct sunlight.

1.1 BIOENERGY RESEARCH AND DEMONSTRATION FACILITY INFORMATION

The Bioenergy Research and Demonstration Facility (BRDF) is a building that houses a large scale generator which converts biomass to green energy that can be used throughout the campus. The facility was conceived with UBC's goals of reducing GHG emissions by 100% by 2050 (Biofuel Research And Demonstration Facility, n.d.).

Currently, the BRDF burns biomass from Cloverdale Fuels based in Langley, which arrive daily with 2 to 3 truckloads filled with wood chips and tree trimmings from local landfills (Tenpenny, 2012). The woody mass is then taken for inspection and screened for any impurities as well as oversized chips. Next, the mass is dried and gasified into synthesis (syn) gas. Following the production of syn gas, the gas is separated into two streams, one to be heated and the other to be converted into electricity. The heating stream burns the syn gas in an oxidizer, extracting the hot gas created from the process and directed off to a boiler to create steam. The steam is then distributed throughout UBC to heat campus buildings. The other portion of the syn gas is filtered of impurities that are potentially harmful to the internal combustion engine. Then, the purified gas is cooled and filtered into an internal combustion engine connected to a generator which produces electricity that is distributed to the UBC power grid. The filtered impurities are salvaged and sent off to the heating stream (Biofuel Research And Demonstration Facility, n.d.).

2.0 METHODOLOGY

As the scope of this project was quite broad, the first step was to define the project deliverables using primary research and make a plan for how to best achieve them. With the type of fuelstock being one of the considerations, secondary research was performed to identify the best crop. Next, further primary research allowed for investigation of the social and environmental impacts of the farm as well as identification of available resources. With a fuelstock species selected, an understanding of the aspects influencing the farm and influenced by the farm and a wealth of secondary resources, the team identified the best plan moving forward and completed the project deliverables.

2.1 RESEARCH

2.1.1 Primary Research

In order to further understand the needs of the stakeholders involved, primary research was conducted. Initially, investigation of the project deliverables as desired by the UBC farm management was conducted in order to better direct the teams efforts. Notes from the interview with Ms. Kate Menzies can be found in Appendix E. To become more aware of the tools and resources available for gathering information, questions were directed to the UBC Engineering and Science Librarian, Ms. Ursula Ellis. Responses to these questions as well as other information were given in a class forum.

To gain a better understanding of the social, environmental and economic implications of the UBC farm, a site visit was made on October 19, 2013. One of the benefits of visiting the farm on this day was that a farmers market was taking place, allowing great insight into the interaction within the community. Additionally, observation of other community programs, current land use, factors influencing crop prosperity, animal habitats and current biofuel projects were investigated.

2.1.2 Secondary Research

For many of the deliverables, considerable secondary research was necessary to gain information on fuelstock characteristics, needs and feasibility as well as economic, social and environmental aspects of growing fuelstock. From a biofuel utilisation and energy perspective, research into the UBC Bioenergy Research and Demonstration Facility and carbon emissions data was beneficial.

2.1.3 Analysis

From the above data collection, an in depth analysis was performed to reach a conclusion on the best fuelstock option for the UBC Farm. Emphasis was placed on triple bottom line (social, environmental and economic) considerations throughout the analysis. By utilising the teams' resources, each member was able to individually investigate one of the considerations without influence of the other aspects. This allowed for unbiased, factual conclusions and recommendations to be made.

3.0 RESULTS AND OBSERVATIONS

3.1 LAND USE DETERMINATION

An essential part of the fuelstock investigation involved measuring the potential land area available for producing biomass. The UBC Farm sits on 24 hectares of land on the south end of campus, offering grounds for diverse agroforestry purposes to which this project intends to make a contribution. In a recent study on the implementation of hedgerows at the UBC Farm, researchers outlined the importance of incorporating a range of plant species on farmland (UBC Farm Agroforestry, 2013). The forest surrounding the perimeter of the farm provides habitat for indigenous wildlife while the inner plots are rotated for food production. Hedgerows offer a natural buffer and connection between wildlife habitat and cropland, making them an optimal space for biomass growth. After visiting the farm and an informational meeting with Kate Menzies, roughly 1ha of land was determined as potentially available for use as fuelstock. This estimate is based on current underutilised hedgerow space and calculated according to the allocated land highlighted in Appendix A.

3.2 FARM VISIT

To conduct primary research for the investigation, the team visited the UBC farm to observe the social and environmental aspects of the triple bottom line and the dynamics of its operation. Immediately through the entrance of the farm, vendors stood marketing locally-grown products and produce available for purchase. Across from the vendors was the farmer's market itself, selling seasonal produce grown and harvested at the UBC farm. A student research project involving living Christmas Tree rentals was also showcased. Upon further investigation, a First Nations agricultural educational program was taking place to teach youth the benefit of growing food sustainably. These observations provided significant evidence that the farm already had a flourishing community, indicating that local involvement would be an integral part of implementing biofuel growth there. Through discussions with farm guides, it was discovered that the farm used rotational crops to rest the soil with habitats residing on the outskirts of the farm. This information was noted for further consideration regarding disruption of natural habitat occupying the farm margins. Current land use was also noted to provide a better understanding of the available space for a biomass crop and the implications that would have on neighbouring crops.

3.3 FUELSTOCK FINDINGS

Table 3.1: Fuelstock data pertaining to feasibility of growth and biofuel effectiveness.

	Miscanthus	**Alder**	**Willow**
Avg. 1yr Crop Yield (t DM/ha)		0.37 (Uri et al., 2001)	
Avg. 3yr Crop Yield (t DM/ha)	25.4 (Heaton et al., 2008)	7.61 (Uri et al., 2001)	
Avg. 5yr Crop Yield (t DM/ha)	37.7 (Heaton et al., 2008)	15.68 (Uri et al., 2001)	
Avg. Annual yield (t DM/ha)	29.6 (Heaton et al., 2008)	14.8 (Tullus et al., 1998)	
Effect on Soil	• Root system decreases soil erosion • Concentration of N and K in soil increase (Kahle et al., 2001)	• 71-76 kg/yr ha of nitrogen introduced into the soil from leaves (Lohmus et al., 1996) • Increase of phosphorus in the soil (Uri et al., 2001)	6-16 (Buchholz & Volk, 2013)
Crop Maintenance Required (i.e. watering, fertilizer)	Weed control during establishment years	N/A	Complete weed control. Nutrients, especially nitrogen, applied after each harvest. Added during the spring (Volk et al., 2004)
Ideal Planting Season	Late May/Early June (Lewandowski et al., 2000)	N/A	
Ideal Harvest Season	March-April (Nov-Feb acceptable)	N/A	During first leaf fall, when the translocation of leaf, branch, and stern nutrients to roots for winter storage has occurred. (Volk et al., 2004)
Planting requirements	Rhizome Propagation	Coppicing (Uri et al., 2001)	Fallow land, using a double row configuration. (Volk et al., 2004)
Harvest requirements	Chopping and baling	No special requirement (Uri et al., 2001)	

Comments	• Hybrid species (sterile) • Root system decreases soil erosion • Storage consideration only needed for large scale yields	• Competition with herbaceous plants in early growing years (Saarsalmi et al., 1995) • Nitrogen fixing species (Uri et al., 2001) • Grows well in humid climates (Niemiec et al., 1995)	

Table 3.2: Collection of Miscanthus yields in various studies

Observation	Location	Avg. Yield	Avg. Peak Biomass	Source
Compilation 97 separate trials (peer-reviewed literature)	Various	-	22t/ha	(Heaton et al., 2008)
3 Year Case Study (2004-2006)	Illinois, USA	3 year average - 29.6%	38.2t/ha	(Heaton et al., 2008)
Various Case Studies	Europe	10-40t/ha	-	(Lewandowski et al., 2000)

3.4 FURTHER MISCANTHUS RESEARCH

Information on the potential of Miscanthus as a biomass product was taken from reports in a variety of climates, including studies made in the mid-west United States, Ireland, and southern Germany. This allows for sensitivity analysis of growth productivity under Vancouver weather conditions.

The most frequently reported method of planting Miscanthus was through rhizome propagation. After an establishment period of 1-3 years, peak yields are available from years 5-10, followed by a decrease in yields for the remaining stand life between years 15-20 (Heaton et al., 2008). The lifetime of Miscanthus stands increased on heavier soils found in climates with higher rainfall, and weed control was typically only found necessary during establishment years (Lewandowski et al., 2003). Growth of the plant has been shown to improve nutrients and enrich the soil it's planted in, as well as act as a carbon sink (Kahle et al., 2001). Studies show that delaying harvest until late winter or early spring improves the quality of the biomass by reducing moisture content, ash, and other chemicals that inhibit the combustion process (Meehan et al., 2013). For small-scale production and immediate transportation to processing facilities, Miscanthus only requires harvesting by hand and chipping.

3.5 CARBON CONTRIBUTIONS

Table 3.3: Constants used in the carbon emissions calculations in table 3.5.

Measure	Unit	Constant	Source/Justification
Carbon emissions from gasoline	Kg CO_2/L	2.4	http://oee.nrcan.gc.ca/publications/transportation/fuel-guide/2007/calculating-co2.cfm?attr=8
Density of gasoline	Kg/L	0.71	www.engineeringtoolbox.com
Distance from UBC farm to BRDF	Km	2.1	Google Maps
Fuel consumption of Honda GX660 Engine	L/hr	6.3	http://honda-motoren.snelbesteld.nl/
Fuel consumption of Husqvarna cutter	Kg/hr	1	http://www.husqvarna.com
Specific fuel consumption of Chevrolet Express Van	L/100km	19.6	http://www.edmunds.com/chevrolet/express/2005/
Assumed average speed of delivery	Km/hr	40	The speed limit is 50 km/hr with only traffic circles and no stop lights
Farm trailer payload capacity	Kg (lbs)	3636 (8000)	http://www.chevrolet.com/express-work-cargo-van.html (the trailer capacity is limited by the towing capacity of the van)
No. of trips necessary to transport all the fuelstock	#	3	Total Yield (kg) / 3636 kg capacity ~ 3

Table 3.4: Carbon emissions data pertaining to fuelstock planting, maintenance, harvest and transportation

Carbon Contributor	Item	Motor hp	Litres/hour	Hours of Use	Litres of gas used	Carbon Cost (kg CO_2)	Comments
Harvesting	Handheld Forest Clearing Cutter	3	1.41	12	16.9	40.6	Husqvarna Forest Clearing cutter
	Chipper	22.1	6.3	8	50.4	121.0	670 cc Honda GX engine (22.1hp)
Delivery	Van/Trailer	N/A	N/A	0.05	0.41	2.96	Chevrolet Express

Table 3.5: Carbon emissions for importing biofuel.

Task	Item	Unit	Value	Source/Justification
Harvest	Swather Fuel Efficiency	L/hr	7.56	http://ucce.ucdavis.edu/files/repositoryfiles/ca1505p2-64859.pdf
	Hours to harvest 1 hectare	Hr/ha	2.17	http://ucce.ucdavis.edu/files/repositoryfiles/ca1505p2-64859.pdf
	Carbon emissions per gasoline volume consumed	Kg CO_2 / L	2.4	http://oee.nrcan.gc.ca/publications/transportation/fuel-guide/2007/calculating-co2.cfm?attr=8
	Mass carbon emissions	Kg CO_2	39.37	
Chipping	Mass carbon emissions	Kg CO_2	121	As determined in table 3.4
Transport	Transport Truck fuel efficiency	L/100km	39.5	http://oee.nrcan.gc.ca/transportation/business/reports/884
	Average distance travelled to BRDF	Km	50	Estimated based on verbal conversation with stakeholder
	Biofuel capacity of one load	Kg	5000	Estimated based on volume and density of biofuel
	No. Of loads to equate farm biofuel output	#	3	See yield data in results section
	Carbon emissions per gasoline volume consumed	Kg CO_2 / L	2.4	http://oee.nrcan.gc.ca/publications/transportation/fuel-guide/2007/calculating-co2.cfm?attr=8
	Mass carbon emissions	Kg CO_2	142.2	
Total carbon emissions (Kg CO_2)			**302.57**	

3.6 BIOFUEL SPECIFICATIONS

The BRDF requires their dry mass to meet certain specifications in order for the heating and electrical conversion system to run efficiently and properly. The size of the dry mass should meet a dimension specification of 3 inches. Oversized material will have to be re-processed to meet specifications. The mass should be free of foreign debris not considered to be part of the natural composition which includes any chemically based content, metal debris, as well as any leafy or rotten material. Proximate specifications state that the moisture content should be within the range of 10-55% along with a volatile content of 70-85%. Other proximate specifications include a fixed carbon rate of 15-25%, ash content of <10% and a higher heating value (HHV) of > 8500 btu/lb. As for ultimate analysis specifications, the BRDF requires dry mass to be composed of 48-52% carbon, 5-6% hydrogen, 36-44% oxygen, <0.3% nitrogen, <0.025%

sulphur, and <0.025% chlorine. Ash specifications allow that less than 5% of wood fuel may be of inorganic material. Finally, ash specifications also require the initial deformation temperature (IDT) to be greater than 2100°F (Nexterra, 2010)

4.0 DISCUSSION

4.1 FUELSTOCK SELECTION

4.1.1 Willow

While selecting possible biofuel plantations for the UBC farm, Willow was selected as a possible choice. Certain factors were taken into consideration to determine whether or not this biofuel would be a beneficial choice. The yield determined for willow was found to be in the range of 6-16t DM/ha per year (Buchholz & Volk, 2013). When comparing these numbers against Miscanthus and Alder, it was concluded to be too small of a yield, especially compared to the Miscanthus. A fair amount of land preparation is required as Willow is planted in fallow land, which not only adds to the time factor, but also adds to labor required. While Willow does not cause detrimental effects to the soil it is grown in, nutrients, especially nitrogen, need to be applied after each harvest (Volk et al., 2004). This implies both extra labor and costs in crop maintenance, which is something that can be avoided with a different biofuel selection. It was also found that since crop harvesting occurs every 3-4 years, habitats were found to be created in the time span in up to one third of the crops (Volk et al., 2004). This would mean extra care would need to be taken during harvesting periods in order to salvage any habitats established.

Overall, Willow was proven to not be feasible for the UBC farm to grow as a biofuel, significantly due to the small yield it produces on average per year as well as the added crop maintenance and preparation needs complicating the process. Being conscious of the possible habitats that would form within the crops also would prove to be too much of a liability, thus it was concluded that Willow would not be a suitable choice of biofuel.

4.1.2 Alder

In considering Alder as a viable biofuel to grow at the UBC farm, several factors were taken into account. Alder is currently growing naturally at the farm, which proves its success in the Vancouver climate. Unfortunately, as it is found naturally, concern for it emerging as an invasive species must be accounted for. Given that Alder is capable of coppicing, planting and harvest would be easily achieved. Again, this raises concern for the uncontrolled growth of Alder around the farm. Additionally, Alder contributes 71-76 kg/year of nitrogen to the soil from decomposition of its leaves, which may have a negative effect on neighbouring vegetable crops (Lohmus et al., 1996). On the contrary, significant phosphorus is given to the soil which may be useful for neighbouring crops (Uri et al., 2001). Compared to Miscanthus, Alder was found to have a much less average yield of dry wood mass. Although several benefits of implementing Alder as a fuelstock at the UBC Farm exist, the concerns and deficiencies cannot be overlooked and therefore, it was dismissed.

4.1.3 Miscanthus

After initial investigation of average annual yields and establishment costs, it was determined that Miscanthus would be the most effective biomass to select for the scale of this project. The average yields produced by Miscanthus in research trials were far greater than those of Willow and Alder, and the costs to establish, maintain, and harvest the crop were also much lower.

Additionally, further research into Miscanthus studies indicated its quality as a source of biomass. As noted in the BRDF specifications, low quantities of chemicals including nitrogen and chlorine are necessary for higher quality combustion of the wood stock; the chemical composition of Miscanthus is ideal for meeting these requirements. For biomass harvesting purposes, the species *Miscanthus x giganteus* is used which is a sterile hybrid. This prevents unwanted seed production so the plant growth does not become invasive. Considering its use as a hedgerow, Miscanthus will also increase carbon sequestration on the farm and the unique root system of the plant will help prevent soil erosion. Following its senescence in the fall, the plant can be harvested in late winter or early spring, aligning with the off-season of other farm labour. The 15-20 year lifespan of the species typically produces high annual yields at a low agricultural cost. Its proven yield efficiency in various climates around the world make Miscanthus an ideal choice for fuelstock growth on the UBC Farm.

4.2 BIOFUEL AWARENESS HARVEST EVENT

In an attempt to create the most benefit for the UBC farm and surrounding community, an awareness event is suggested. This will be further defined in the conclusions and recommendations section but will be described here so it can be incorporated into the discussion.

The proposed awareness event will be focused around the fuelstock harvest. Two stages of the event are proposed; the first being a work celebration in which members of the community volunteer to take part in the actual harvest of the Miscanthus and second, a community social gathering. Although the farm currently has a harvest festival in October, the fuelstock event will take place in early February when farm community activities are few. With environmental awareness initiatives being adopted by many companies, sponsorship of this event could provide resources for marketing and celebration costs. Specifically, BC Hydro offers sponsorship to projects and events that promote environmental sustainability which would not only make the harvest event more financially feasible but would also extend the reach of the marketing from the UBC community to Vancouver.

In addition to bringing green energy awareness to community, the UBC farm can also showcase other programs. By utilizing volunteer’s labour for the fuelstock harvest, cost and carbon emissions are minimized. Triple bottom line benefits of such an event are many and will be discussed in more detail in the next section.

4.3 TRIPLE BOTTOM LINE ASSESSMENT

4.3.1 Economic

4.3.1.1 *Introduction*

Cost of Miscanthus production depends on inputs, such as fertilizers, rhizomes, equipment, storage and transportation, and the opportunity cost of land. Due the scale of this project as well as the proposed plan of allocating volunteer resources to the harvesting task, costs can be significantly reduced. In fact, studies have found that machine harvesting is the most expensive cost, accounting for roughly two-thirds of the cost of Miscanthus production (Bullard, 1999). Also, by restricting Miscanthus production to hedgerows and farm margins, the opportunity cost of the land can essentially be eliminated. The cost of inputs, maintenance, storage and transportation will be discussed here as well as the implications of yield.

4.3.1.2 *Establishment*

Miscanthus can be propagated vegetatively or by seed, however Giant Miscanthus (Miscanthus x giganteus) is a sterile hybrid that must be propagated asexually by rhizome division (Khanna et al., 2008). The cost of rhizomes, as reported in literature, varies between $0.03 and $0.60 per rhizome (Smeets et al., 2010). The variation is attributed to the method of rhizome production, quality, and quantity purchased. These costs however are from projects in various geographic regions and span a period of more than a decade. For the purposes of this study, price quotes from a large North American supplier, New Energy Farms (NEF) will be used. NEF specialize in rhizome production for biomass applications. The 2013 costs for *Miscanthus x giganteus* rhizomes produced in Illinois, USA are $0.05-0.08 (USD) per rhizome. At a planting density of 1 rhizome/m^2, which is common practice, and a planting area of 1ha this equates to 10,000 rhizomes at a cost of $650 USD. Thus initiation costs in the establishment year, which are a function of planting area and planting density, are the most expensive costs for this project. Furthermore, the potential of using rhizomes from the established UBC Farm Miscanthus to propagate biofuel throughout the hedgerows can be investigated in which case the cost of purchasing rhizomes can be eliminated altogether.

4.3.1.3 *Maintenance*

Literature shows that very low input requirements are needed for Miscanthus growth. Fertilizers are not significantly beneficial if there is good soil quality. In cases where soil quality is not adequate nitrogen fertilizer as well as phosphorous and potassium are recommended. Considering the scale of the potential UBC Farm biofuel project, a heuristic approach can be used to optimize yield and perhaps a research opportunity can be created. Costs for inputs such as irrigation, land maintenance, fertilizer application, and storage are difficult to predict individually for a project of this scale. The more reasonable approach would be to analyse case studies for annual per ton operating costs. An extensive 2008 study in Illinois, USA showed an average cost per ton of $79.10/t (CDN). However, two-thirds of this cost was attributed to machine harvesting (mowing and baling), and so operating costs excluding harvesting would amount to $27.4/t. The sensitivity analysis performed accounted for ±50% fluctuations in the operating cost.

4.3.1.4 *Assessment of Yield*

The yield of Giant Miscanthus was determined through literature study and relevant case studies. Specifically, three major case studies were investigated, the results of which are summarized here:

- European study - observed a yield range of 10-40t/ha depending on climate, irrigation, and soil quality (Lewandowski et al., 2000).

- Compilation of findings from peer-reviewed articles (97 observations) showed that Miscanthus produced and average peak annual biomass of 22t/ha (Heaton et al., 2008).

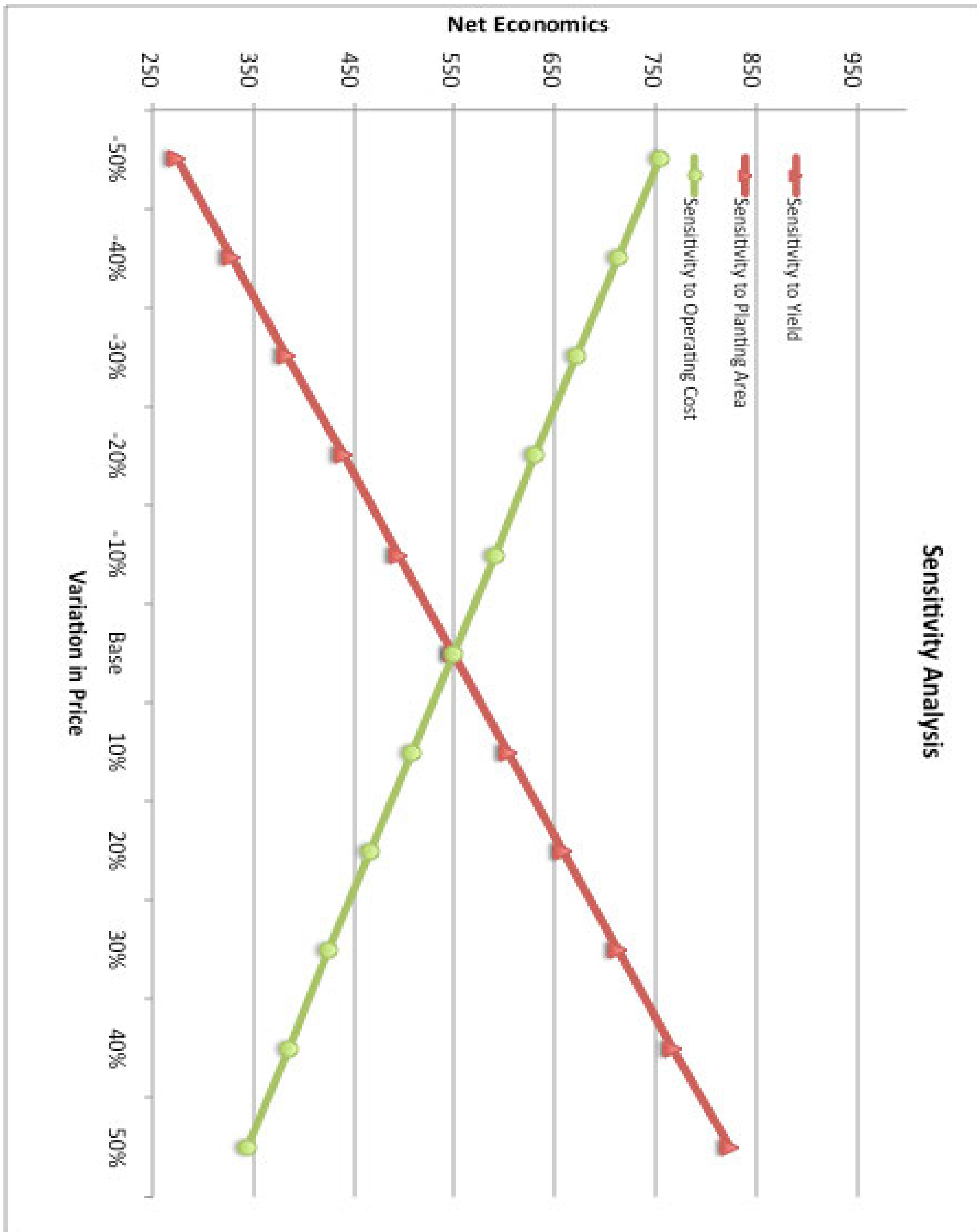
- Midwest USA (Illinois) - Three-year average (2004-2006) yield of 29.6t/ha and a peak annual biomass of 38.2t/ha. Thus a 22.5% winter loss (Heaton et al., 2008).

Given the results of the case studies, it is safe to assume a conservative yield of 15t/ha and to analyse the economics of variations in this yield through a sensitivity analysis. Winter and harvest losses are included in this value. Also, experimental small-scale growth of Miscanthus, which is the scope of this project, will see higher yields than farm-scale biomass production, which is what the scope of the mentioned case studies (Venendaal et al., 1997).

Table 4.1: Sensitivity of yield, planting area, and operating cost

	-50%	-40%	-30%	-20%	-10%	Base	10%	20%	30%	40%	50%
	Sensitivity to yield (planting area = 1ha)										
Yield t/ha DM	7.5	9	10.50	12.00	13.50	15.00	16.50	18.00	19.50	21.00	22.50
Gross	480	576	672	768	864	960	1056	1152	1248	1344	1440
Net (CDN)	274.43	329.31	384.20	439.08	493.97	548.85	603.74	658.62	713.51	768.39	823.28
	Sensitivity to planting area (Yield = 15t/ha, Cost = $27.4/t)										
Planting Area (ha)	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50
Yield t/year DM	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	21.0	22.5
Gross	480	576	672	768	864	960	1056	1152	1248	1344	1440
Net (CDN)	274.43	329.31	384.20	439.08	493.97	548.85	603.74	658.62	713.51	768.39	823.28
	Sensitivity to operating cost (Yield = 15t/ha, Planting Area =1ha)										
Operating Cost	13.70	16.45	19.19	21.93	24.67	27.41	30.15	32.89	35.63	38.37	41.11
Net (CDN)	754.43	713.31	672.20	631.08	589.97	548.85	507.74	466.62	425.51	384.39	343.28

Figure: 4.1: Result of Sensitivity Analysis



Note: as profit is equal to the product of yield, planting area and BRDF credit, varying yield and planting area have the same effect.

Table 4.2: Base Costs

Base Case Economic Parameters	Value
Rhizome Cost ($/Rhizome)	0.05-0.08
Planting Density (Rhizome/m^2)	1.0
Planting Area (ha)	1.0
Rhizome Quantity Required (# of rhizomes)	10,000
Rhizome Purchase Cost (USD)	650
Rhizome Purchase Cost (CDN)*	682.5
BRDF credit ($(CDN)/t)	64
Operating Cost ($(CDN)/t)**	27.41
Yield (dry t/ha)	15

*1.05 World Bank Exchange Rate - October 2013 average.
** Operating costs include: Fertilizer, irrigation, herbicide, storage, and chipping.
This is an average value from various case studies less machine harvesting costs.

4.3.1.5 *Transportation/BRDF Credit*

Transportation of biofuel to the UBC Bioenergy Research and Demonstration Facility (BRDF) will take place annually. A proposed method of transportation is to haul the farm trailer with the farm van. Assuming an annual yield of 15t, three trips (~4km round trip) would be required to transport the harvest. The costs associated with this task are limited to fuel costs. Moreover, ideally harvesting, chipping, and transportation would take place on the same day to prevent moisture and rotting issues. An appropriate date in terms weather can be coordinated annually for the proposed Biofuel Awareness Event. In the case that post-harvest moisture is a concern, an effective method is to store the biomass on concrete bricks (or crushed rocks) on re-usable tarp (Khanna et al., 20098). BRDF currently purchases biomass at $64/t. Assuming the base case parameters from Table 4.2, UBC Farm would receive an annual credit of $960CDN.

4.3.1.6 *UBC Farm and Campus Impact*

The economic impact on UBC Farm is minimal. The project is revenue generating, however it is relatively insignificant. The sensitivity analysis shows annual net project economics of $274-823 (CDN). This range is attributed to variations in yield, planting area and operating costs. On the scale of the UBC campus, the economic impacts of this project is even more minute. It should thus be established that the social benefits, which will be discussed in the following sections, are numerous and are the main advantages of this project.

4.3.2 Social

Implementing Miscanthus fuelstock at the UBC farm has numerous social benefits ranging from research opportunities to increased awareness for green energy initiatives. The project is expected to create educational opportunities for UBC Farm visitors, undergraduate students, as well as agroforestry and biofuel researchers. It is also expected to add to UBC's image as a living lab as well as to promote UBC Farm as a whole. As a result of these social benefits, it is expected that biofuel production will in turn further UBC's reputation as an environmental leader in GHG reduction.

4.3.2.1 *Biofuel Awareness Event*

The proposed Biofuel Awareness Event is expected to provide many social aspects that will further UBC's image as a sustainability leader. The event will gather students and local community members, and provide a platform to learn about and advocate for biofuel initiatives. Not only will this raise awareness within the community, but the harvesting itself will provide those interested with additional volunteering opportunities. The event is also expected to strengthen bonds with collaborative researchers and prospective farmers due to the communicative and social nature of the event.

4.3.2.2 *Biofuel Research*

Small-scale Giant Miscanthus biofuel production is relatively uncommon in Canada with most major case studies taking place in Europe and the Midwest United States. This project can therefore create unique research opportunities to investigate the response of Miscanthus to various inputs (fertilizers, herbicides, irrigation methods), the yield implications of varying these inputs, and general ecological benefits. Moreover, research projects can consider the climate and weather patterns found in the Vancouver region and evaluate how they affect Miscanthus growth. Finally, the data and results from this project could provide more information on the feasibility of Miscanthus as a renewable energy source in Western Canada as opposed to relying on case studies from different geographic regions.

4.3.2.3 *Agroforestry Research*

Alongside possible biofuel research, there lies a possible educational opportunity in Agroforestry research. The research done in the view of agroforestry is expected to further information on the effects of integrating biofuels, specifically Miscanthus, with surrounding plant species that grow in Vancouver specific climates. The research is also expected to provide information on animal habitat creation with focus on animals and wildlife native to Vancouver, and the general climate. These possible studies will provide collaborative researchers with case studies to refer to in parallel with their own research.

4.3.2.4 *UBC as a Living Lab*

Currently, the UBC campus is promoted as a place where students and researchers in collaboration with external organizations are encouraged to explore and experiment with the technological, environmental, and societal aspects of sustainability. This system is described as a living laboratory. Miscanthus production for the purposes of energy creation and GHG reduction on the UBC farm would further UBC’s image as a living laboratory and provide more opportunities for experimentation.

4.3.2.5 *Farm and Campus Connection*

One of the many UBC farm initiatives is the Tu’wusht garden project. This project hosts gardening programs such as Maya in Exile Garden and Musqueam (cite Tu’wusht Garden Project, n.d.) that closely work with indigenous youth, integrating them with the UBC farm community and the UBC community at large. Implementation of the biofuel program will raise awareness amongst this group and give added opportunities for the indigenous community to become even more involved with the UBC community, thereby strengthening Aboriginal bonds with UBC. Also, biofuel production at the UBC farm is expected to strengthen bonds with various other communities such as prospective farmland owners and sustainable energy leaders looking to grow and use biofuels. This bond strengthening will also anchor UBC’s image as an environmental leader through influencing these communities to follow the same energy systems for GHG reduction

4.3.3 Environmental

To perform a complete analysis of the environmental impacts associated with using Miscanthus as a biofuel, several considerations need to be integrated. Complete carbon emission throughout the process, clean energy generation, effects on the soil and neighbouring crops and impact on insect and animal habitats all contribute to the environmental balance.

4.3.3.1 *Carbon Emissions*

Given biofuels are used as an alternative to fossil fuels, a significant part of their advantage lies in the amount of carbon released into the atmosphere. As such, an investigation of the carbon savings will illuminate a large part of the environmental benefit. Please refer to tables 3.3-3.5 for the data relevant to computing the mass of emitted carbon.

Main contributors identified are the harvesting, chipping and transportation using gasoline-powered methods. For 15 tonnes DM of Miscanthus, the mass of carbon for importing from 50km away (ie. Cloverdale) was found to be approximately 302 kg CO2. This is in contrast to approximately 164 kg CO2 (54% of the long distance alternative) when the same procedure occurs at the UBC Farm. The largest contributor to this difference was the transport of the fuelstock. This was taken as a conservative estimate as Cloverdale was identified to be one of the closer external sources and in actuality, wood chips are often shipped from the North-western United States.

It should be noted that carbon costs were limited to only harvest, chipping and transport so that the scope of the project could be met. There are definitely carbon contributors prior to harvesting but it was anticipated that this would only further support the main finding of significant carbon savings when using biofuel grown at the farm. Additionally, the farm harvest calculation included the use of gasoline powered hand cutters. If the biofuel awareness event was to take place, an additional 40 Kg CO_2 could be saved through human powered harvest techniques.

4.3.3.2 *Energy Offset*

To approximate the energy benefit from supplying biofuel to the BRDF, specifications of the energy properties were investigated. Although technical data relating to the BRDF was difficult to find, a biofuel requirements data sheet was used to estimate energy output based on a minimum energy content of 8500 BTU/lb DM. Given an annual output of 15 tonnes DM from the UBC farm biofuel crop, we found the green energy (as heat) output to be approximately 62.5 megawatt hours or 225 GJ.

To put this outcome in relative terms, the energy potential of gasoline is referenced. It was found that approximately 6540 litres of gasoline contain the same energy as 15 tonnes of biofuel, given $3.44 * 10^7$ joules/litre of gasoline (Engineering Toolbox, 2013). Crudely estimating an idling farm tractor to be 5 litres per hour, it would take 54.5 days to consume this amount of gasoline.

Although this analysis can provide an estimate of the energy benefit, one main limitation may affect the accuracy of the values. As little information could be found for the specification of the BRDF, this calculation assumes 75% efficiency of the BRDF process.

4.3.3.3 *Agricultural Effects*

To further evaluate the environmental impact of implementing Miscanthus biofuel crops at UBC farm, the effect on agriculture must be investigated. Given that the Miscanthus will be implemented in the hedgerows next to many vegetable crops, particular consideration must be given to this are.

One of the main factors associated with crop success is soil quality. Miscanthus was found to contribute both nitrogen and potassium to the soil (Kahle et al., 2001), mainly through the decomposition of its leaves. Although the nitrogen may have a negative effect on the success of neighbouring crops, potassium in controlled quantities can be beneficial to a plant's metabolism.

Further agricultural benefits include providing wind shelter for neighbouring crops, root systems preventing soil erosion and displacing other invasive species (Keery et al., 2009). From primary research at the farm, the blackberry bush was observed to be quite invasive so bringing in a hybrid species such as Miscanthus will be great in reducing the density of such a dominant species.

4.3.3.4 *Impact on Wildlife and Insects*

As wildlife and insects rely heavily on their ecosystem and habitat, so do the ecosystems on the wildlife and insects. Although having an annual biofuel crop may negatively impact animal habitats, neighbouring forests will still serve this purpose. In fact, planting Miscanthus in the hedgerows of the farm may provide corridors for travel and refuge from predators. Additionally, the biofuel crop can serve as a habitat for pollinators in the spring and summer months, which provides significant benefit for the entire ecosystem at the farm. As the harvest would take place in February when few pollinators are present, there would be little impact of an annual harvest.

5.0 CONCLUSION AND RECOMMENDATIONS

In summary, this triple bottom-line assessment shows numerous and significant social and environmental benefits as well as profitable yet minor net project economics. The following conclusions were made:

- Giant Miscanthus is superior to Alder and Willow in terms of input requirements, yields, and environmental impacts.
- A yield of 15t/ha can be expected at an operating cost of around $30/t.
- Variations in yield, planting area, and operating costs create a range in net economics of $274-823/year.
- Literature shows that variations in inputs (fertilizer, herbicide, irrigation) do not significantly increase the yield of Miscanthus. Thus, a heuristic approach can be used to optimize yield on UBC Farm.
- The Biofuel Awareness Event will provide educational and research opportunities, increase general awareness for UBC farm initiatives.
- Carbon emissions savings amount to ~140 kg compared to the current process of acquiring biofuel for the Bioenergy Research and Demonstration Facility. This is further reduced by 40 kg by harvesting the biofuel using human labor
- Annual green energy output is estimated to be 62.5MWh or 225 GJ
- Positive agricultural and wildlife impacts outweigh the negative ones

Summarizing the conclusions drawn from the triple bottom line assessment, the following recommendations are made:

- Giant Miscanthus (*Miscanthus x giganteus*) has the most advantages as a biofuel. It has the highest yields relative to Alder and Willow and will not be invasive as it is a sterile hybrid.
- Plant Miscanthus in the designated hedgerows (Appendix A) which totals 1ha.
- Use the proposed Biofuel Awareness Event for the harvesting task. This will decrease carbon emissions and costs significantly.
- Corporate and community sponsorships can assist with implementing the Bioenergy Awareness Event.

6.0 ACKNOWLEDGMENT

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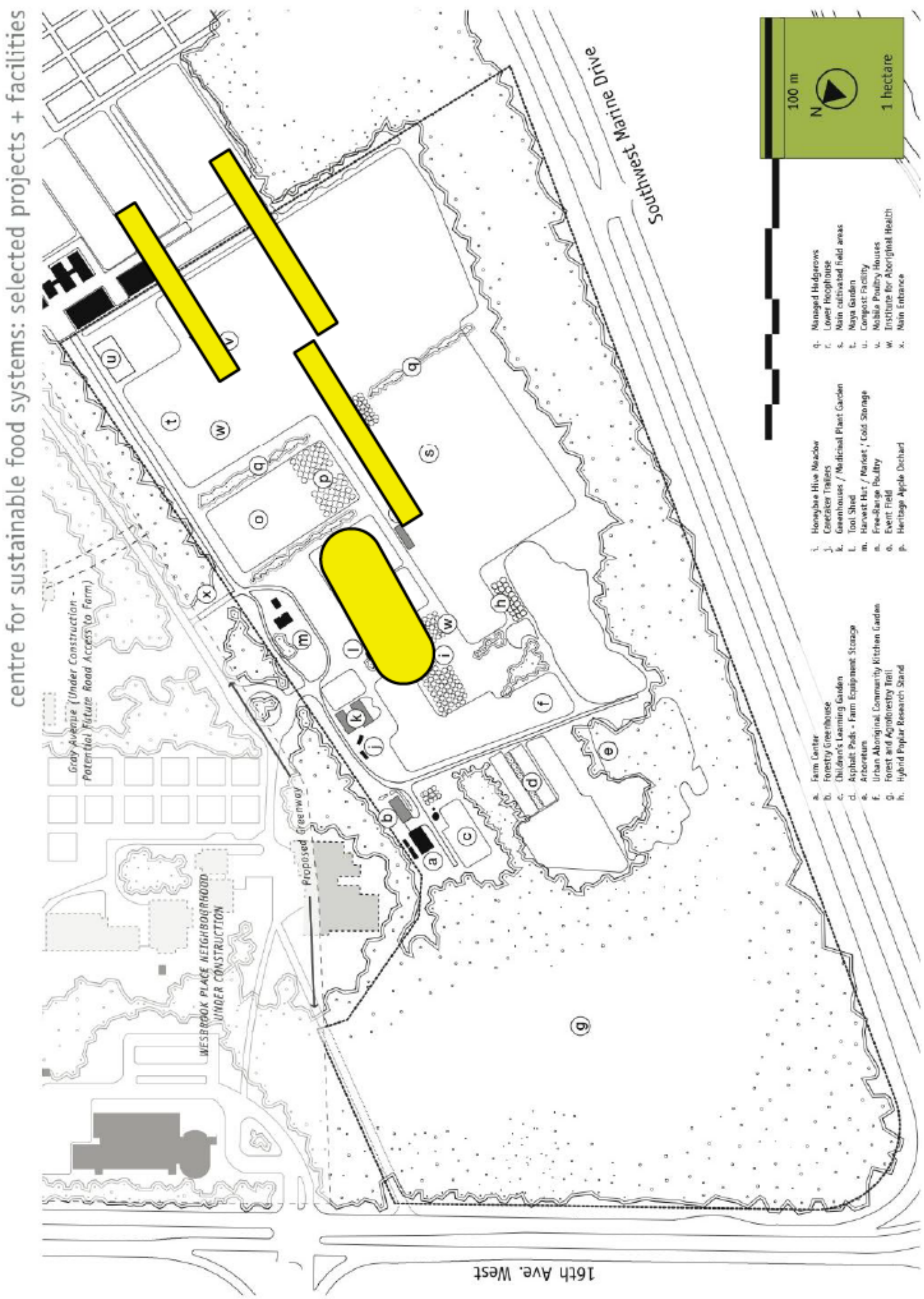
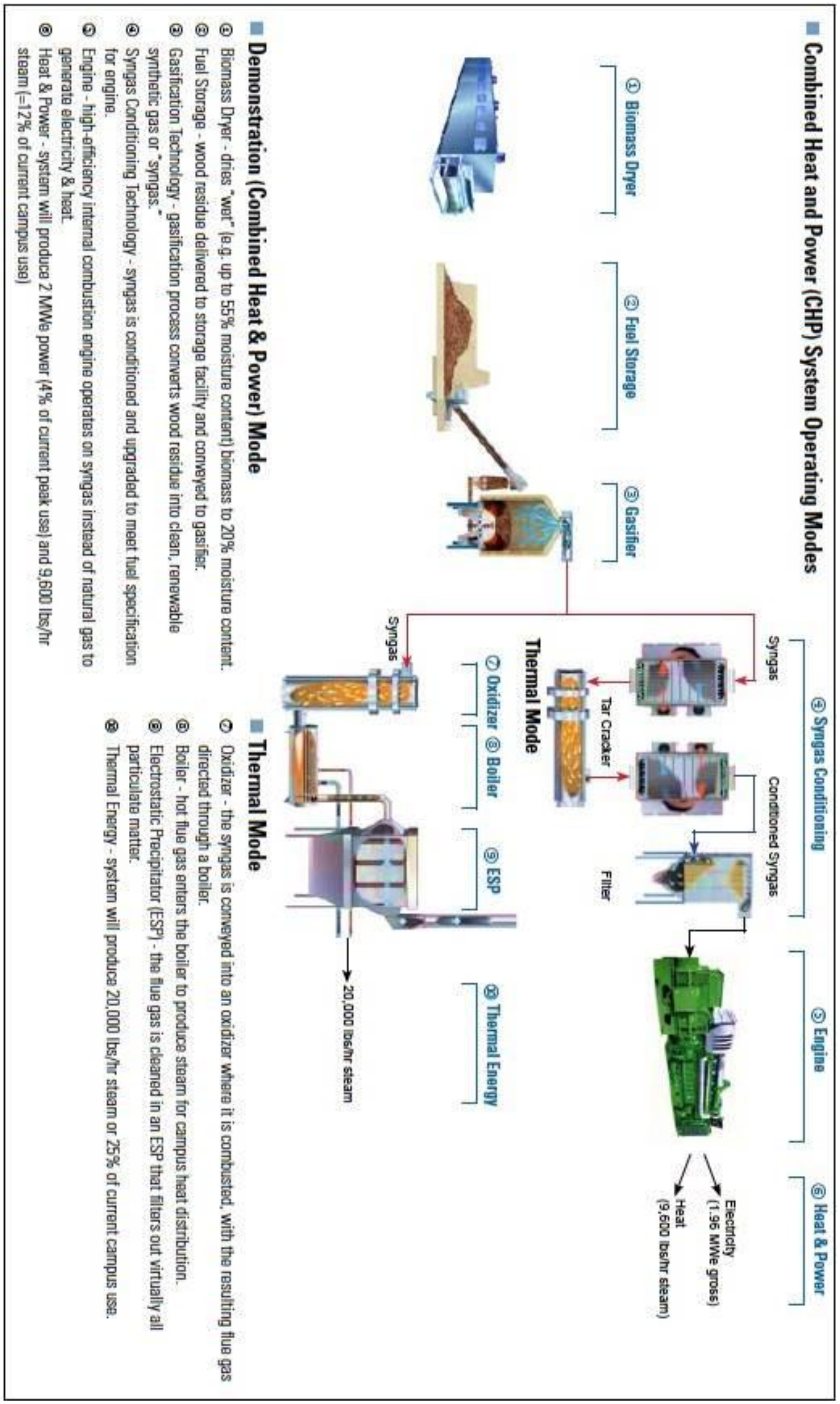
APPENDICES

Appendix A – Map of UBC Farm

UBC Farm Map with potential land use highlighted in yellow



Appendix B – BRDF Process Flow sheet



Appendix C – Interview with Ms. Kate Menzies

Notes from workshop:

Focus of project, choose area, crop type, estimate/evaluate triple bottom line

Area:
- existing hedgerows
- don't use crop land
- erosion protection
- animal/insect habitat
- soil quality similar across farm (south edge floods in winter)

Crop Type: keep in mind difficulty to harvest (ie time of year, labor)
- Miscanthus
- Willow
- Alder (already exists on farm, needs to be cut)
- planting/harvesting must meet organic standards
- use case studies made in Pacific Northwest

Equipment Available:
- Tractor (might require attachment to harvest wood stock)
- Trailer/Farm van to transport to BRDF
- Wood Chipper

Economic Cost:
- ideally low cost inputs (ie seeding vs fallen trees already there)
- BRDF cost specs
- labor (skilled vs. unskilled, volunteer–$25/hr)

Social Impact:
- industry contribution
- farm connections/stakeholders (who visits the farm for research)
- engage community

Environmental Impact:
- displaced natural gas cost
- utilization of farm land